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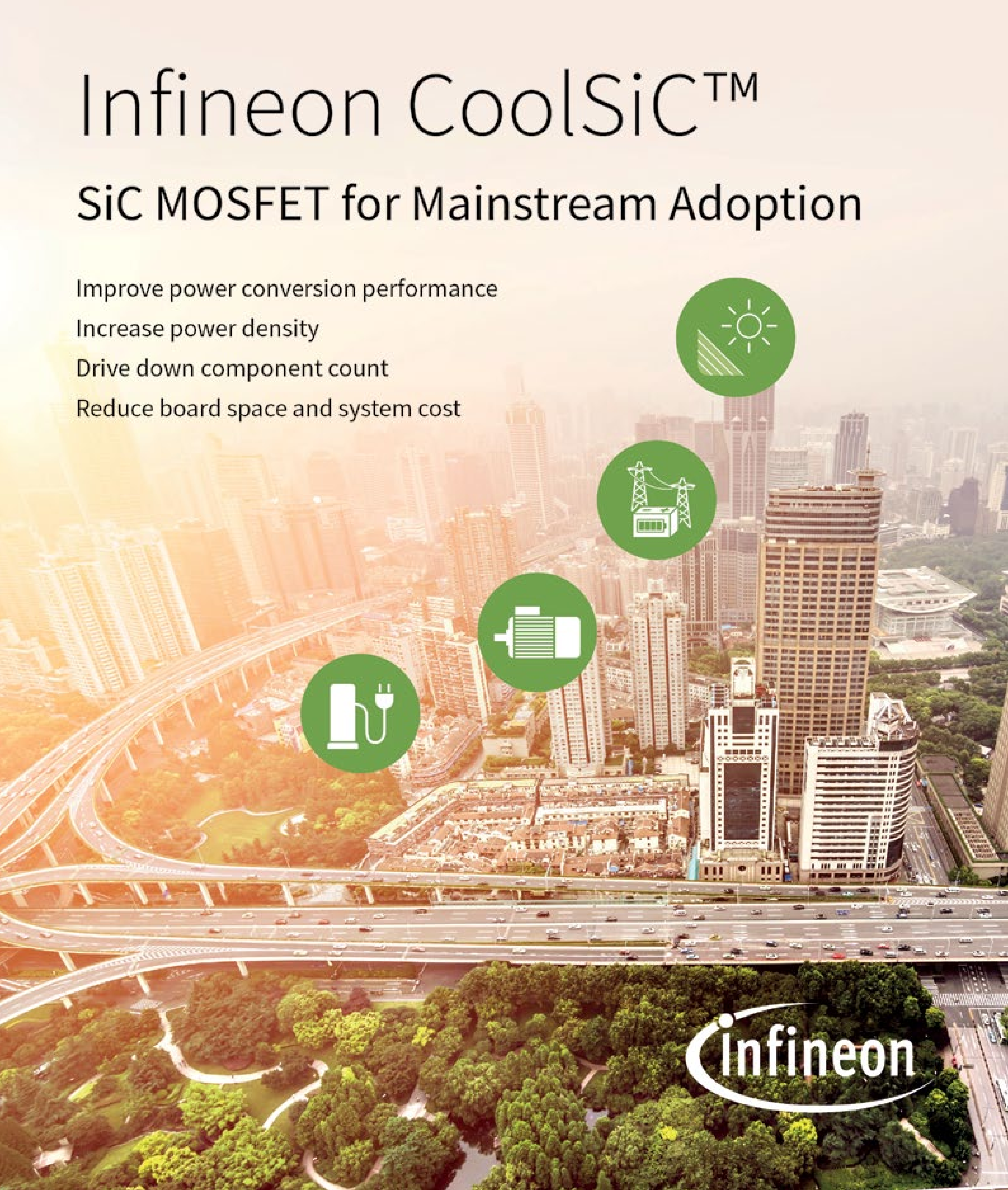
Bodo´s Power Systems®

Electronics in Motion and Conversion

April 2018



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GvA Power Electronics

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The Gallery

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For a short introduction of Horticulture LEDs read our Application Note:
www.we-online.com/AN-Horti

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Events

smartsystemintegration 2018
Dresden, Germany, April 11-12
www.mesago.de/en/SSI/home.htm

PEMD 2018
Liverpool, UK, April 17-19
www.theiet.org/pemd

Hannover Messe 2018
Hannover, Germany, April 23-27
www.hannovermesse.de

SEMICON Southeast Asia 2018
Kuala Lumpur, Malaysia, May 8-10
www.semiconsea.org

ISPSD 2018
Chicago IL, USA, May 13-17
www.ispsd2018.com

The Lone Star State

Texas beckoned and the Power Electronics community came to San Antonio. The Applied Power Electronics Conference was in the beautiful Gonzalez Convention Center, located only a short walk from historic Fort Alamo and the stunning River Walk. It was a worthy spot for the meeting, a nice environment in the shadow of the Tower of Americas - very pleasant to get the latest News and to meet known as well as new business partners, friends, new people, and of course the members of the trade press. A big "Thank You" goes out to Peter Rogerson and Power Integrations for sponsoring the press room. Tasty snacks, chilled drinks and a stable network made working there and the meeting a pleasure for us members of the media.

Of course, the dominating subject was the progress in Wide Band Gap. More and more companies started to deal with SiC or GaN, a few with both. It was very interesting speaking to the applying engineers - everyone pointing to big improvements through using these materials, with demonstrations by the leading innovators of charging everything from your mobile device to your EV. And of course, a broad range of other applications powered by the new materials.

Of note was the presentation of a semiconductor-based thermal energy harvester as a battery alternative. It harvests thermal energy in environments with no perceptible thermal differential. Therefore, it uses a passive four-layer structure. A presentation of High Voltage Switches as a replacement for electromechanical relays, as well as pin diode switches, can be named as one of the most interesting components, at the Texas show. Bodo was very excited about these ones!

There was a lot of buzz about Microchip acquiring Microsemi - after buying Micrel and Atmel not long ago, another strategic step towards the future. Another giant is born, providing chips for automotive and computer applications as well as devices for demanding environments like aviation and military. Let's see how the implementation proceeds. A win/win-situation is possible – the future will tell …

PCIM Europe is only a few weeks ahead. Asked for the biggest differences between these two leading events, many people explained, that APEC is more about the conference, while at PCIM the show is a standout. A summary of the APEC conference by our expert Dr. Gary Dolny will follow in the next issue. It will be exciting to see new products announced in the very historical Nuremberg (a little older than San Antonio). And who knows, maybe the GaNMan will find his way to Europe !

Bodo's Power Systems reaches readers across the globe. If you are using any kind of tablet or smart phone, you will find all of our content on the new 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 March:
When you're in town, enjoy a trip in one of those horse carriages. Transportation with just 1 HP gives you a good, green feeling, although those animals are producing CO2 after a good meal of oats. And their illumination is a performance in itself – LED lights of course !

Best Regards

Holger Moscheik

Dr. Andreas Bauknecht is new Industrial Sales Director at ROHM

Dr. Andreas Bauknecht is Industrial Sales Director at ROHM since February 1st, 2018. Bauknecht (49) has 17 years of experience in the semiconductor industry, where he held several leading positions in development and marketing. In his new position, he will strengthen the industrial area at ROHM.

After his PhD at the Hahn-Meitner-Institute in Berlin on semiconductors for photovoltaics he started his industrial career at Philips Semiconductors. Subsequently he held several positions in development before he switched to international marketing. Among other things he was International Product Marketing Manager for NXP Semiconductors. He set up regional sales and marketing teams for the communications section, establishing business with Samsung in South Korea and with Chinese smartphone manufacturers. Most recently Bauknecht was Marketing Senior Director for NXP's spin-out Nexperia, driving strategic development for worldwide business. In this position, he made major contributions towards implementing processes for sales and marketing concerning topics like market launches, customer prioritization and business guidelines for long-term success. Bauknecht is Kotler Certified Marketing Manager since 2007.

At ROHM Dr. Bauknecht will strengthen the strategically important industrial area. He will use his knowledge of the industry to create impulses, which will move the industrial area further forward.

"ROHM's target is to reach 50% of its global revenue on Automotive and Industrial segments. Europe region will play an important role to accomplish this objective. The industrial areas show a constant high growth rate in the infrastructure, Energy and Automation where Power Discrete and analog IC technologies are one of the major contributors", says Dr. Bauknecht.

www.rohm.com/eu

SEMICON Europa 2018 Call for Papers Now Open!

This year SEMICON Europa will take place in Munich co-located with electronica!

Are you influencing the direction of semiconductor technology? If so, we invite you to submit an abstract to present and contribute on critical industry topics shaping the design and manufacturing of semiconductors and adjacent markets.

The SEMICON Europa 2018 Call for Papers is currently open for:

Advanced Packaging Conference (APC)
Technology trends – what's new, what's missing, what's next

Advanced packaging is an indispensable part of the final electronic product and is facing new challenges in achieving required higher performance, smaller form-factor, higher reliability levels, and lower cost. This is driven by a continuously increasing number of new applications for instance in the field of IoT with integrated sensor and MEMS, 5G connectivity, automotive, big data, mobile phones, image recognition systems, power electronics and many others.

2018FLEX Europe / be flexible Conference
Innovations enabled by Flexible Electronics

End users, supply chain companies, R&D organizations, start-ups and universities are invited to submit abstracts for the 2018FLEX Europe Conference. FLEX Europe Conference will be held in cooperation with Fraunhofer EMFT's forum BE-FLEXIBLE. This two half-day conference, an integral part of SEMICON Europa 2018, will address materials, manufacturing, new technologies, and applications for flexible hybrid electronics (FHE) and printed electronics (PE) and will demonstrate the strong history of Europe in the field.

Important deadlines:
Abstracts Due: April 27, 2018
Notification: July 20, 2018

www.semiconeuropa.org

Opening of a China Sales Office

Magna-Power Electronics announced the immediate opening of its China sales office, Magna-Power Electronics Co., Ltd. The sales office follows significant growth of the Magna-Power brand in China. Located in Beijing, the office represents a significant commitment in the Chinese market for the Magna-Power Electronics brand. Xiaoke Li, with over 15 years of experience in the programmable power industry, is leading Magna-Power Electronics Co., Ltd. as Managing Director. "I am very excited to join Magna-Power team. I am confident that with Magna-Power's innovation product line, we can drive continued growth through strong industry knowledge and support from Magna-Power's vibrant team." states Xiaoke Li. "We look forward to helping more local engineers to realize their dream of technology innovation with Magna-Power's world leading programmable power products."

"Similar Magna-Power sales offices in the United Kingdom and Germany have proven very successful in facilitating increase sales activities, while ensuring proper technical customer support," said Ira Pitel, President of Magna-Power Electronics. "With China representing the largest market for Magna-Power products beyond the United States, this new office continues Magna-Power's commitment to improving the company's sales and support infrastructure for its increasing customer base."

The company's experience in power electronics is reflected in its 1.25 kW to 2000 kW+ product line, quality service, and reputation for excellence.

www.magna-power.com

Analog Devices GmbH Appoints New Managing Director

Analog Devices GmbH announced the appointment of Stefan Steyerl as new Managing Director for its German operations. He succeeds Peter Kolberg, who left the company after 31 years of service, effective from January 2018. Stefan brings a wealth of both company and industry experience to this role, having worked at Analog Devices (ADI) for over 24 years. Currently, Stefan has the responsibility as Director Sales for the Mobility & Transportation Cluster and the lead for the marketing activities within EMEA, roles he will continue in addition to his position as Managing Director. Under Stefan's leadership in the late 1990s, the Digital Signal Processing (DSP) business was built up and expanded in EMEA. Having undertaken roles within both business development and product marketing in Germany, Stefan later relocated to the company's headquarters in the U.S. During this period, he played an instrumental role in successfully positioning ADI's DSP business, before heading back to Munich in 2004 to lead the DSP division in Europe. In 2008, Stefan assumed the position of Director Sales Automotive EMEA, whilst also taking on responsibility for automotive customers in North and South America (2009 – 2015). Under his direction, the automotive business was a key contributor to ADI's strong growth.

www.analog.com

Xcerra Test Cell Solutions Expand to the Japan Market

Xcerra announced that a leading global manufacturer of high-quality electronic components located in Japan, has placed an order for a complete test cell for barometric pressure sensors. The business represents the first test cell solution sold into Japan and further validates the value customers see in the test cell solution approach for this high volume market. The Xcerra test cell solution includes an LTX-Credence Diamondx tester, a Multitest InStrip handler based on InCarriers and a Multitest InBaro test module. The customer chose the Xcerra TCI solution, because it offers faster time to volume, cost-efficiency and high throughput, all of which are mandatory for being successful in the high volume consumer market. Combining its expertise in ATE, test handling and interface solutions, Xcerra is able to provide a fully integrated and prevalidated test cell for highly accurate test of barometric pressure sensor devices. The test cell solution includes the InBaro module,a proven solution for accurate barometric sensor test with high throughput and stability, the Diamondx test platform, a flexible SOC tester which provides for cost-effective and high efficiency multisite test and the InCarrier which offers high parallelism and reliable handling for sensitive and challenging packages.

www.Xcerra.com/TCI

The 15th Edition of the Fortronic Power 2018

Fortronic Power returns from 27th to 28th June 2018 in Modena (close to Bologna). Once again, Emilia Romagna, a region of great excellences and with one of the most innovative manufacturing industry, confirms to be a privileged place to bring together all the latest technologies, products and systems in the power sector (and not only) with focus on some cutting-edge fields, including automotive, mechatronics, industry and biomedical. Promoted by Assodel – Italian Federation of Electronics Clusters – and by the Elint Consortium, the event promises to be even larger and with a richer program.
Engineers, designers, EMS, buyers, managers and technicians will have the opportunity to get in touch with the sector's top players. In addition, visitors will have access to conferences, workshops and demo areas offered by companies, to get a 360° view of the entire supply chain.
In 2017 the power electronics market in Italy grew by 14% reaching a value of 120 million euros for the semiconductor power components segment (Assodel data). The "power" therefore shows a better performance of the market in its entirety and 2018 will surely be another positive year.
Among the most interesting sectors, the E-Mobility and Electric Vehicles area will provide exclusive contents. In 2017 the number of electric cars registered in Italy reached 2000, with a growth of 38%, while hybrid vehicles grew by 71% and according to the "eMobility Revolution report", 3 million electrified vehicles will circulate in Italy by 2025.

www.fortronic.it

pSemi Recognized on Distinguished "IEEE Spectrum" Patent Power Scorecard

pSemi Corporation announces its ranking for the second consecutive year on the "IEEE Spectrum" Patent Power Scorecard. This annually published benchmark identifies the technology world's most valuable patent portfolios and ranks the companies by a Pipeline Power score. The 2017 scorecard ranks the pSemi patent portfolio among the top 10 in the semiconductor manufacturing sector. The pSemi patent portfolio now exceeds 500 issued and pending patents and continues to aggressively grow. Recently pSemi announced its corporate name change from Peregrine Semiconductor to pSemi and celebrated its 30-year anniversary of semiconductor technology innovation.

"pSemi is honored to be recognized for the second year by the Patent Power Scorecard," says Dan Nobbe, vice president of corporate research and intellectual property (IP) development at pSemi. "Our top 10 ranking within semiconductor manufacturers demonstrates our team's commitment to innovation and our patent portfolio's strength. Though we are excited to surpass the 500-patent-filings milestone within our portfolio, we are even more proud of the quality of our patents. It is a testament to our forward-thinking engineers and the groundbreaking role our team has played in advancing semiconductor technology for the last 30 years."

www.psemi.com

Workshop 'DC Grids, Technologies and Applications' & further ECPE Events

ECPE Workshop 'DC Grids, Technologies and Applications'
17 - 18 April 2018, Aachen, Germany
Chairmen: Prof. R. de Doncker (RWTH Aachen University),
Dr. P. Steimer (ABB Switzerland), Dr. A. Rojko (ECPE)

ECPE Lab Course 'EMC Optimised Design (Parasitics in Power Electronics)'
16 - 17 April 2018, Berlin, Germany
Course Instructor: Prof. E. Hoene (Fraunhofer IZM)

ECPE Tutorial 'EMC in Power Electronics'
14 - 15 May 2018, Vienna, Austria
Chairmen: Prof. E. Hoene (Fraunhofer IZM), Prof. J.-L. Schanen (INPG-LEG-ENSIEG - G2ELab)

ECPE Workshop 'Power Electronics for Grid Integration of Wind Energy'
19 - 20 June 2018, Husum, Germany
Chairmen: Prof. M. Liserre (CAU Kiel), Prof. F. Blaabjerg (Aalborg University)

ECPE Tutorial 'Power Electronics Packaging'
27 - 28 June 2018, tbd (programme will be published soon)
Chairmen: Prof. U. Scheuermann (Semikron), Dr. J. Popovic-Gerber (TU Delft)

ECPE Tutorial 'Model Predictive Control for Power Electronics, Drives and Power Grid Applications'
2 - 3 July 2018, Frankfurt, Germany
Chairman: Prof. R. Kennel (TU Munich)

www.ecpe.org

Infineon Technologies and SAIC Motor Establish Power Module Joint Venture SIAPM in China

SAIC Motor Corporation Limited and Infineon Technologies AG announced the establishment of a joint venture to manufacture power modules for the dynamically developing electric vehicle market in China. SAIC Motor holds a stake of 51 percent of the JV and Infineon 49 percent, respectively. The partners have received all approvals by public authorities. The JV is named SIAPM (SAIC Infineon Automotive Power Modules (Shanghai) Co, Ltd.). The JV is headquartered in Shanghai; its new manufacturing facility resides in Infineon's site expansion in Wuxi. Volume production is scheduled to start in the second half of 2018.

The joint venture SIAPM offers power solutions for electric vehicles in China, the world's largest and fastest growing market for electro-mobility. It aims to supply to all customers producing in China. Infineon will continue to independently serve all other markets. The joint venture will focus on frame-based HybridPACK™ modules for the Chinese market. First generation automotive frame-based IGBT modules within the HybridPACK™ family were introduced by Infineon in 2006 and are widely used in plug-in hybrid and full electric vehicles worldwide. Their robustness allows easy integration in cost-optimized systems and fast time-to-market.

www.saicmotor.com

www.Infineon.com

Microchip Technology to Acquire Microsemi

Microchip Technology Incorporated, a leading provider of microcontroller, mixed-signal, analog and Flash-IP solutions, and Microsemi Corporation, a leading provider of semiconductor solutions differentiated by power, security, reliability and performance, announced that the two companies have signed a definitive agreement pursuant to which Microchip will acquire Microsemi for $68.78 per share in cash. The acquisition price represents a total equity value of about $8.35 billion, and a total enterprise value of about $10.15 billion, after accounting for Microsemi's cash and investments, net of debt, on its balance sheet at December 31, 2017. "We are delighted to welcome Microsemi to become part of the Microchip team and look forward to closing the transaction and working together to realize the benefits of a combined team pursuing a unified strategy. Even as we execute a very successful Microchip 2.0 strategy that is enabling organic revenue growth in the mid to high single digits, Microchip continues to view accretive acquisitions as a key strategy to deliver incremental growth and stockholder value. The Microsemi acquisition is the latest chapter of this strategy and will add further operational and customer scale to Microchip," said Steve Sanghi, Chairman and CEO of Microchip.

www.microchip.com

Infineon and Cree Agree on Long-Term Supply of Silicon Carbide Wafers

Infineon Technologies AG and Cree, Inc. agreed on a strategic long-term supply agreement for the provision of silicon carbide (SiC) wafers. Thus, Infineon will be able to broaden its offering of SiC products to address today's high-growth markets such as photovoltaic inverters and electro-mobility. Since Infineon has already converted all its SiC manufacturing lines to the most advanced 150 millimeter SiC wafers, the agreement with Cree covers only this wafer diameter.

"We have known Cree for a long time as a strong and reliable partner with an excellent industry reputation," said Reinhard Ploss, CEO of Infineon. "Based on the secured long-term supply of SiC wafers, we strengthen our strategic growth areas in automotive and industrial power control. As a consequence we will create additional value for our customers."

"Infineon is a longstanding, valuable commercial partner with an excellent reputation," said Gregg Lowe, CEO of Cree. "This agreement validates the quality of Cree's SiC wafer technology and our capacity expansion, as well as the accelerated adoption of SiC-based solutions that are critical to enabling faster, smaller, lighter and more powerful electronic systems."

Semiconductors based on silicon carbide technology are the basis for most high-efficiency and disruptive system solutions in power conversion and in the electric car. The use of SiC-based power semiconductor solutions has shown a strong increase over the last years.

www.infineon.com

Expansion of 1700V HiPak Line-Up

New single IGBT and IGBT chopper modules from ABB

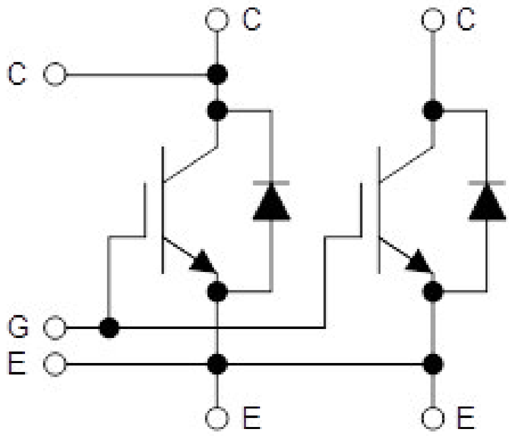
The new single IGBT and IGBT chopper modules are available with a voltage rating of 1700V and currents of 1600A and 2400A. They feature the highly rugged and low loss SPT+ chip-set technology.

Target applications for the new single IGBT modules are traction drive converters for urban transportation and regional trains as well as high-power converters for renewables.

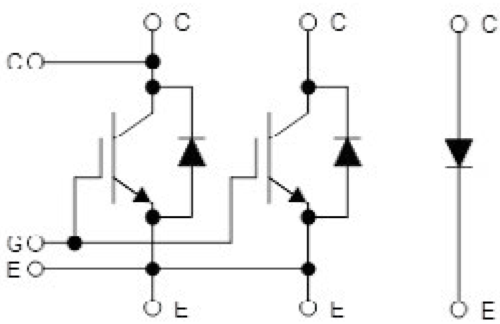
The chopper modules are an ideal fit for DC-chopper or general high-power DC-DC boost and buck converters.

The new modules can be ordered with the following part numbers:

www.abb.com



HiPak1 single IGBT modules
- 5SNA 2400N170300
- 5SNA 1600N170300



HiPak2 Chopper IGBT modules
- 5SNE 2400E170300
- 5SNE 1600E170300

Highly Efficient Power Supply System with High Dielectric Strength

New powerful semiconductor modules with high reverse voltages facilitate modern medium-voltage applications. Auxiliary components such as power supplies are increasingly becoming vital key components.

Surprisingly, it is not the silicon of the power semiconductors that presents the biggest problems in applications involving high operating voltages. Rather, it is the standard auxiliary components that are required, such as coolers, capacitors, clamping devices or even power supplies that do not meet the requirements in respect of their insulation properties in medium-voltage applications.

Figuer 1: The GvA Power Supply System (GPSS) supplies 150W per channel and at the same time provides insulation for up to 21kV partial discharge free.

Auxiliary power supplies are used, for example, to feed driver boards for IGBT, IGCT or GTO, and to supply power or voltage sensors and other auxiliaries. It is essential here to have secure galvanic isolation between the secondary medium-voltage level and the supply level from which the auxiliary power supply is fed. Depending on the application, the insulation requirements are in the double-digit kV range. In addition, at all operating points a defined freedom from partial discharges (<10pC/50Hz) must be ensured in order to prevent premature ageing of the insulation barrier. When it comes to implementing the product, particular attention is therefore paid to the high requirements placed on the insulation materials and the field distribution in the device. Last but not least, the insulation requirements in medium-voltage applications for clearance and creepage distances according to DIN/IEC must be taken into account.

The new highly efficient power supply GPSS from GvA Leistungselektronik GmbH precisely takes account of these market requirements in an ideal way. Its scalable 2-channel platform can easily be extended to 4 or 6 output channels. An insulation voltage of 35kV with a freedom from partial discharges of at least 21kV (higher values on request) and the high output power of 150W per channel cover a very wide range of applications. With a supply voltage of 24V, GPSS provides an output voltage of 35V. Low power consumption and a level of efficiency of up to 94% ensure operation with low power losses. Independently controlled temperature and short-circuit or overloading and operating states for all connected devices simplify the entire system monitoring and guarantee a high level of operational reliability.

www.gva-leistungselektronik.de

TI Expands GaN Power Portfolio with Small and Fast GaN Drivers

Two New FET Drivers Benefit Nanosecond LIDAR Applications and 50-MHz DC/DC Converters

Expanding on its industry-leading gallium nitride (GaN) power portfolio, Texas Instruments (TI) announced two new high-speed GaN field-effect transistor (FET) drivers to create more efficient, higher-performing designs in speed-critical applications such as light detection and ranging (LIDAR) and 5G radio-frequency (RF) envelope tracking. The LMG1020 and LMG1210 can deliver switching frequencies of 50 MHz while improving efficiency and enabling five times smaller solution sizes previously not possible with silicon MOSFETs.

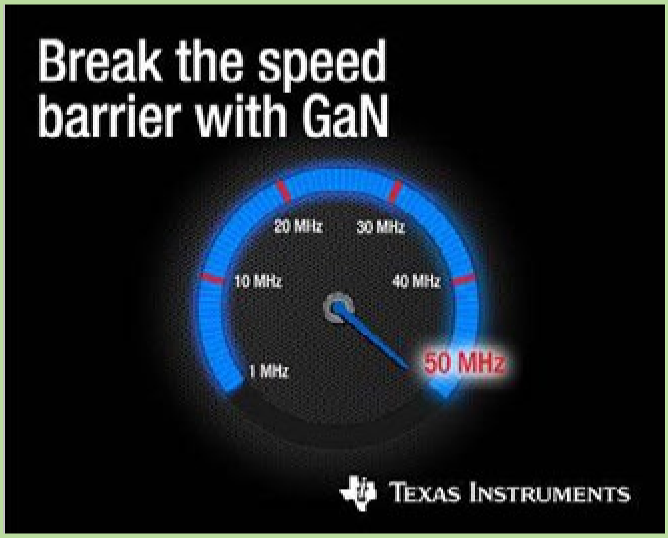
With an industry-best drive speed as well as a minimum pulse width of 1 ns, the LMG1020 60-MHz low-side GaN driver enables high-accuracy lasers in industrial LIDAR applications. The small wafer-level chip-scale (WCSP) package of only 0.8 mm by 1.2 mm helps minimize gate-loop parasitics and losses, further boosting efficiency.

The LMG1210 is a 50-MHz half-bridge driver designed for GaN FETs up to 200 V. The device's adjustable dead time control feature is designed to improve efficiency as much as 5 percent in high-speed DC/DC converters, motor drives, Class-D audio amplifiers as well as other power-conversion applications. Designers can achieve high system-noise immunity with the industry's highest common-mode transient immunity (CMTI) of more than 300 V/ns.

Key features and benefits of the LMG1020 and LMG1210

- High speed: The two devices' ultra-fast propagation delay (2.5 ns [LMG1020] and 10 ns [LMG1210]) enables power solutions that are 50 times faster than with silicon drivers. Additionally, the LMG1020 is capable of delivering high-power 1-ns laser pulses, enabling long-range LIDAR applications.
- High efficiency: Both devices enable high-efficiency designs. The LMG1210 offers a low switch-node capacitance of 1 pF and user-adjustable dead time control to improve efficiency by as much as 5 percent.

Figure 1: LMG1020



- Power density: The integrated feature of dead time control in the LMG1210 allows for reduced component count and higher efficiency, enabling designers to reduce power-supply size by as much as 80 percent. The increased power density of the LMG1020 enables the highest resolution in LIDAR in the industry's smallest package.

Figure 2: LMG1210

TI's GaN advantage

The LMG1020 and LMG1210 are the latest additions to the industry's largest GaN power portfolio, ranging from 200-V drivers to 80-V and 600-V power stages. With over 7 million hours of GaN process reliability testing, TI is addressing the need for proven and ready-to-use solutions through reliable GaN products, bringing decades of silicon manufacturing expertise and advanced device-development talent to GaN technology.

www.ti.com/lmg1020-pr-eu

www.ti.com/lmg1210-pr-eu

SEMIKRON
innovation + service

Expect More from Standard Modules.

Industry standard power module packages are commodities today. Supply chain safety for these modules is one of the most important requirements. Being compatible on the one hand, SEMIKRON standard modules even exceed these standards on the other hand.

Our portfolio of sintering and bonding technologies takes output power capability and reliability to new levels. Module-integrated current measurement shunts, plug & play drivers and pre-applied Thermal Interface Materials reduce the number of system parts, cutting development time as well as system costs and time-to-market.

www.semikron.com/semitop-e1e2
shop.semikron.com

SEMITOP® E1/E2

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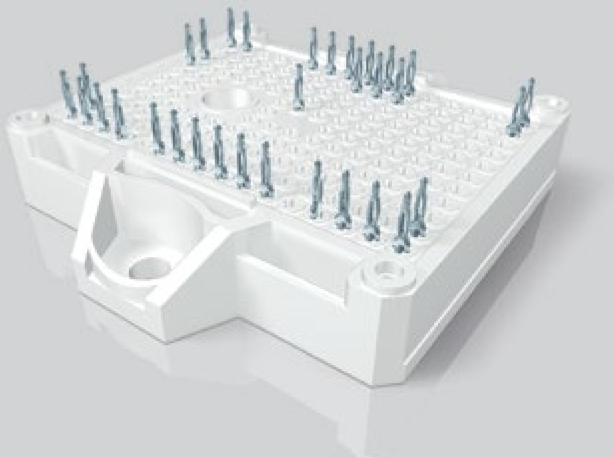


AC | DC

Power Modules Portfolio
MiniSKiiP, SEMITOP E1/E2, SEMIPACK, SEMiX 3 Press-Fit, SEMiX 5, SEMiX6p, SEMITRANS 2/3/4, SEMITRANS 10

'Negative Capacitance' Could Bring More Efficient Transistors

Researchers have experimentally demonstrated how to harness a property called negative capacitance for a new type of transistor that could reduce power consumption, validating a theory proposed in 2008 by a team at Purdue University.

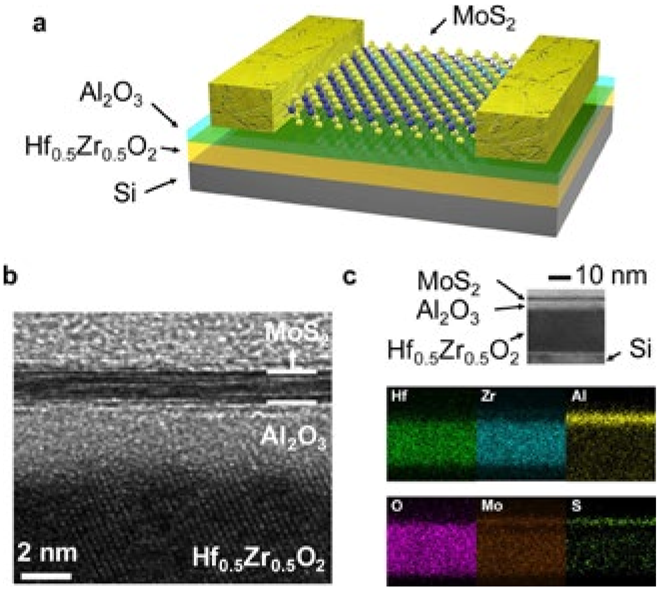
By Henning Wriedt, US-Correspondent Bodo's Power Systems

The researchers used an extremely thin, or 2-D, layer of the semiconductor molybdenum disulfide to make a channel adjacent to a critical part of transistors called the gate. Then they used a "ferroelectric material" called hafnium zirconium oxide to create a key component in the newly designed gate called a negative capacitor.

Capacitance, or the storage of electrical charge, normally has a positive value. However, using the ferroelectric material in a transistor's gate allows for negative capacitance, which could result in far lower power consumption to operate a transistor. Such an innovation could bring more efficient devices that run longer on a battery charge.

Hafnium oxide is now widely used as the dielectric, or insulating material, in the gates of today's transistors. The new design replaces the hafnium oxide with hafnium zirconium oxide, in work led by Peide Ye, Purdue's Richard J. and Mary Jo Schwartz Professor of Electrical and Computer Engineering.

"The overarching goal is to make more efficient transistors that consume less power, especially for power-constrained applications such as mobile phones, distributed sensors, and emerging components for the internet of things," Ye said.



A new type of transistor (a) harnesses a property called negative capacitance. The device structure is shown with a transmission electron microscopy image (b) and in a detailed "energy dispersive X-ray spectrometry" mapping (c). Credit: Purdue University/Mengwei Si

Findings are detailed in a research paper published on Dec. 18 in the journal Nature Nanotechnology.

The original theory for the concept was proposed in 2008 by Supriyo Datta, the Thomas Duncan Distinguished Professor of Electrical and Computer Engineering, and Sayeef Salahuddin, who was a Purdue doctoral student at the time and is now a professor of electrical engineering and computer sciences at the University of California, Berkeley.

The paper's lead author was Purdue electrical and computer engineering doctoral student Mengwei Si. Among the paper's co-authors are Ye; Ali Shakouri, the Mary Jo and Robert L. Kirk Director of Purdue's Birck Nanotechnology Center and a professor of electrical and computer engineering; and Muhammad A. Alam, the Jai N. Gupta Professor of Electrical and Computer Engineering, who made critical and wide-ranging contributions to the theory describing the physics behind negative capacitance devices.

Transistors are tiny switches that rapidly turn on and off, enabling computers to process information in binary code. Properly switching off is of special importance to ensure that no electricity "leaks" through. This switching normally requires a minimum of 60 millivolts for every tenfold increase in current, a requirement called the thermionic limit. However, transistors that harness negative capacitance might break this fundamental limit, switching at far lower voltages and resulting in less power consumption.

New findings demonstrate the ferroelectric material and negative capacitance in the gate results in good switching in both the on and off states. The new design achieves another requirement: for the transistors to switch on and off properly they must not generate a harmful electronic property called hysteresis.

The negative capacitance was created with a process called atomic layer deposition, which is commonly used in industry, making the approach potentially practical for manufacturing.

The research is ongoing, and future work will explore whether the devices switch on and off fast enough to be practical for ultra-high speed commercial applications.

"However, even without ultrafast switching, the device could still have a transformative impact in a broad range of devices that may operate at lower frequency and must operate with low power levels," Ye said.

Portions of the research were based at the Birck Nanotechnology Center in Purdue's Discovery Park. The work was funded by the U.S. Air Force Office of Scientific Research, National Science Foundation, Army Research Office and Semiconductor Research Corporation.

The work was performed by researchers from Purdue, the National Nano Device Laboratories in Taiwan, and National Laboratory for Information Science and Technology of Tsinghua University in Beijing.

ABSTRACT:
Steep Slope Hysteresis-free Negative Capacitance MoS2 Transistors

Mengwei Si1,3, Chun-Jung Su2, Chunsheng Jiang1,4, Nathan J. Conrad1,3, Hong Zhou1,3, Kerry D. Maize1,3, Gang Qiu1,3, Chien-Ting Wu2, Ali Shakouri1,3, Muhammad A. Alam1 and Peide D. Ye*,1,3

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Emerging Player in Power Control and Sensing

VIP-Interview with David Heinzmann, President and CEO of Littelfuse Inc. about his company's move into power semiconductors for industrial and automotive markets.

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

Henning Wriedt: During the last 90 years, your company acquired more than a dozen different companies, including IXYS. What was the outcome of all these activities?

David Heinzmann: To achieve our growth targets - both organic and inorganic -acquisitions have played an important role in the strategy of our company in recent years. We have achieved these growth targets by investing in the future - through acquisitions and new product development that strengthen our global infrastructure - and by adding value to customer relationships. Our brands are the cornerstone of that investment and are our commitment to each customer. Offering some of the world's best known and top-performing brands in electronics, telecommunications, automotive and electrical, Littelfuse stands as the global leader in circuit protection and an emerging player in power control and sensing.

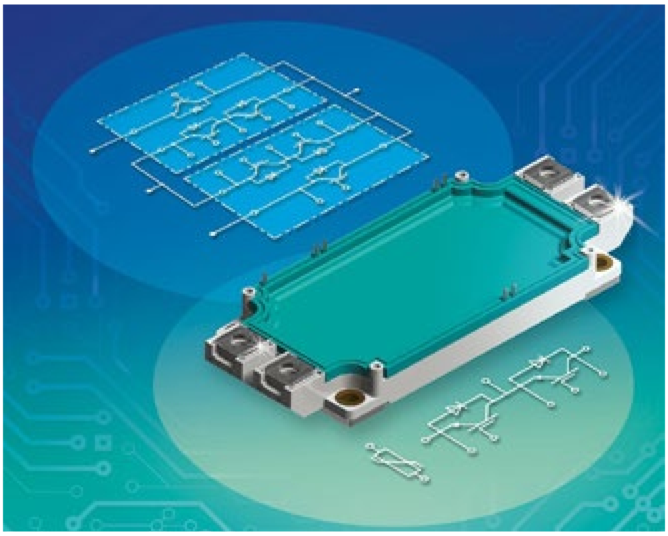

Figure 1: The SimBus F is one of many innovative packaging solutions currently offered by IXYS. It is popular in applications that leverage various phase leg configurations such as AC motor control, UPS inverters, and welding equipment.

Henning Wriedt: With at least 15 different product groups, do you want to cover every application in the diverse energy markets?

David Heinzmann: It's never been our goal to be everything to everyone. When we evaluate our strategy, we look closely at our product portfolio, our capabilities and our strengths … and we choose to play in the markets that align with those strengths and where we can create value for our customers.

Henning Wriedt: Are the IoT and Automotive markets already attractive enough for your company?

David Heinzmann: When we set out on our strategy in 2012 and we refreshed that strategy at our Investor/Analyst Day in December 2016, we were sure to align our strategy with broad, sustainable global megatrends like safety, connectivity and energy efficiency.
These global megatrends play to our strengths. Our circuit protection products ensure the safety of products that run the spectrum from small electronics to home automation and appliances – on up to the auto industry.
Certainly, trends like hybrids, EVs, and EV charging stations all present opportunities, but the continued electrification of traditional gasoline-powered automobiles also plays to our strengths. As cars get smarter, add more sensing technologies, add more electronic navigation systems and infotainment components, all of these shifts in technology allow us to add to our content-per-vehicle.
More and more automotive functions are shifting from mechanical technologies powered by belts and the car's internal combustion engine to electric, battery-powered motors. Again, all of these play to our strengths in circuit protection, as well as our emerging technologies in sensing and power controls.

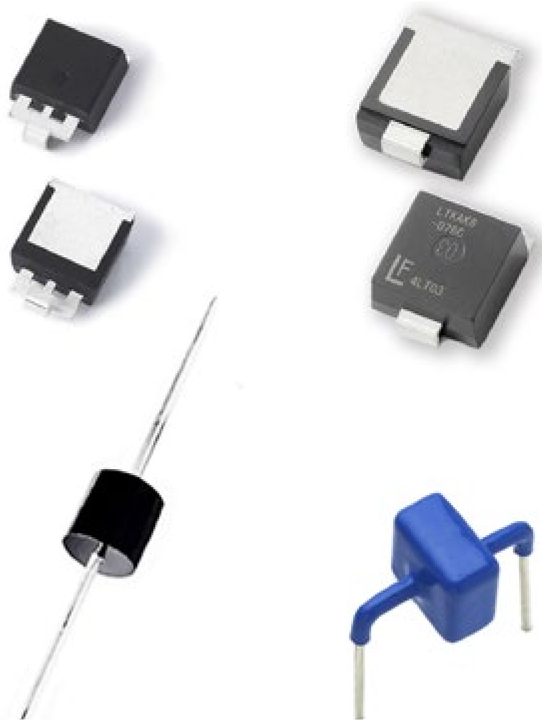

Figure 2: Littelfuse TVS diodes are used to protect semiconductor components from high-voltage transients. The p-n junctions of these devices have larger cross-sectional areas than those of normal diodes, allowing them to conduct large currents to ground without sustaining damage.

Henning Wriedt: Electronics sales increased 32 percent. Which role play power electronic products in this segment?

David Heinzmann: The growth in the electronics industry has taken place across multiple end market and products. We have seen strong growth in automotive products driven by energy efficiency and electronics content in passenger car and also in communication networks driven by faster mobile communications. Together with the IXYS acquisition, which Littelfuse has just completed, we have a stronger position in industrial markets including renewables and motor drives.

Henning Wriedt: How are you going to structure your portfolio of power electronics products in reference to market demands and available technologies?

David Heinzmann: We are in the very early days of the IXYS integration but we have a significant customer overlap in key industrial and automotive markets. We can leverage these relationships to grow the Littelfuse position in industrial markets and use Littelfuse expertise in the automotive space to expand the IXYS presence. The IXYS product portfolio fits very well with the existing Littelfuse Semiconductor manufacturing footprint, and we look forward to developing those capabilities further.

Henning Wriedt: Why did Littelfuse invest in Monolith Semiconductor?

David Heinzmann: Our strategy has centered around a more significant move into power semiconductors for industrial and automotive markets. Silicon carbide technology is a promising advancement in the semiconductor market today, and our investment in Monolith allows us to quickly evolve our portfolio with strategically relevant and innovative technology.

Henning Wriedt: In 2016, you opened a Technology Center in Silicon Valley. Is this about keeping up-to-date in technology and expertise?

David Heinzmann: Our Silicon Valley Technology Center allows Littelfuse to do just that - to keep up-to-date with technology and expertise. It allows us to accelerate the development and validation of next-generation materials and products for the automotive and electronics markets. In addition, it builds upon our network of global design centers and testing labs and brings together advanced development and materials development teams into a single dedicated facility.

Bottom line, creating innovative solutions that solve our customer's most complex and demanding needs is the foundation of our company. And, our tech center in Silicon Valley enables the collaboration and creativity needed to create the key technologies of the future.

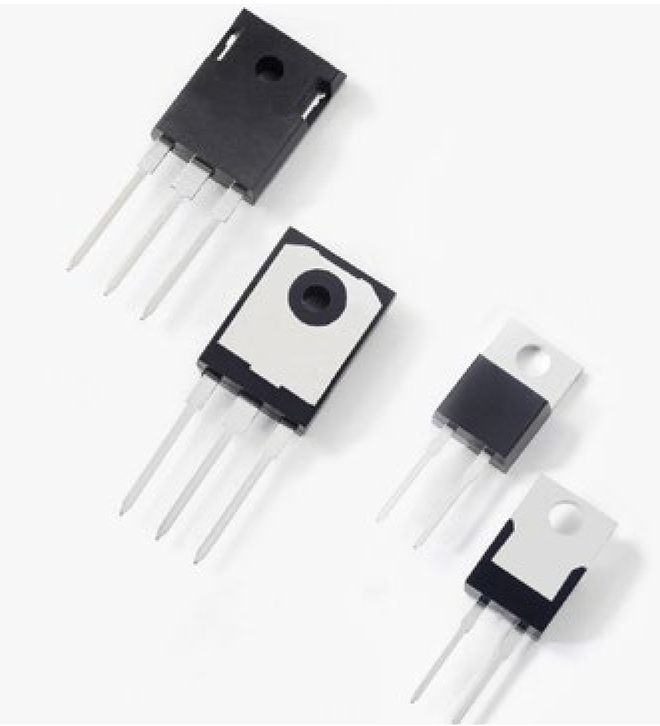

Figure 3: Silicon Carbide (SiC) products are ideal for applications where improvements in efficiency, reliability, and thermal management are desired. Littelfuse and Monolith focus on developing the most reliable Silicon Carbide MOSFETs and Diodes available while delivering industry leading performance.

David Heinzmann, President and CEO of Littelfuse Inc.

David W. Heinzmann, became President and Chief Executive Officer, and a member of the Board of Directors, in January 2017. He was previously the company's Chief Operating Officer responsible for all three Littelfuse business units, as well as the company's global operations and information technology. Mr. Heinzmann began his career at the company in 1985 and possesses a broad range of experience within the organization. He has held positions as a Manufacturing Manager, Quality Manager, Plant Manager and Product Development Manager. Mr. Heinzmann served as Director of Global Operations for the Electronics Business Unit from 2000 to 2003, Vice President and General Manager, Automotive Business Unit from 2004 to 2007, Vice President, Global Operations from 2007 to 2013 and Chief Operating Officer from 2014 to January 2017, when he was promoted to his current position. Mr. Heinzmann currently serves on the Board of Directors of Pulse Electronics Corporation and the Advisory Board of the University of Illinois at Chicago Engineering College. Mr. Heinzmann has a bachelor of science degree in mechanical engineering from Missouri University of Science and Technology.

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A SiC MOSFET for Mainstream Adoption

To become a mainstream product, the silicon carbide (SiC) MOSFET´s outstanding technical functionality must come together with the right cost position, system compatibility features, silicon-like FIT rates and volume manufacturing capability. These multiple levers must all match within a working business case for power system manufacturers in order to change the game in power conversion. This especially targets energy efficiency and making "more out of less".

By Fanny Björk, Product Marketing Manager at Industrial Power Control division at Infineon

Infineon shows the corresponding feature set of the CoolSiC™ MOSFET family and matching driver ICs. These support entry applications like photovoltaic inverters, un-interruptible power supplies (UPS), drives, battery charging infrastructure and energy storage solutions.

Introduction

A growing number of power electronics applications can no longer address the future target requirements when relying on silicon (Si) devices alone. Improving power conversion performance while increasing power density, reducing board space and driving down component count as well as system cost are conflicting challenges due to silicon devices' high dynamic losses. To fix this, engineers are increasingly deploying solutions with power semiconductors based on silicon carbide (SiC) material.

Infineon and SiC Schottky diodes have been an innovative duo for a long time now, with first 600 V products launched in 2001. Over the years a broader portfolio including 650 V and 1200 V voltage classes has grown. New generations with higher current handling capability per given chip area while reducing power losses were developed and released. Hundreds of millions of SiC diode chips have been produced and shipped to the market. In applications such as MPP tracking in solar inverters or power factor correction in switch-mode power supplies, the use of a Si IGBT plus SiC diode or a superjunction Si MOSFET with SiC diode became state-of-the-art solution for more than a decade now, achieving high conversion efficiency and highly reliable systems. Market reports even highlight that a plateau of productivity is being entered for SiC diodes [1]. Volume manufacturing skills in SiC technology, production quality monitoring and a field track record with excellent FIT rates built a base for taking the next step in product strategy encompassing also a SiC MOSFET. Transistor functionality in SiC semiconductor material provides further potential for getting out more of less energy - energy efficiency – in the whole electrical energy supply chain from energy generation, transmission and distribution to consumption.

Boosting efficiency factors

Let´s take a closer look at the performance advantage of a SiC MOSFET versus a Si IGBT. Figure 1 shows an example of a state-of-the art silicon solution: one phase-leg of a three-level T-type topology with 650 V and 1200 V silicon (Si) IGBTs typically used in three-phase systems like photovoltaic inverters and UPS if high efficiency and high power density are targeted. High efficiency can be reached up to a switching frequency of 20-25 kHz [2] with such a solution. A 1200 V SiC MOSFET converts current at about 80% lower losses than a 1200 V Si IGBT thanks to low device capacitances, low partial load conduction losses and the absence of a current turn-off tail. Using 1200 V SiC MOSFETs in the outer switch positions boosts efficiency significantly and enables higher output power for a given frame size. Raising switching frequency further would quickly deteriorate efficiency and maximum output power for the Si-based solution, while a SiC MOSFET´s low switching losses make this possible.
Demonstrated by this example, a tripling of the operating frequency up to 72 kHz still results in higher efficiency than achieved by the silicon solution operated at 24 kHz. As a result, reduction of the physical size of passive components, lower cooling effort, reduced system weight and cost can be achieved.

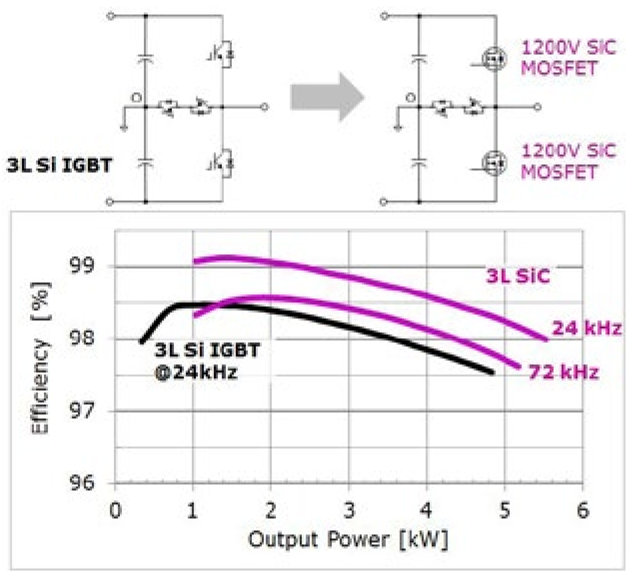

Figure 1: Comparison of efficiency for a 1200V SiC MOSFET (45mOhm typ., IMW120R045M1) versus 1200V Si IGBT (40A, IKW120N120H3) in outer switch positions, in a three level (3L) T-type topology, one phase-leg. For the 72 kHz operation case, 650V SiC diodes are replacing Si diodes in the inner switch positions.

Another three-phase power conversion example is charging infrastructure for electric vehicles. A 1200 V SiC MOSFET enables building one LLC full-bridge stage for the DC-DC conversion stage, where a typical silicon solution relies on 650V Si super junction MOSFETs where then two cascaded LLC full-bridges are needed to support the DC link of 800 V. As shown in Figure 2, four sets SiC MOSFET plus driver ICs can replace eight sets of Si super junction MOSFETs plus driver ICs. Other than the reduced part count and board space, also efficiency may be optimized. For a SiC MOSFETs solution only two switch positions are turned on in every on-state, in comparison to four switch positions in the Si solution. Highly efficient charging cycles can be realized by using a SiC MOSFET in fast battery charging.

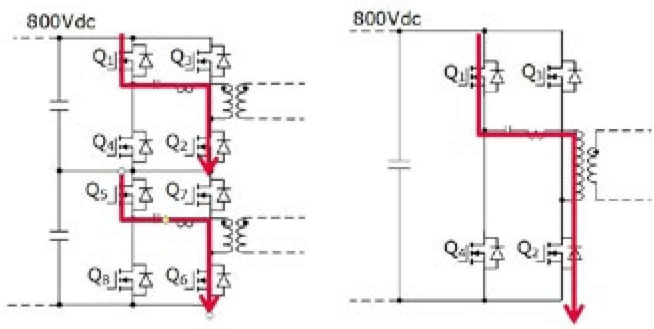

Figure 2: Three-phase LLC DC/DC stage comparison for same power rating, showing reduced part count and benefit in on-state current path if 1200V SiC MOSFETs (right) rather than 650V super-junction Si MOSFETs (left) are used.

Thanks to dynamic losses being an order of magnitude lower than in the 1200 V Si-class, a SiC MOSFET also gives traditional simple topologies a revival by increasing performance. In Figure 3 a conventional two-level solution using 1200V SiC MOSFETs is compared to the previously mentioned state-of-the art three-level silicon solution. Benefits by a two-level topology are far simpler control schemes, and reduced part count by 50%. Such a solution can be used in photovoltaic and UPS inverters, as well as in active front-ends with bi-directionality in drives systems, battery charging and energy storage

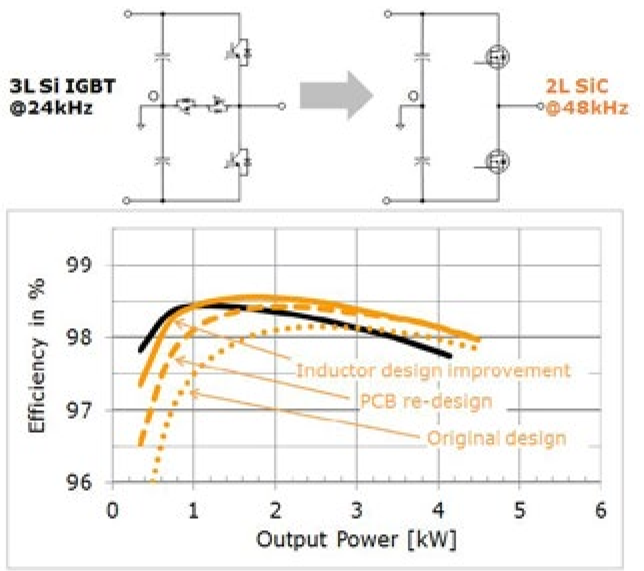

Figure 3: Comparison of efficiency for a 1200V SiC MOSFET (45mOhm typ., IMW120R045M1) in a two-level (2L) configuration versus a three level (3L) T-type configuration using 1200V and 650V Si IGBTs, one phase-leg. Efficiency increase from PCB layout improvement and inductor core losses improvement are shown respectively.

solutions. As can be seen from Figure 3, despite doubling the switching frequency from 24kHz to 48 kHz a 0.3-0.4 % efficiency increase results at high load condition for a two-level SiC MOSFET solution, which indeed is impressive as the switching voltage is doubled compared to three-level operation – 800V versus 400V.

However, there are also challenges when designing in a SiC MOSFET. The switching transients of a SiC MOSFET must be considered. A dv/dt of 50 V/ns or more is not unusual in comparison to 5-20 V/ns typically seen in a 1200 V Si IGBT. A parasitic coupling capacitance on board level will thus lead to excessive energy loss. For the case of replacing a three-level Si IGBT solution with a simpler two-level solution, the parasitic coupling capacitance will generate eight times higher energy losses if switching voltage and frequency both are doubled. Figure 3 shows the original efficiency line when a SiC MOSFET is used plug and play in a standard IGBT two-level solution, while the next efficiency line shows how a careful PCB design with respect to drain-source parasitic board capacitance will contribute to reducing the losses [2]. A second topic to consider when switching frequency is increased concerns the core losses of the inductor. With ripple current and its corresponding loss staying constant over the whole load regime, an improvement of core losses by changing the core material influences mainly the partial-load efficiency. These two improvements finally resulted in the attractive efficiency line above 98.5 % versus the three-level Si IGBT solution. This demonstrates that a SiC MOSFET is mostly not a plug and play option to Si IGBT and significant design-in work is required to bring performance to a higher level. One of the development targets for Infineon´s CoolSiC™ MOSFET therefore was to tune device parameters to values making system design implementation as easy as possible.

System compatibility

One system compatibility feature is the gate driving scheme. Until now, SiC MOSFETs required a higher gate drive voltage than Si IGBTs or Si MOSFETs and usually suffer from a low gate-source threshold voltage with just minor margin to zero volts. This minor margin makes gate voltage ringing spikes at high dv/dt slew rates a concern for the system designer. The novel trench technology introduced with Infineon's CoolSiC™ MOSFET enables a standardized gate driving scheme as for Si IGBTs with +15 V being sufficient for turn-on, and a benchmark threshold voltage of 4 V for a robust signal to noise ratio during current turn-off.

SiC MOSFETs also require matching driver ICs to unlock their full potential. These drivers must handle high dv/dt reaching 50 V/ns or above, and high switching frequencies, posing tougher requirements on timing and tolerances. A SiC MOSFET might also need negative gate voltage, especially when used in hard-switching topologies, or a Miller clamp. Infineon´s EiceDRIVER™ ICs are well-suited to drive SiC MOSFETs, and come in a broad portfolio offering various features depending on application needs [3]: tight propagation delay matching, precise input filters, wide output-side supply range, negative gate voltage capability or Miller clamping, and extended CMTI capability.

Reliability and robustness assurance

Reliability and robustness assurance in SiC are strongly linked to Si mainstream technologies. With Infineon´s long track record in power semiconductors and understanding of application needs, tough requirements were set for CoolSiC™ MOSFET products. SiC is a great power semiconductor, however designing a MOSFET in this material involves technological challenges for tuning of performance parameters versus reliability and robustness.

Designing a planar SiC MOSFET is a major trade-off between area-specific on-resistance and gate oxide reliability, in other words “chip cost and performance versus reliability”. The defect density on the planar SiC – SiO2 interface is very high in 4H-SiC [4], which leads to scattering of electrons in the MOSFET channel and thereby a reduction of electron channel mobility. The reduced performance shows up as increased channel resistance and increased power losses in on-state. Only by applying an excessive electric field across the oxide for turn-on, either via higher gate-source voltage or thinner SiO2 layers the area-specific on-resistance can be kept on an attractively low level.

For a trench MOSFET device structure in SiC material, the need to overdrive the oxide is not in place thanks to SiO2 interface in the vertical crystal lattice plane having a far lower defect density than a planar interface [5]. However, a trench structure is a bigger challenge with regards to blocking mode at the trench corners due to high electric fields in SiC material. Design measures to achieve a proper field reduction are more complex than in planar structures. CoolSiC™ MOSFETs contain a unique asymmetric trench structure [6] reducing the electric field in off-state, see Figure 4. A large portion of the bottom of the trench is embedded into p+ wells, which extend below the bottom of the trench thus reducing the off-state electric field. For gate oxide reliability as described in [6, 7] the resulting extrapolated 20 years operation lifetime of the product at an on-state operation of +15 V, shows a predicted low failure rate including extrinsic defects of 0.2 ppm.

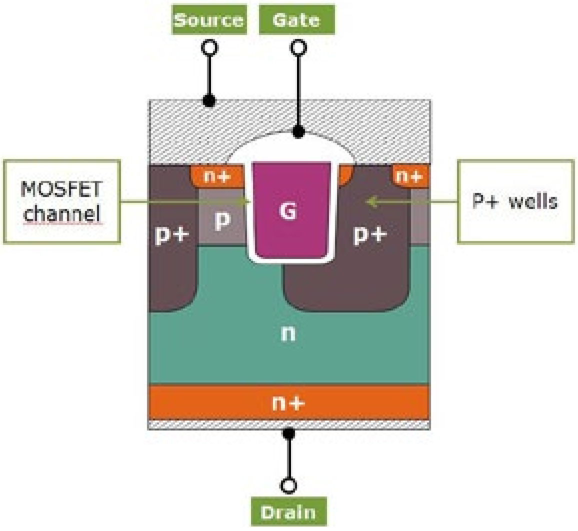

Figure 4: Schematic cross-section of the CoolSiC™ MOSFET cell.

Gate threshold voltage stability has also been a concern for SiC MOSFETs for a long time. A well-optimized MOS process is required for guaranteeing a narrow and predictable drift [8] over lifetime, a pre-condition for a datasheet specification of this parameter.

As can be seen in Figure 4, the large area of the p-emitter also enables the device to be used as a rapid free-wheeling diode. It is a strong value adder for a SiC MOSFET in many applications if the intrinsic diode can be utilized, as no extra SiC Schottky diode is needed. This intrinsic diode comes with high commutation robustness and low reverse recovery charge [7]. The CoolSiC™ MOSFET intrinsic diode is reliable in long term operation, Figure 5 demonstrates this by a performed DC current stress test: forward voltage (VF) and on-resistance (RDSon) correlations before and after stress have proven that the intrinsic diode is stable and ready to be used.

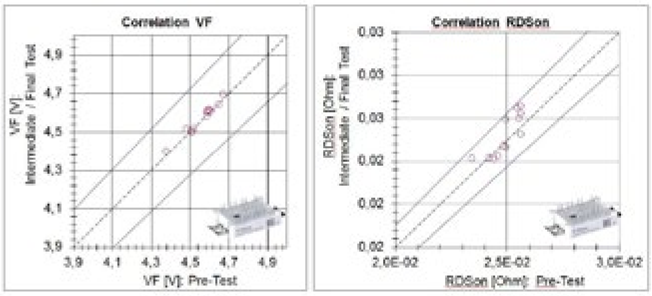

Figure 5: DC stress test result of intrinsic diode of CoolSiC™ MOSFET. Test conditions: VGS=-9 V, 20 A per chip, Tvj~150°C. VF and RDSon correlations after >100h DC operation.

Infineon was pioneering in SiC MOSFET studies as can be seen from publications from the 90s [9]. The deep knowledge of the limits and options, the strong internal benchmark and the quality of Si-MOS technologies was the fundament for the decision on the CoolSiC™ trench technology. CoolSiC™ MOSFET products now come with robustness levels equivalent to Si IGBT based systems, as illustrated in Figure 6.

Volume capability

Before widespread adoption of SiC MOSFETs can take place, customers will need to be sure that their chosen supplier will be able to provide consistent supply of high-quality products, and continues to deliver when demand increases. Established production flows at Infineon for high volume and high flexibility are proven for both Si and SiC chip manufacturing, as well as for assembly into discrete packages or power modules. Advanced power device technologies have successfully been ramped before, e.g. CoolMOS™, TRENCHSTOP™ IGBT, and CoolSiC™ Schottky diodes. The company´s skills are in place to also bring CoolSiC™ MOSFET products through a market introduction and volume ramp.

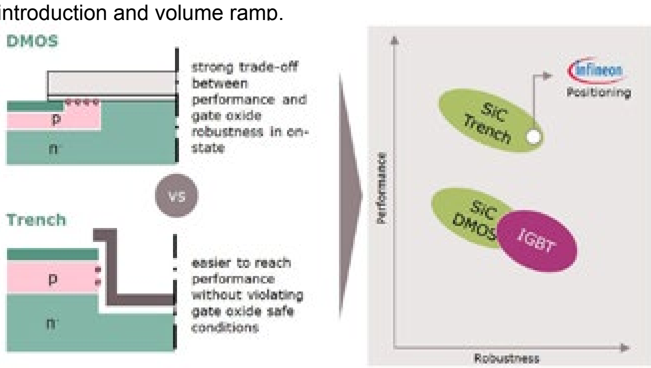

Figure 6: Novel CoolSiC™ MOSFET technology from Infineon comes with robustness levels equivalent to IGBT based systems.

Cost position

One of the factors that historically blocked broader adoption of SiC devices in the market was the higher price compared to silicon devices. Still SiC devices are more expensive and cost parity will not be reached in a foreseeable future due to fundamental differences to silicon in the fabrication process of raw wafers. SiC diode prices have declined over the years as a result of increased adoption, economy of scale, new area-effective chip designs and moves to larger wafer diameters in production. The lower prices and increased availability of SiC devices in the market have now resulted in renewed demand from power designers who are under pressure to improving power conversion performance while reducing system cost at the same time. The first entry applications for CoolSiC™ MOSFET meanwhile are successfully ramping up where a total system cost reduction can be achieved with today´s price level. These first applications are triggering future volume growth for productivity improvements via economy of scale, and over time, there is an attractive cost-down roadmap for SiC in comparison to Si technologies as illustrated in Figure 7.

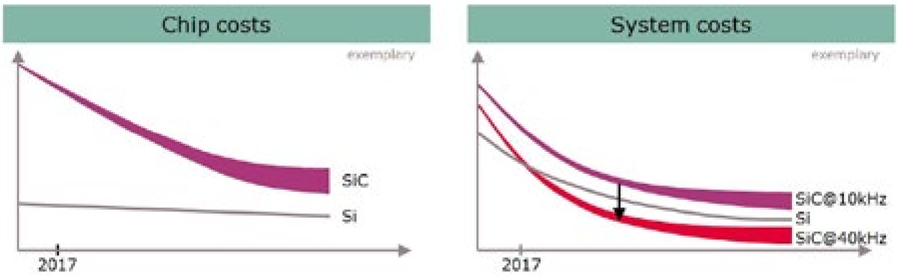

Figure 7:Exemplary view on productivity potential for SiC chips, and corresponding system costs.

Summary

CoolSiC™ semiconductor solutions are the next step towards an energy-smart world. It is shown in this article how implementation of a 1200 V CoolSiC™ MOSFET in state-of-the-art three-phase Si based solutions can increase efficiency by more than 0.5%, reduce part count by 50%, as well as triple the switching frequency to 72kHz at even higher efficiency than a Si IGBT solution operated at 24 kHz. CoolSiC™ MOSFET together with EiceDRIVER™ ICs hereby offer a new degree of flexibility for system designers to improve on efficiency, save space and weight, reduce cooling requirements and improve reliability while achieving lower system cost. CoolSiC™ MOSFET family will match all the key requirements for a broad market adoption in various power conversion schemes including performance, cost position, system compatibility features, silicon-like FIT rates and volume manufacturing capability.

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Acknowledgment

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1.5A, Negative Regulator Expands Family of Current-Reference Linear Regulators

The LT3080, introduced in 2007, represented a new linear regulator architecture featuring a current source as reference and a voltage follower for the output amplifier. This new architecture has a number of advantages, including easy regulator paralleling for increased output current and operation down to zero output voltage. Since the output amplifier always operates at unity gain without a resistor-setting divider, bandwidth and absolute regulation are constant across the output voltage range. Transient response is independent of output voltage and regulation can be specified in millivolts rather than as a percent of output.

By Dawson Huang, Applications Engineer, Power Management Products, Analog Devices

Table 1 summarizes the family of devices that use this architecture. The LT3091, the latest addition to this family, is a 1.5A low dropout negative linear regulator featuring adjustable current limit and current monitor. The LT3091 is similar to the other negative linear regulator in the family, the LT3090, but with more than double the LT3090's current rating.

	LT3091	LT3090	LT3081	LT3080
Output current	1.5A	600mA	1.5A	1.1A
ISET	−50µA	−50µA	50µA	10µA
Adjustable current limit/current monitor	Yes/Yes	Yes/Yes	Yes/Yes	No/No
LDO (low dropout)	Yes	Yes	No	Yes
Positive/Negative voltage	Negative	Negative	Positive	Positive

Table 1: Some of Linear's regulators featuring the current reference architecture

The LT3091 is useful in high current, negative voltage applications requiring low noise or precision output. It features fast transient response, high PSRR and low output noise. Low dropout helps keep it from overheating when supporting loads up to 1.5A. Built-in protection includes reverse output protection, internal current limit with foldback and thermal shutdown with hysteresis. This versatile negative regulator architecture can operate down to zero volts out and as a negative floating regulator.

How It Works

The negative output voltage is set with a −50µA precision current source driven through a single resistor RSET from ground to the SET pin. The internal follower amplifier forces the output voltage to match the negative voltage of the SET pin. With this architecture, all of the internal operating current flows in from the output pin. Only a 20µA load is required to maintain regulation at all output voltages. Figure 1 shows the basic hookup for the LT3091. It provides 1.5A of output current, can be adjustable to zero output voltage, and features both positive and negative monitors for output current. It is also reverse protected, when output voltage is lower than input.

The current limit can be reduced below 1.5A by connecting an external resistor RLIM between ILIM and IN pins, as shown in Figure 1. This function can effectively protect the load and limit the temperature of the IC.

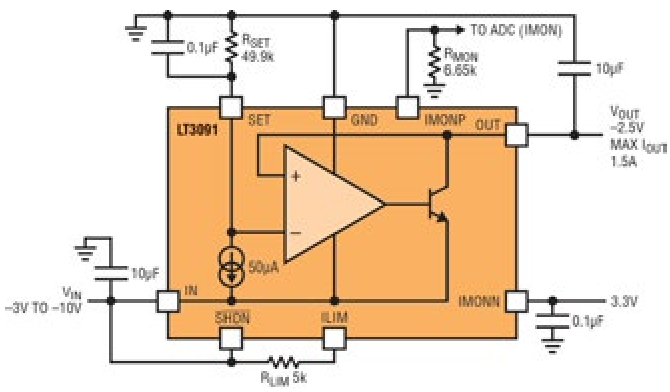

Figure 1: 1.5A, negative linear regulator with current limitation and monitor

With 3.3V feeding the IMONN pin, the IMONP pin sources current equal to 1/4000 of the output current. This current source is measured by tying a resistor, RMON, to ground in series with the current source and reading the voltage across the resistor. With the IMONP pin tied to VIN, the IMONN pin sinks current equal to 1/2000 of the output current. In this way, positive or negative output current can be monitored with minimal components, no additional sense resistors or amplifiers required.

Paralleling Devices for More Current

Paralleling LT3091s is easy with this new current source reference regulator. Paralleling is useful for increasing output current or spreading heat. Since the LT3091 is set up as a voltage follower, tying all the SET pins together makes the outputs the same voltage. If the outputs are at the same voltage, only a few milliohms of ballast, ROUT1,2, are required to allow them to share current.

Figure 2 shows a schematic of two LT3091s paralleled to obtain 3A output. The set resistor, RSET, now has twice the set current flowing through it, so the output is −100µA times RSET. The 10mΩ output resistors, ROUT1,2 ensure ballasting at full current.

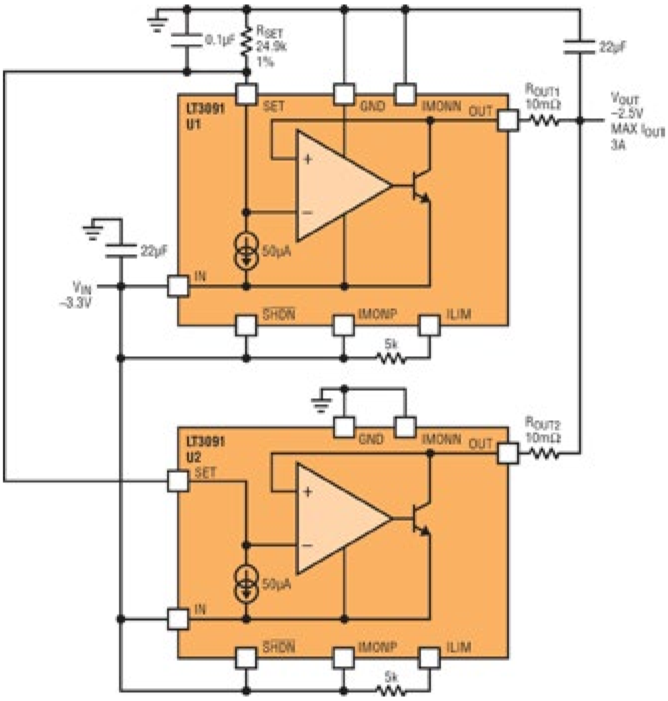

Figure 2: 3A negative linear regulator with paralleled LT3091

There is no limit to the number of devices that can be paralleled for higher current.

Figure 3: Thermal performance of two paralleled LT3091s

Figure 3 shows the thermal distribution of the design of Figure 2—U1 and U2 reach similar temperatures, indicating equally shared current.

Low Noise Positive-to-Negative Converter

Inverting converters generate a negative voltage from a positive input, and feature low output ripple. If combined with a high bandwidth LDO such as the LT3091, the overall converter can have very high transient response with even lower noise.

Figure 4 shows a low noise coupled-inductor positive-to-negative converter. The inverting converter is based on LT3581, a PWM DC/DC converter with built-in power switch. Its 4mm × 3mm DFN package and tiny externals can be combined with the LT3091 in a compact and quiet solution. Figure 5 shows the transient response of the two output voltages. Figure 6 shows the thermal performance of the entire system.

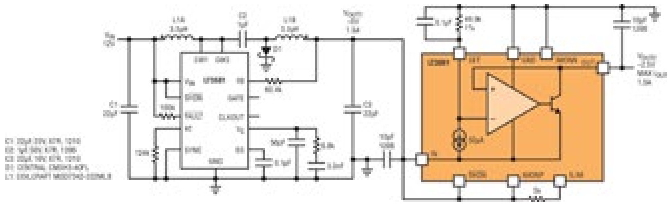

Figure 4: 1.5A low noise and fast transient positive-to-negative converter

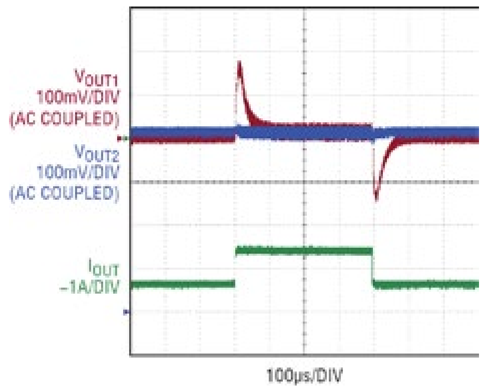

Figure 5: Transient response for positive-to-negative converter

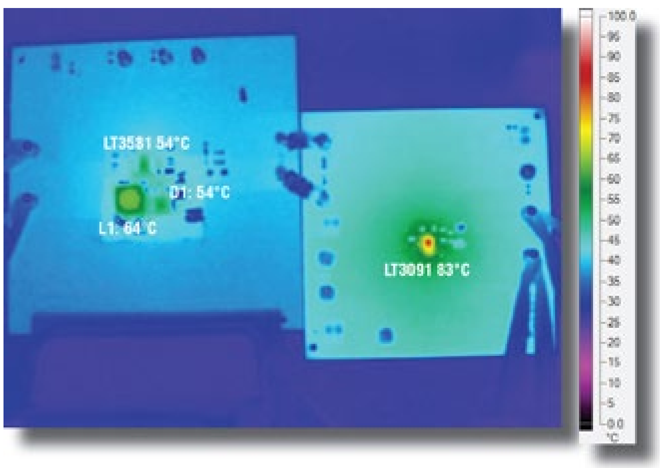

Figure 6: Thermal image for positive-to-negative converter

Low Noise Positive and Negative Power Supply

A high current positive-to-positive-and-negative converter can be built with a positive 1.5A LT3081 linear regulator and its negative 1.5A linear counterpart, the LT3091. The LT8582 is a dual-channel PWM DC/DC converter with internal switches in an available 7mm × 4mm DFN package. It can generate both a positive and a negative output from a single input.

Figure 7 shows a 1.5A 12V-to-±3.3V low noise power supply using the LT8582, LT3081 and LT3091. Figure 8 shows the transient response of the negative rail. Figure 9 shows the temperature of the entire system.

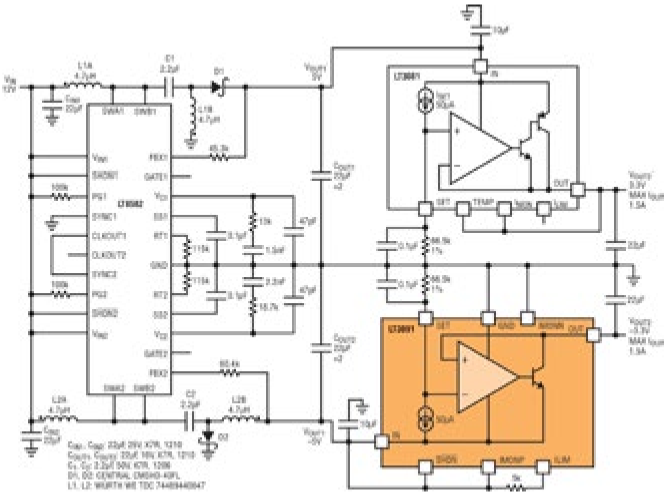

Figure 7: 12V to ±3.3V low noise power supply

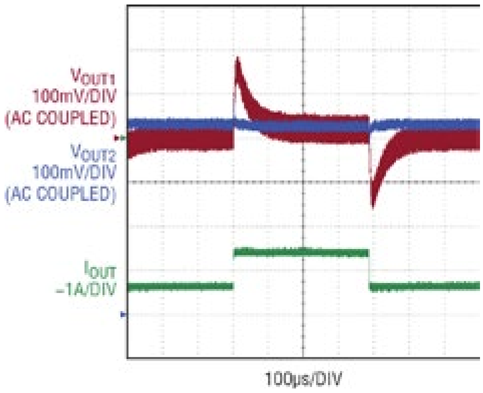

Figure 8: 12V to ±3.3V low noise power supply

This setup can be used as an operational amplifier power supply—where a high speed operational amplifier requires a low noise, high speed ±3.3V power supply.

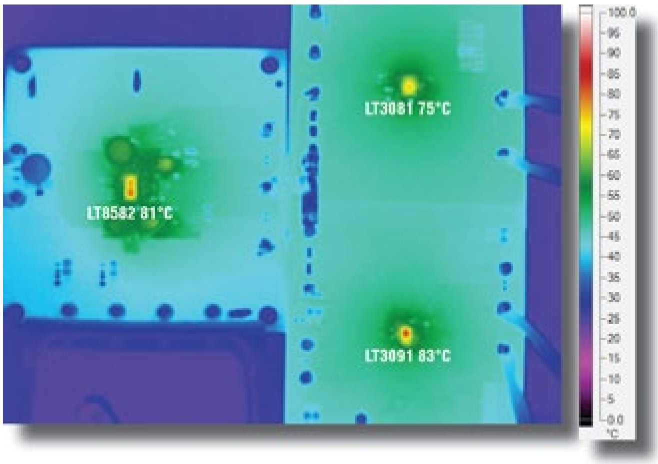

Figure 9: Thermal image for 12V to ±3.3V low noise power supply

Conclusion

The LT3091 is a 1.5A, low dropout, current reference negative linear regulator. This regulator is easy to parallel to increase output current. It also features fast transient response, high PSRR and low output noise, making it ideal as a post regulator. It can be used for power supplies capable of sinking and sourcing current.

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Practical Solutions Design with GaN Power Transistors

Analyst firm IHS is projecting continued growth in the power semiconductor market with Wide Bandgap (WBG) devices in the 100-650V range to have the greatest overall gain. Among WBG semiconductors, GaN is fast becoming the leading transistor technology with the many successes companies are realizing with GaN devices.

By Peter Di Maso, Director, Product Line Management, GaN Systems

Its use in power is being proven in designs ranging from power supplies in data center servers and racks, computing and communications systems to renewable energy systems (e.g. solar energy storage systems and inverters), motor drives and pumps, class D audio systems, and electrification of transportation (e.g. EV wireless battery charging systems and automotive onboard chargers). Improvements in other power electronics systems such as high-speed wireless charging and AC adapters in consumer applications are easily achieved.

The largest growth markets for WBG semiconductors including GaN are in automotive and transportation, which is projected to exceed $7.1 Billion USD by 2023, industrial systems (to exceed $10.5 Billion USD), and consumer electronics sector (to exceed $6 Billion USD). Other industries are worth looking at as well. The computing, datacenter, communications, and datacom (5G enablement)/telecom sector will also grow with rising appetites from consumers for greater speed, data, and convenience. This is accelerating the need to upgrade the power supplies in areas such as data centers for greater efficiency, scalability, and flexibility as that market becomes a higher percentage of the overall power demand.

In all, the common theme is the insatiable appetite for greater efficiency in all these applications. The largest percentage of growth in WBG semiconductors, which will have the greatest impact as the need or increasing efficiency, reducing size, weight, and power density and overall systems cost, is most proximate in applications from 20W to 20KW. These applications are moving forward at an ever-increasing pace due to the tremendous benefits to the end user.

GaN Performance Advantages
One of the biggest advantages of GaN is offering better high frequency and high voltage performances that results in developing power device designs that are smaller in size and reduce cost. In the ease of evaluation in new designs, GaN E-HEMTs already use similar techniques to what power electronics designers use today. GaN Systems e-mode devices use comparable techniques for maximizing efficiency of their designs by providing similar gate drive signals and PCB layout techniques can be used so the learning curve is very short.

In our case, it's very easy to take advantage of the higher frequency operation and low parasitic inductance, which has already been taken care of by our GaNPX® Packaging – making it easy by supplying SPICE models, thermal models, schematic symbols and PCB footprints for incorporation into PCB development and layout software packages. In comparison to the industry's legacy packaging approaches such as TO-247 and PQFN, GaNPX is designed to lower the possibility of failure and maintain the power efficiency benefit that GaN technology uniquely provides through the production process.

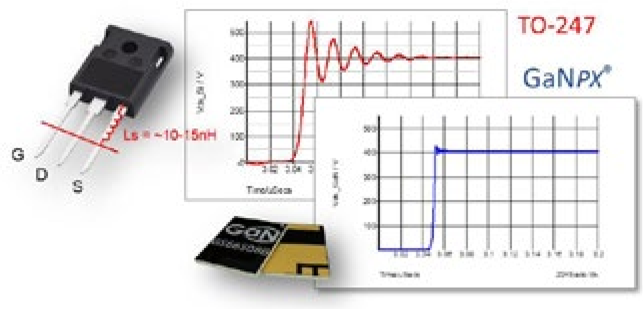

Figure1: Designed to lower the possibility of failure and maintain the power efficiency benefit that GaN technology provides

As the gate drive of GaN Systems devices are similar to existing silicon MOSFETs, many of the existing isolated and non-isolated gate drivers can be used. In fact, with lower gate capacitance they are often easier to drive. This, combined with the existing nature of GaN makes them as close to as MOSFETs as possible but much faster thus getting closer to the ideal switch needed in power electronics designs. Due to the benefits of GaN EHEMTs in power in conversion, many existing and new IC suppliers are developing GaN drivers to further optimize these benefits. If higher currents are needed, GaN Systems devices are easily paralleled and the lower gate charge capacitance makes them easy to drive while increasing speed and circuit efficiency.

GaN comparison to Silicon Carbide (SiC) – Performance and Application
Any non-ideal semiconductor switches will have loss contributions. When compared to traditional silicon switches, GaN devices exhibit the following properties.

- Lower "Conduction loss" that is due to the DC resistance in the device current loop.
- Lower "Switching loss" that occurs during the transition between "On" and "Off" states.

GaN devices can cut power conversion losses from the state of what's possible today with silicon switches by 50-90 percent.

We can see that GaN has clear advantages when compared to silicon. However, what about comparisons to SiC? Power devices

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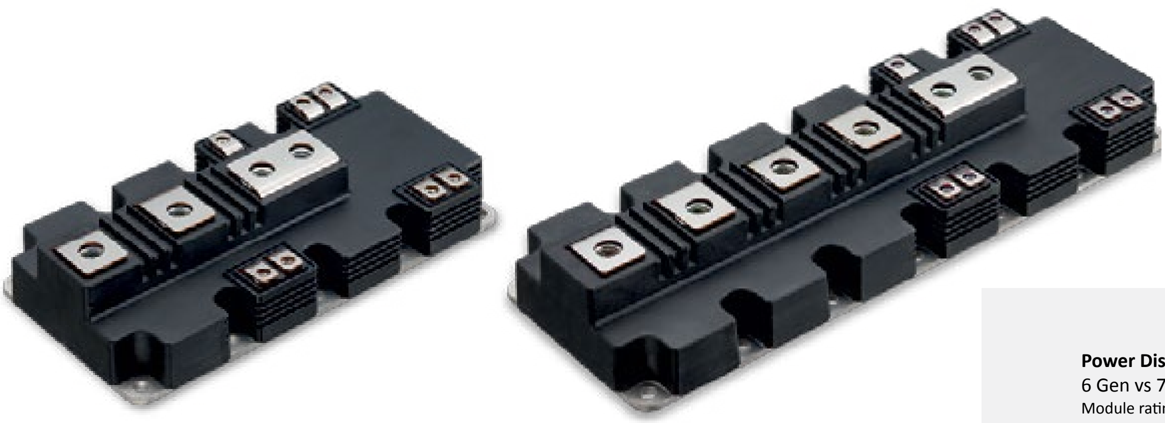

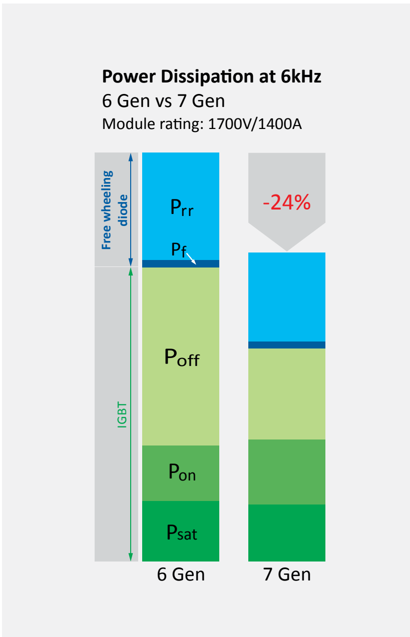

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today are increasingly based on SiC and GaN as both have material properties superior to traditional silicon.

However, there are some comparisons to note between GaN E-HEMTs and SiC MOSFETs in performance and in certain applications. In many applications, GaN E-HEMTs exhibit much higher efficiencies than ones that use SiC MOSFETs and exceeds the performance in terms of switching speed, parasitic capacitance, switching loss, and thermal characteristics. Compared with SiC counterparts, GaN E-HEMTs facilitate the construction of significantly more compact and efficient power converter designs.

With the same layout design, it has been shown and demonstrated that GaN devices exhibit four times faster turn on and two times faster turn off time in actual operating converters. This means, three times less switching losses and 40-60C degrees lower temperature operation while giving one percent greater efficiency in a sync buck converter. These are critical advancements towards the ideal switch and we are closer than ever before to achieving this theoretical limit.

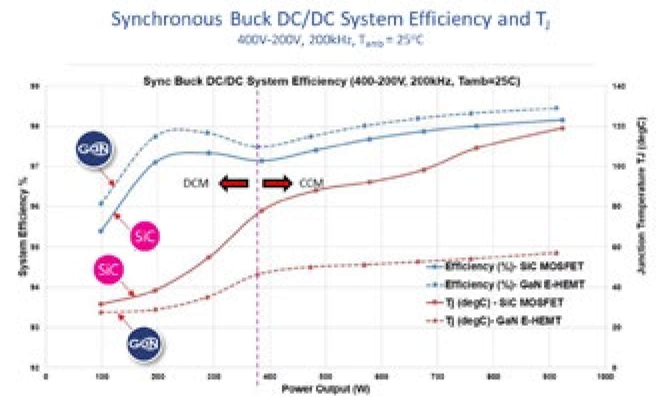

Figure2: Four times faster turn on and two times faster turn off time in actual operating converters

What else can be done other than simply improving existing topologies?

GaN offers the opportunity to create new topologies and enhance existing ones, which in many cases allow the reduction of component counts while increasing reliability at the same time.

The bridgeless Totem pole topology is now easily enabled with GaN Systems devices. Since GaN devices have no parasitic BJT or body diode and offer zero reverse recovery charge, designers can implement topologies that take advantage of these characteristics. One of the efficiency limitations for AC offline applications has been the input bridge rectifier.

By implementing the bridgeless totem pole architecture, the input bridge rectifier can be eliminated and stages can be combined. In other words, if rectification from the mains can be combined with the PFC function then we can achieve several benefits at once to increase the overall power converter efficiency by eliminating the forward voltage drop of the bridge rectifier. No body diode results in zero reverse recovery charge however, it is reverse conduction capable without the need for an anti-parallel diode. External parts count is reduced as well.

GaN reduces losses, increases efficiency, and reduces size as less heat sinking is required, and the size of magnetics components decrease. In DC-DC designs especially in the ZVS (Zero Volt Switched) LLC converter, GaN technology contributes reduced output capacitance, COSS, which makes the converter not only easier to achieve ZVS, but also reduces the transformer losses and RMS currents. This translates to smaller magnetics resulting in higher efficiency typically by 50-90 percent, smaller size (quarter of the original size in many cases), and higher power density. Moreover, the weight is also reduced to a quarter of the non-GaN implementation weight.

GaNPX packaging technology also creates flexible and innovative thermal solutions. For example, GaN Systems offers IMS modular evaluation platforms up to and greater than 5KW, which incorporate commonly used topologies such as half bridge and full bridge converters for ease of trial in applications.

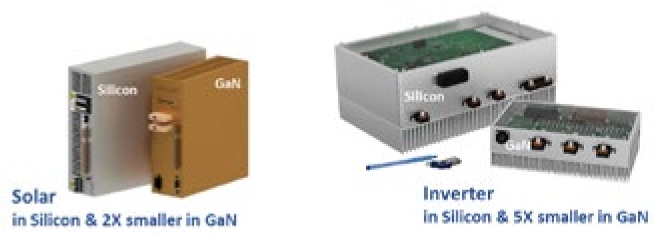

Figure3: GaN reduces size as less heat sinking is required

A Ready Ecosystem of Support Components

GaN covers almost any design need from 100Vat 90A to 650V at 60A today. It's also never been easier to use GaN with a robust ecosystem of support component – gate drivers, controllers, magnetics and module partnerships in place. Additionally, GaN Systems has invested in developing this network with industry leaders, which enables new topology implementations that further increase efficiency of new designs while reducing component count.

Conclusion

In many applications the superior thermal performance and cost effective GaNPX packaging makes implementation in any design easy while making it possible to reduce system cost, increase reliability by lowering heat dissipation, lower shipping costs via smaller size and weight, and reduce maintenance and system operating costs.

All of these benefits combined with an ecosystem of support components results in lower bill of materials cost, lower shipping and installation costs, lower operating costs, and lower maintenance and repair costs, resulting in lower total cost of ownership. While we have just scratched the surface here we invite you to view the entire presentation and explore what's possible in creating designs with a competitive edge and adding more value to your end customers. View the presentation at https://player.vimeo.com/video/247310389.

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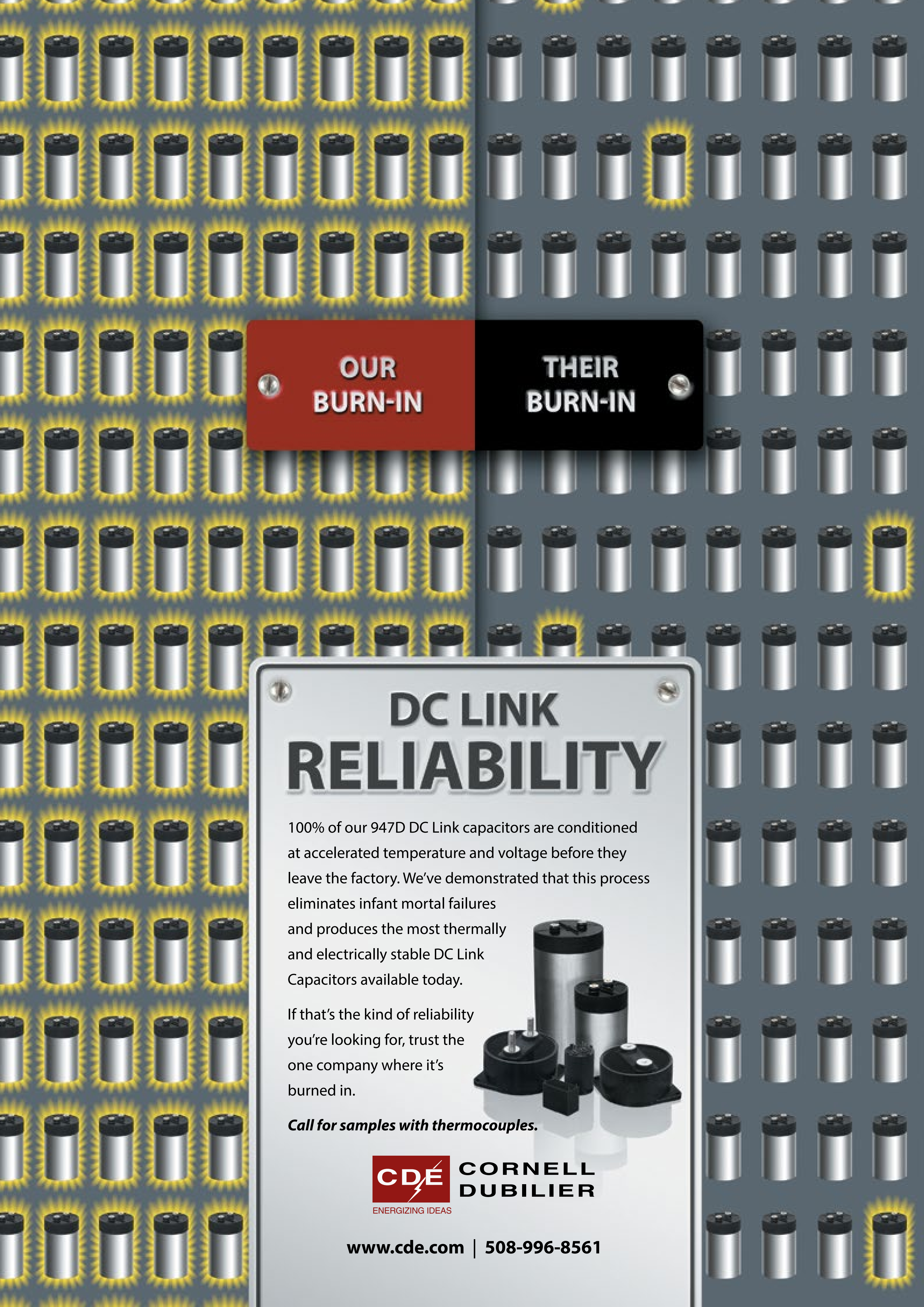
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PQSine Active Harmonic Filters

The complex power networks of skyscrapers and other modern buildings must serve a wide range of nonlinear loads. Cutting-edge active power conditioning solutions based on the EPCOS PQSine S series of active harmonic filters help skyscrapers and large commercial buildings eliminate potential power quality issues.

By Dr. Raghavan Venkatesh, Product Marketing PFC, EPCOS AG

The many power electronics systems in use in large commercial buildings such as skyscrapers include nonlinear loads such as variable speed drives, UPS systems, computers and servers, lighting, TV sets, and more. A major challenge facing building operators is the harmonics pollution in their power networks, leading to a marked deterioration in the quality of the supply voltage.

TDK field applications engineers are joining forces with specialized power quality distribution partners to create a cutting-edge power conditioning solutions for such buildings based on the PQSine S series of active harmonic filters.

The dangers of harmonic pollution
The nonlinear current draw results in harmonics that cause distortion in the sinusoidal voltage, which in turn can cause interference for other loads. Harmonics are integer multiples of the basic frequency, i.e. of the line frequency of 50 Hz or 60 Hz. The harmonics have varying amplitudes and can extend into the upper kHz range. Harmonic pollution has a series of negative effects on power quality, including:

- malfunctions of other loads due to the poor grid power quality;
- additional current load on the neutral conductor, as the harmonic currents of the 3rd, 9th, 15th, and 21st orders etc. are accumulative and lead to inadmissibly high currents;
- phase asymmetry (specifically when operating single-phase switch-mode power supplies) which additionally promotes the generation of harmonics.

In addition, harmonics can severely impair the function of sensitive devices or even destroy them. IT networks with their servers and PCs are a typical example, where the malfunction of network devices can lead to corrupted data and enormous consequential damage.

Towering power quality challenge
Due to the sheer size of skyscrapers and the complexity of its various electrical loads and systems, power quality therefore plays a central role in ensuring lowest possible energy consumption and costs, as well as avoiding overheating, production/process downtimes, and malfunction of equipment.

The major electrical loads and their characteristics are:

- Elevators
  The required reactive power compensation for up to more than 100 elevators is very dynamic, and changes very fast between capacitive and inductive during operation and when they feed recuperative power back into the network. The THD-I is also very high and changes rapidly. The main contributors to THD are in the 5th, 7th, 11th and 13th orders.
- Indoor and outdoor lighting
  All lights are LED and CFL (compact fluorescent lamp), which are used to save energy, generate significant harmonic distortion in the range from 150 Hz up to 2500 Hz. Large-screen LED digital billboards (with up to more than 2000m² dot-matrix lighting); the main harmonic current is of the 3rd order, but harmonic distortion is also present up to the 50th order.
- Air-conditioning
  The inverters employed are a source of harmonic distortion and require reactive power compensation. They produce dominant harmonics typically in the 5th, 7th, 11th and 13th order, but also in the 17th and19th order and above.
- Fans, water pumps, cooling machines, and fire protection
  The many smaller 6-pulse power converters in the system contribute current harmonics in the 5th and 7th order and above.
- IT networks, UPS, security systems, and access control systems
  The many SMPS in the servers, clients and other network devices generate harmonics from the 3rd to 23rd order and above. Moreover, they require a reliable and secure power supply without interruptions.

Complete power conditioning solution
The extremely complex load profile of skyscrapers requires both dynamic reactive power compensation and the mitigation of harmonics over a broad frequency spectrum. An ideal solution for such large commercial towers is a complete power conditioning solution based on the PQSine S series of active harmonic filters.

The first step is a detailed analysis of the building's power network. In this case, TDK field application engineers work together with specialized power quality distribution partners. For new skyscrapers, this will take place during the building's construction phase. Such analyses generally reveal significantly elevated THD levels and transient harmonics in all feeders of a building's network (Figure 1). In a typical

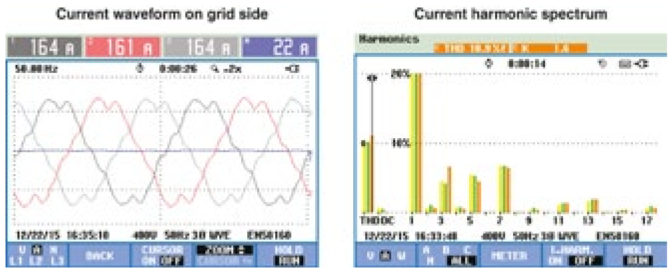

Figure 1: Typical performance analysis of a power supply system, showing the presence of significant harmonic distortion in all harmonics, especially in the 3rd, 5th, 7th, 11th and 13th orders

office tower distortion is especially high in the 3rd, 5th, 7th, 11th and 13th harmonics.

Based on the analysis and the requirements for power quality, energy savings, reliability, the advanced PQSine S series of active harmonic filters and power optimizers represents an ideal solution (Figure 2). The PQSine S series extends the comprehensive portfolio of EPCOS components and systems for power quality solutions covering solutions such as active and passive harmonic filters, de-tuned capacitor banks, and low and medium voltage automatic power factor correction systems.

Figure 2: EPCOS PQSine S series of active harmonic filters can be installed in floor cabinets (left) or wall-mounted cabinets (right).

PQSine S series for high performance and reliability
The PQSine S series is designed for 3-phase grids with or without neutral conductors and enables harmonics of up to the 50th order (2500 Hz/3000 Hz) to be detected and filtered.

In addition to outstanding filtering capabilities, PQSine active harmonic filters also ensure balancing of the loads to all three phases. Moreover, neutral conductor currents are also compensated when using 4-wire devices. These features avoid line resonance and ensure high performance and reliability.

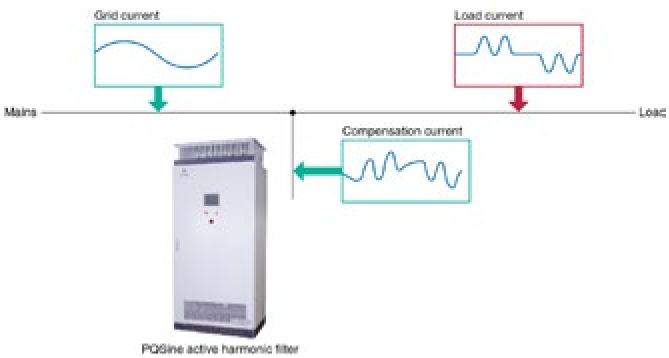

Figure 3: Functional principle of EPCOS PQSine. PQSine ensures a sinusoidal current draw. Harmonics and phase shifts are effectively reduced.

The optimized active harmonic filtering solution with PQSine has the following key features:

- **Harmonic and reactive power compensation dual function**
  The PQSine S series of active filters effectively compensate system harmonics, while at the same time providing fast reactive power compensation for both capacitive and inductive loads, which can keep the system power factor at very nearly 1.0.
- **Intelligent switching design**
  Special bus system, to ensure that any two of the three ACB cabinets (two incoming and one bus coupler) are always switched in for performance and redundancy purposes.
- **Ultra-fast reaction speed**
  The PQSine S series of active filters feature a reaction time of under 50 µs and can thus respond quickly to the high and rapidly changing loads;
- **Modularity and scalability**
  In order to allow for future system expansion to meet changing power conditioning requirements, each installed PQSine cabinet has two or three empty slots.

Optimum reliability is ensured by means of a series of self-monitoring systems. The most important of these are: overload protection, shutdown on overtemperature, protection against overvoltage or undervoltage and fan monitoring. The PQSine S series includes a 7-inch TFT color touchscreen for user-friendly input and reading of the data. PQSine offers a number of Modbus (RTU) and TCP/IP (Ethernet) interfaces for control, programming, and diagnostics purposes.

The PQSine S series of active harmonic filters are based on the latest state of the art in power electronics technology. They are installed in parallel to the polluting loads. The active filter analyzes the line current and its associated harmonics and generates a compensation current which neutralizes the harmonic currents and creates an almost sinusoidal waveform (Figure 3). With its fast reaction time, PQSine offers excellent performance for fast-changing loads, such as those generated by elevators. Using the data determined in real time, PQSine feeds a compensation current into the grid, which cancels the nonlinearity of the load current.

Optimized design for demanding harmonics
In order to optimally compensate harmonic currents from the electrical loads in a recent installation, a total of 76 PQSine S series units were

installed for the various feeders on eleven levels of the skyscraper. Figure 4 shows a typical single line diagram of an electrical distribution board.

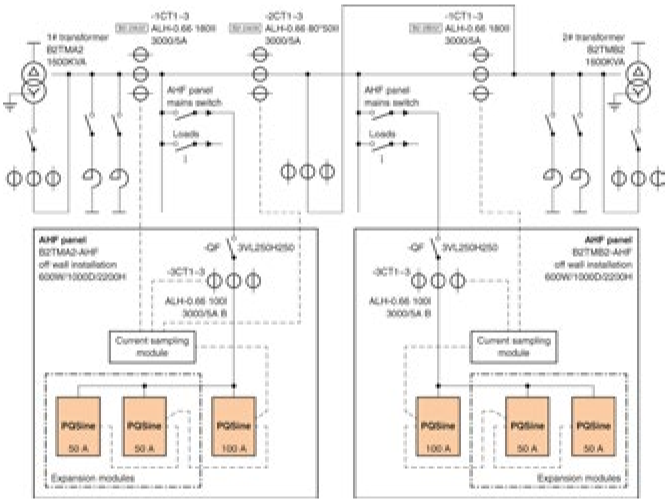

Figure 4: Typical single line diagram of an electrical distribution board.

Reliable harmonic current compensation for a wide range of applications

After the installation of the complete power conditioning solution, the TDK field application engineers and their partners typically perform a comprehensive power quality analysis with specific focus on harmonics as proof of the installation's effectiveness.

According to the power quality data gathered on site at a recent installation, the PQSine S series limits the system THD-I to below 3 percent. The system current was about 160 ARMS during the specific measurement. Overall, the PQSine solution successfully delivered the highest level of power quality. The current phases were sinusoidal with a very low level of THD-I (Figure 5), and the power factor was nearly 1.0.

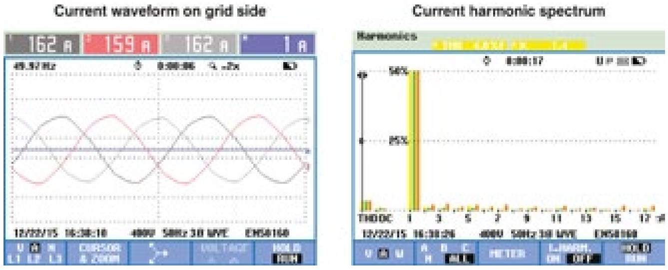

Figure 5: With the PQSine active harmonic filter and power optimizer, the current phases were sinusoidal with a very low level of THD-I and the power factor was nearly 1.0.

PQSine has proven very effective in mitigating harmonics and also providing dynamic reactive power compensation to ensure the optimal power quality for all loads and users of large commercial buildings.

PQSine active harmonic filters and power optimizers are especially suitable for fast current harmonics, reactive power compensation or neutral current compensation in a wide range of power networks in

- Data centers and IT-enabled service facilities,
- Renewable energy power generation,
- Process industries,
- Sensitive manufacturing facilities, and
- Office buildings, shopping centers, hospitals.

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Dealing with Common-Mode Voltage Influence

The extreme signal rise-times made possible by wide-bandgap semiconductors create common mode voltages at the switching frequency and above. Without appropriate measures, instrument readings will show huge deviations from the true value. We will present possible approaches to address this challenge and discuss their relative merits.

By Bernd Neuner, ZES ZIMMER Electronic Systems GmbH

The quest for clean and sustainable sources of energy has always been accompanied by a race for more efficiency. Clean production of energy needs to go hand in hand with avoiding waste of energy. Since electric motors and motor-driven systems account for about 40% of the global consumption of electricity, switching to variable-frequency drives carries enormous potential for energy savings. Advances in semiconductor technology – like SiC and GaN – allow the construction of ever more efficient frequency converters and inverters, helping to close the gap between green production and overall consumption.

Unfortunately, the increase in efficiency is paid for with downsides on the signal side: increased switching speed results in extremely steep rising and falling voltage flanks, which in turn can cause severe common-mode issues. In this article, we will focus on the consequences of common-mode voltages for accurately measuring power and efficiency.

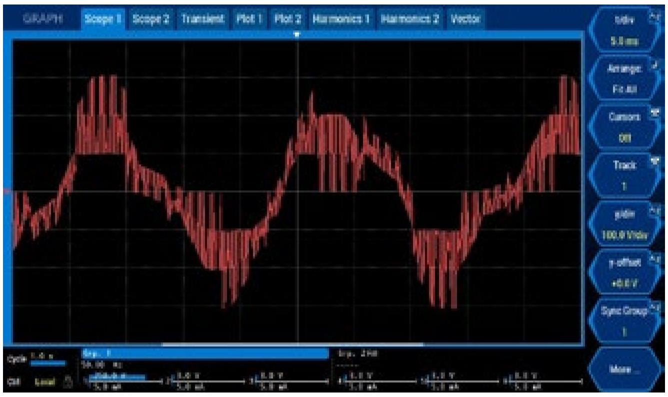

Figure 1: Example PWM signal

The CMRR is defined as the ratio of the powers of the differential gain over the common-mode gain, measured in positive decibels. This definition is geared towards amplifiers, but we can redefine the CMRR in a wider sense to look at how well an instrument can deal with common mode influence. In the instrument, the rather symbolic "gain" can be defined as the ratio between the amplitude applied to the measurement channel input and the result displayed on-screen; it thus equals 1. It has to be noted, however, that the susceptibility of an instrument to common-mode influence is not a direct consequence of the CMRR of its op amps, since those never get exposed to common-mode signals in the first place. Rather, the CMRR is a consequence of a variety of asymmetries in the analog design, differing path lengths, stray capacitances etc. Leaving the root causes aside, we will look at three differing approaches found in the market to deal with the issue:

Approach #1: The obvious approach is the choice of an instrument (e.g. a power analyzer or an oscilloscope) that already offers an excellent CMRR. In terms of complexity and usability this choice has clear advantages over more intricate solutions, and it can also easily be handled by less experienced users. However, not all instrument manufacturers even specify their CMRR, so it might be difficult to get the required information for selecting the appropriate model in the first place. It is important to read the specification correctly: what matters is the CMRR at the desired operating point, which might be considerably worse than the one typically specified at 50/60Hz.

Approach #2: The use of an artificial star point for measuring three-phase systems. This approach is low-cost and trivial to implement, it merely requires an additional piece of hardware (basically a combination of three resistors) between the instrument and the DUT. Unfortunately, it does nothing to mitigate common-mode issues when measuring signals with high du/dt values, as can easily be demonstrated by monitoring the voltage of the star-point. It still occasionally being implemented probably stems from the confusion of the influence of the phase voltages with that of the switching pulses. The former are not significantly relevant for common-mode issues.

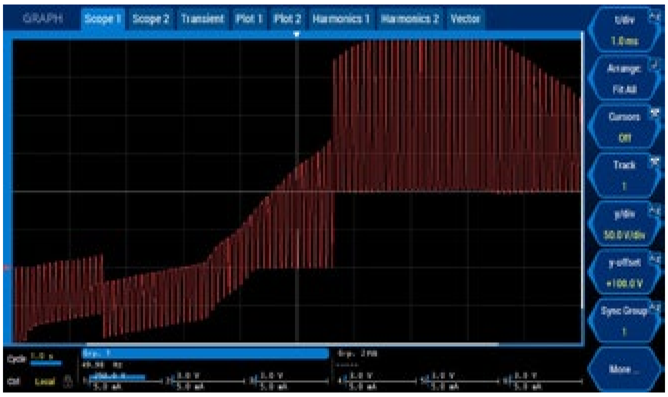

Figure 2: Star-point floating voltage

Approach #3: The use of high-quality differential probes can eliminate common-mode problems, as long as the specified CMRR is sufficient - the same considerations already listed in the paragraph about CMRR in instruments apply. The cost impact is considerable and needs to be taken into account when playing with the idea to save budget by going for a low-cost instrument with poor "built-in" CMRR. Of course, in many cases existing probes that are also used for non-power measurements could be re-purposed for the job – although this might create conflicts when calibrated measurements are required, as we will see below. The addition of probes, does however, add complexity to the measurement setup. This needs to be taken into account both when calculating the uncertainty of the measured results and when calibrating the system. Strictly speaking, the system should get calibrated as a whole, and for the results to remain valid it must not be modified in any of its parts – the probes need to stay attached to the channels they were connected to during calibration. This is rarely ever the case in practice, though. Typically, all components get calibrated separately, often at different times and maybe even different points of operation. To calculate the correct measurement uncertainty for the combination of all parts of the chain can become a laborious task that needs to be carried out painstakingly in order to obtain valid results.

Whether CMRR gets optimized in the instrument itself or its measurement accessories, there is a relatively straightforward test to judge the effectiveness of the measures taken. In the first step, the voltage input of the instrument needs to be shorted in order to eliminate any difference in potential. The area of the conductor loop used for the purpose needs to be kept minimal in order to avoid unwanted inductive coupling of leakage currents to earth. Once inputs are shorted, the voltage reading needs to be written down (U_1). It basically shows the combination of the DC offset and the noise floor of the measurement channel. Next, the phase voltage of the DUT, e.g. an inverter, needs to be applied to one input.

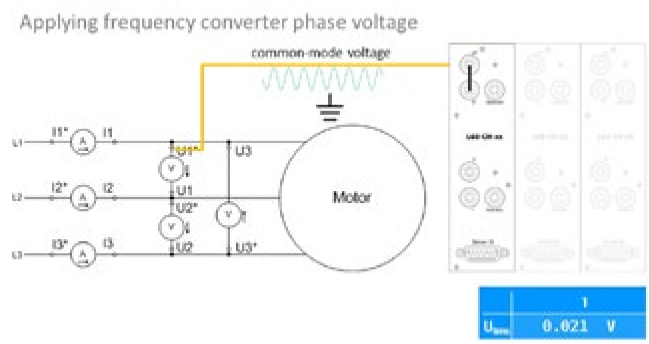

Figure 3: CMRR measurement setup

From this point on, said input will float up and down with the common-mode voltage. Again, the resulting voltage reading needs to be recorded (U_2). From these two values, the common-mode voltage (U_{CM}) can easily be calculated:

$$U_{CM} = \sqrt{U^2 - U^2}$$

With typical values of U_1=9mV and U_2=21mV we thus obtain:

$$U_{CM} = \sqrt{21mV^2 - 9mV^2} = 19mV$$

Accordingly, the common-mode rejection at a phase voltage of 180V with a real-life frequency mix can be calculated for this example as:

$$CMRR = 20 * \log\left(\frac{U_{cm}}{U_{phase}}\right) \hat{=} 0.019V \div 180V \approx -80dB$$

The obtained value of -80dB is excellent for a realistic PWM signal with steep edges. When comparing data sheets of different instruments you will observe that many models struggle to beat this result even with a rather benign sinusoidal signal at 50/60Hz that completely avoids sharp voltage peaks.

Take-home messages:

- With GaN/SiC, CMRR becomes more important than ever for power analysis.
- Too narrow focus on cost optimization will be punished by compromised accuracy.
- It is up to the user how much to invest in the core instrument vs. peripheral equipment.

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Smart Handling with Surge Current in PFC Using Silicon Carbide Schottky Diode

The Silicon Carbide diodes are widely used in different applications with aim to reach high efficiency and power density. The optimization process behind CoolSiC™ G6, the new sixth generation of Silicon Carbide Schottky diodes reduced conduction losses, but at the same time caused the lowering of the surge current parameters in certain areas. However, the resulting performance of the CoolSiC™ G6 fulfills application requirements well.

By Damijan Zupancic, Infineon

With the adoption of SiC Schottky diodes in PFC topologies, a bypass diode has been used in order to restrict the forward current through the SiC diode in case a surge current affects the mains of the power supply. Figure 1 illustrates how the bypass diode is usually implemented in a classic PFC. The bypass diode conducts only when the rectified voltage is higher than the output voltage (e.g. surge events).

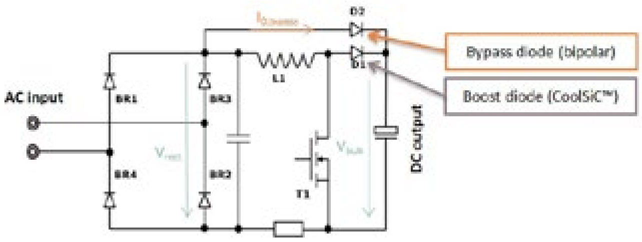

Figure 1: Simplified circuit of a classic PFC

The first test had the original set-up of the 800 W PFC evaluation board1 and it was performed with the bypass diode implemented. In order to show the worst possible surge current conditions, the following test set-up was selected:
Input voltage: V_{in} = 90 V AC
Switching frequency: f_{sw} = 130 kHz
Output power: P_{out} = 800 W
Surge pulse: V_{surge} = 4 kV, Z = 2 Ω, φ = 90°, L-N configuration

The surge immunity test was carried out at 90° (i.e. positive voltage pulse added on top of the sine wave). Specifically, a combination wave test using an impulse voltage wave of 1.2/50 µs with a 4 kV peak value was selected. The test is defined by the standard IEC 61000-4-5, which applies to telecom requirements.

This study includes the worst possible conditions in the PFC circuit with respect to surge immunity. When the lowest input voltage is applied, the highest current enters the circuit. At this operation point, the highest current flows through the PFC choke, and saturating it. This saturation leads to a reduction of the inductance and a decrease in the choke features. The saturated choke cannot contribute much in limiting the surge current pulse when the surge happens. This leads to higher stress on the boost diode, while more surge current is routed through it instead of being routed via the bypass diode. In this precise scenario, the boost diode experiences the highest stress (the highest current flows via the boost diode).

The first screenshot of current waveforms was captured on the boost diode (IDH06G65C6) and bypass diode (S5K) in order to show the current split between these two diodes during the surge event. The waveforms were captured, when the surge pulse was applied to the power supply input (800 W PFC). Both diodes were conducting simultaneously approximately 80 µs at peak current values:

- Boost diode (IDH06G65C6): $IF_{,max}$ = 23.4 A,
- Bypass diode (S5K): $I_{F,max}$ = 308 A.

Beside current waveforms was captured also input voltage, which was rapidly increased at the surge pulse. The tested board has MOV (metal oxide varistor), which clamps high voltage during the surge event. The MOV impacts on the current flow through the bypass diode as well as the boost diode.It was applied a differential mode surge pulse, which caused a special behavior on the current flow through bypass diode. There were two current pulses after the surge event. The first pulse came at the point when the surge pulse was applied. The second pulse was secondary effect of the MOV clamping. When the MOV was clamping, the rectified voltage was decreased and the bypass diode stopped conducting. When MOV released, the voltage on the input increased and the second pulse through bypass diode was injected.

The current through the boost diode was smooth since the PFC choke was limiting fast transients. In operation conditions the boost diode (the Silicon Carbide diode) did not see any additional stress. The current through the diode was within the specification.

The second scenario considered the surge immunity test without the bypass diode in the circuit. The bypass diode was de-soldered from the 800 W PFC board. That means all features of bypass diode were disabled. In order to have the same test conditions as in previous scenario were applied the same input voltage, output load, and the surge current.

When surge pulse passed the circuit, the current through the boost

Link: https://www.infineon.com/dgdl/Infineon-ApplicationNote_Evaluation-Board_EVAL_800W_130PFC_C7-AN-v01_00-EN.pdf?fileId=5546d4624cb7f111014d6b42c932713c diode increased to 24 A. This current value is still within the specification of the surge current given in the datasheet. The boost diode (CoolSiC™ G6) passed the test, but the bridge rectifier (LVB2560) failed due to the too high voltage stress.

The CoolSiC™ G6 diode is not limiting the surge immunity of the PFC stage, even if no bypass diode is used. The comparison between designs with and without bypass indicates the clear benefit of the bypass diode. It fully protects the PFC circuit against high surge current, and does not generate any additional power losses under steady-state conditions because it conducts only when the voltage on the anode is higher than on the cathode. Therefore, it is a safety component which conducts only rarely, under conditions such as surge current.

Link: https://www.infineon.com/dgdl/Infineon-ApplicationNote_EvaluationBoard_EVAL_800W_130PFC_C7-AN-v01_00-EN.pdf?fileId=5546d4624cb7f111014d6b42c932713c

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How to Assure Correct RMS Measurements

In power electronics we deal almost exclusively with nonsinusoidal signals. The article describes the many obstacles and pitfalls on the way to correct RMS results.

By Dr.- Ing. Artur Seibt

1. Definitions.

Signals can be characterized by a variety of numbers: peak, peak-to-peak, average, and, most important, by their root-mean-square (rms) values. By definition an AC signal of 230 V AC_{rms} creates the same amount of heat as 230 V DC, the shape may be any as long as its rms value remains constant. While e.g. the peak value can be read directly from the signal display of a scope or the average value from an average reading instrument, the rms value must be calculated from:

$$I_{TrueRMS} = \sqrt{(1/T \times \int_0^T I^2\,dt)} \qquad \text{(T = signal period)}$$

Beware of the first pitfall: "RMS" is ambiguous and can mean "AC only" or "AC + DC" which is designated "True RMS". Most measuring instruments measure the AC content only, so in most cases "RMS" means RMS_{AC}. If an instrument is labelled "RMS" it may well measure True RMS, on the other hand an inscription "True RMS" does not guarantee just that. It is advisable to always consult the manual before using an unknown instrument.

If the DC content of a signal is ignored gross errors may result. In practice a DC content can be expected unless the signal is clearly ac-coupled via a capacitor or transformer.

If only a RMS_{AC} instrument is available, the DC content can be measured separately from a true averaging instrument, the True RMS value can be calculated from the familiar formula

$$I_{True\ RMS} = \sqrt{(I_{AC}^2 + I_{DC}^2)}.$$

This is cumbersome, the extra expenditure for a True RMS instrument saves time and prevents errors. The above formula is generally applicable if there are e.g. RMS currents from several sources which may be correlated or not; their effects add up the same:

$$I_{RMS\ total} = \sqrt{(I_1^2 + I_2^2 + \ldots)}.$$

Example: In an offline SMPS the capacitor following the line rectifier sees 100 Hz line ripple current and the switching frequency ripple current. The output capacitor of a SMPS which drives a DC motor sees the switching frequency ripple current and the motor's ripple current. In a multiple output SMPS the ripple currents of the individual outputs are interrelated such that their waveforms and hence their RMS values depend on the loads on all outputs.

This example demonstrates that all other measuring instruments can not be used, because they are calibrated in RMS for sine waves, nonsinusoidal signals cause gross errors! See also the article "DC and AC Signals/Parameters and their Correct Representation by Measuring instruments" in "Bodo's Power" July 2015.

2. Accuracy.

First of all it is important to be realistic about the necessary accuracy of RMS measurements and also to have no illusions about the accuracy which can at all be achieved in a given situation. Before buying an instrument it is wise to seriously consider the truly required accuracy and to reckon with the many conditions to be met in order to achieve accurate results, see below.

RMS measuring instruments are available with basic measurement errors < 0.05 %, however, in order to verify such high accuracies special ultraclean and ultraprecise signal sources (calibrators) are used while in the real world such perfect signals are not encountered. Such specs like 0.1 or 0.05 % are likely to impress buyers and tend to make them believe that their measurement results can indeed be that precise.

In reality, in the field of power electronics, pulse trains with high repetition frequencies and short rise and fall times prevail. often superimposed by other signals, correlated or not. It is vital to understand that the basic error of a RMS meter is often inconsequential, that other specifications like crest factor, bandwidth and integration time as well as a correct signal pick-off will determine the measurement error which can easily surpass the basic error by one or two orders of magnitude!. Few applications will call for a better accuracy than 1 %.

Example: In SMPS it is mandatory to check the RMS currents in all capacitors; electrolytics typically have tolerances at best of + - 20 %, and their capacitance is highly temperature and age dependent. A RMS meter with a 5 % accuracy is by far adequate; high bandwidth and crest factor are much more important in order to catch the high frequency components and signal peaks. Look at the ripple current in the output capacitor of a flyback converter which feeds a DC motor. Because the flyback is a two-phase converter there will be no switching current from the transformer during the primary charging time, so the capacitor must supply the load during these intervals. During the other phase current will flow from the transformer into the capacitor and the load. The DC motor draws a substantial uncorrelated low frequency AC current with a DC content, such that during the positive excursions current is drawn while during the negative excursions the motor delivers current into the capacitor - which is often overlooked. If the RMS meter is not synchronized to the motor frequency or a very long integration time is chosen, the RMS reading will fluctuate.

3. Methods of RMS measurement.

3.1 Thermal converters.
A thermocouple generates a DC output which is proportional to the RMS value of the input current, several can be stacked and are called a thermopile. It is thus a true RMS-to-DC converter, conforming ideally to the definition of RMS. However, a thermocouple is impractical in its basic form: It can not differentiate between a temperature change by the ambient or the heater, the relationship is non-linear, and it is easily destroyed by overloads.

Already in the 60's these problems were solved, and the principle is still used in many of today's RMS/DC - converters. Figure 1 shows the block diagram of the famous HP 3400 RMSAC meter which sported at that time 1 mV to 300 V full scale ranges, 10 Hz to 10 MHz bandwidth and a crest factor of 10 at full scale. The error was specified 1 % f.s., but the units were far better.

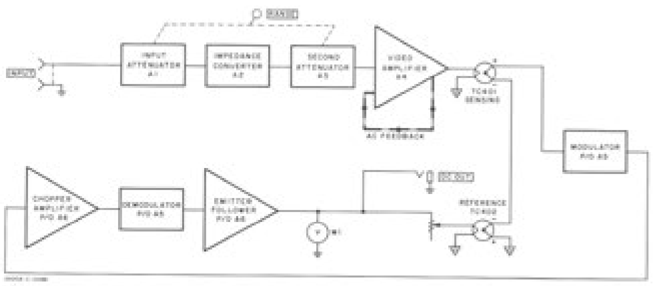

Figure 1: Block diagram of the HP 3400 RMS meter with two thermocouples.

Two identical and matched thermocouples were used. The input signal was amplified by a wideband amplifier and applied to one. The other one was driven by a DC current in a servo loop. The thermocouples were series connected in opposition, i.e. if both were heated to the same temperature the difference output voltage was zero. This signal was amplified by a chopper amplifier; the demodulator DC output drove the heater and the meter. The loop tracked thus the temperature of the first thermocouple until the second one attained the same temperature, and the difference voltage became zero. The RMS values of the AC signal and the DC were then identical. The ambient temperature was a common-mode signal and thus compensated.

High precision could also be achieved with one thermocouple by alternately driving it with the amplified input signal and the output of a servo loop.

Thermocouples are expensive, in the 80's some semiconductor firms built RMS/DC converters according to the above principle driving the cost of RMS meters way down.

Figure 2 shows the construction of a variety of semiconductor equivalents made by firms like AD and LT. The thermocouples were replaced by two matched diodes. Due to the tiny structure of the associated heaters the first of this kind already operated up to 100 MHz with 1 - 2 % error and a crest factor of 50; today such units reach 10 GHz. Special chip mounting materials are used in order to isolate the chips thermally from each other and from the package. Such bandwidths are presently unattainable by other measuring methods. Thanks to the tight matching possible with semiconductors these converters achieve higher precisions than their predecessors.

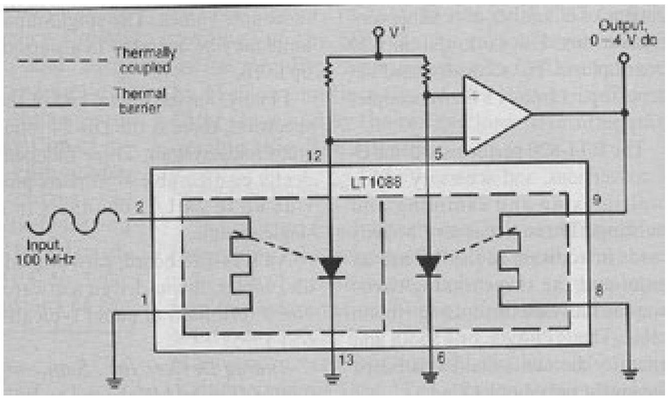

Figure 2: Principle of the semiconductor equivalents of the two-thermocouple method: the thermocouples are replaced by two matched diodes. A practical circuit just needs one op amp and one transistor plus some passive components more.

A disadvantage of all thermal converters is their slow settling time around 1 s. It can be shortened by compensation circuits. All these converters have to be protected from destructive overloads.

3.2 Power Analyzers.
Power Analyzers measure all voltages and currents applied, they calculate the RMS values, the three power values, the spectra etc. Today's instruments digitize the input signals synchronously and perform the calculations in the digital domain. Undersampling can be used to determine the RMS values which is all right as long as there appear no artifacts, if those are detected, the sampling frequency is changed. These are the highest precision instruments with errors down to 0.05 % at low frequencies. Their bandwidth extends only to a few hundred KHz, at best to a few MHz. The built-in shunts are special low inductance designs, external ones can be connected. Their use is limited to circuits in which voltages and currents can be connected to the terminals without detrimental effects. It is e.g. impossible to measure the drain voltage of a SMPS switching transistor, the long screened cable to the PA's input terminals would load the test point and even disturb the function.

3.3 Oscilloscopes.
Digital Storage Oscilloscopes (DSO's) all feature mathematical functions including the calculation of RMS. Their accuracy is modest compared to (True) RMS meters or Power Analyzers but by far sufficient for most purposes. They are the measuring instruments of choice for switching circuits. They also speed up work because RMS values are automatically displayed without any additional connections.

Most DSO's are still 8 bit types, 10 and 12 bit types are presently extremely expensive. Whenever using DSO's it is mandatory to check whether the display is valid in order not to fall for aliases and grossly false results: if the display is an alias all numbers derived and displayed are also false! Many if not most DSO's presently in use, even with 4-digit price tickets, have unacceptable 1 to 10 K memories! At last, competition is forcing the established DSO manufacturers to provide larger memories. If the memory is at least 1 MB, the danger of false displays is low unless very slow time scales are chosen.

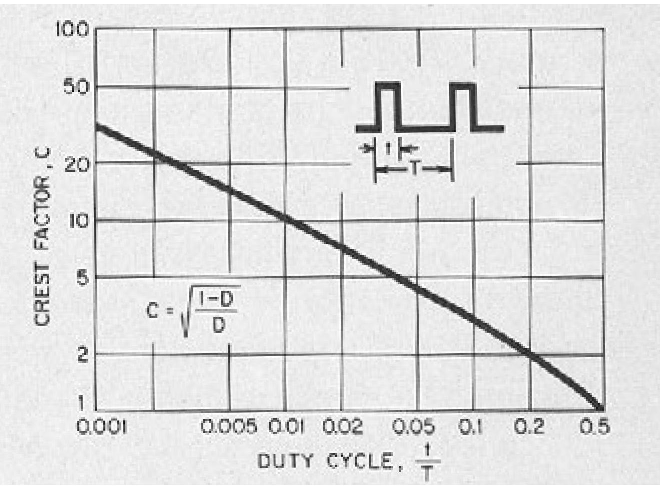

Figure 3: CF and duty cycle D are related as depicted.

Scopes are seldomly used without probes so their errors contribute to the total error which is in the area of 5 %. "DC accuracy 0.5 %": This accuracy holds only up to the transition frequency of passive probes, that is the transition from resistive to capacitive division,which is in the KHz area; i.e. all frequencies above the transition frequency depend on the accuracy of the capacitive division, the precision resistors are irrelevant. Just bending of the probe cable or the probe can generate percent errors! Scopes excel by their high bandwidth, most sport > 100 MHz, which assures that all relevant high frequency components of the signals are included in the measurement, but it is necessary to check whether the whole signal is onscreen, because signal portions outside the screen are clipped, leading to false measurements. Hence the crest factor of DSO's is low!

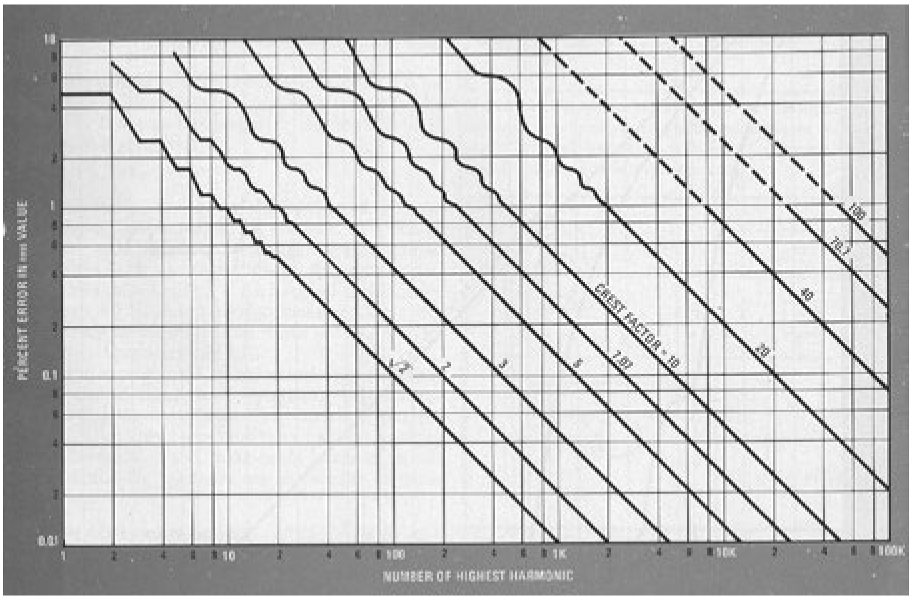

Figure 4: Additional measurement error as a function of the highest harmonic which a RMS instrument can measure with the crest factor as the parameter.

The use of scopes and their accessories like probes and current probes assures the least loading of the circuit under test and is in general the only practical measuring method applicable to SMPS and similar circuitry. Example: It is no problem to measure the RMS current in the drain lead of a switching transistor with a DC/AC current probe inspite of the fact that the drain voltage may rise within some ten nanoseconds up to 800 Vp. The 8 bit resolution problems of a DSO can be circumvented by connecting the DC/AC current probe's output, properly terminated, to a (True) RMS instrument. The accuracy of this measurement can be better. By measuring the voltage and the current in a circuit DSO's can also calculate the three types of power.

4. Pitfalls.

4.1 Crest factor and bandwidth.
The crest factor (CF) of a signal waveform is defined as the ratio peak/RMS, the CF of a sine wave is hence 1.41. With non-sinusoidal signals like pulse trains it can be very high. A RMS meter must have a correspondingly wide linear dynamic input range, the CF is therefore one of the most important specifications. Also the bandwidth is of major importancen because pulse trains contain very high frequencies.

The CF is specified for a full-scale reading and increases proportionally when the reading is lower; at 1/10 of a range the CF is hence ten times higher than at full scale. There is a simple check for an adequate crest factor: just switch to a higher range: if the reading does not change the crest factor was sufficient, i.e. the reading was correct as far as the crest factor is concerned. If the readings differ, the instrument was first overdriven. It is therefore recommended to start a measurement in the highest range and downrange until the reading changes or goes off-scale and then back off one range.

Relationship between crest factor and duty cycle of a pulse train:

$$CF = \sqrt{[(1 - D)/D]} = \sqrt{(1/D - 1)}$$

Figure 4 shows the additional measurement error as a function of the highest harmonic in a pulse train with the crest factor as the parameter. The number of the highest harmonic which an instrument still recognizes is given by the bandwidth divided by the repitition frequency.

Note e.g. that for the additional error to remain e.g. below 1 % at a CF = 10 the 400th harmonic must still be measured by the instrument! Thus a basic measurement error of 0.1 % is fast ruined by insufficient bandwidth. This is especially to be reckoned with when using a Power Analyzer because their bandwidth is only some hundred KHz to a few MHz.

This diagram dramatically illustrates the superiority of scopes also for RMS measurements in switching circuits. RMS meters also feature wide bandwidths, and, as mentioned, the 50 ohm outputs of current probes can be accepted, but scope voltage probes can not be adjusted to meter inputs.

4.2 DC content.

Unless the circuit configuration clearly excludes a DC content it is wise to assume there is one. It is difficult to judge from a scope display of a pulse train whether the areas above and below zero are equal, but there is a simple test: just switch from "AC" to "DC" coupling and check for any movement of the display in vertical direction: if it does move there is a DC content. The True RMS value of an asymmetrical square wave is:

$$I_{True\ RMS} = 1/\sqrt{2} \times \sqrt{(I_+^2 + I_-^2)},$$

where I_+ and I_- are the positive and negative going portions of the signal. If e.g. $I_+ = 10$ A and $I_- = 5$ A, the result is $I_{True\ RMS} = 7.9$ A. A DC coupled scope would show a 15 App square wave with a 7.5 A DC content, an average reading instrument 7.5 A, and a RMS_{AC} instrument would only see the 15 App AC signal and show 7.5 $A_{RMS\ AC}$. In general, most of the power in a non-sinusoidal signal is in the DC content, the fundamental frequency and the lower harmonics.

4.3 Extraneous signals and ground loops.

The wide bandwidth of RMS instruments implies that all signals at the input contribute to the reading whether desired or not: hum, noise, hf pickup, distortions. This is in contrast to e.g. an average measuring instrument which suppresses high frequencies and does not react to signals with zero average which applies to most extraneous signals. Even with a pure sinusoid an RMS instrument will indicate a higher reading if the signal is corrupted; it does not matter whether the undesired contributions' average may be zero, because the RMS value is derived from the square which is always positive. Imagine a high power noise source with an average of zero: the average responding instrument will indicate zero while the RMS instrument will show the true power because by squaring the negative signal portions will be treated alike the positive ones. Example: The output of a CD player will also contain residual hf above the audio band. The output of a FM receiver will contain residual 19 and 38 KHz and more. The output of an analog tape recorder during recording will contain some bias signal above 100 KHz. Frequency response measurements are performed - 20 to 26 dB below reference level, i.e. the signal-to-noise will deteriorate Due to the noise the readings will be too high.

This problem becomes the more acute the smaller the useful signal is. Unless a signal has been looked at with a scope and found to be clean, any measurement of small signals with a RMS instrument is highly uncertain. It is good practice anyway to check all signals with a scope before applying them to any other instrument.

Some RMS instruments use BNC connectors mounted to the case, this is an invitation to ground loops because the case is connected to safety earth.

4.4 Integration interval.

A stable display can only be achieved if the RMS meter integrates over complete periods. Example: The standby power consumption of a small SMPS is to be measured. In order to meet norms, such SMPS go into burst modes when idling. Depending on the integration interval chosen different results will be obtained. In such cases it is necessary to select long integration times.

4.5 Current probes.
If higher accuracy is desired than available from a scope, scope DC/AC current probes can be connected to RMS meters if they are properly terminated into 50 ohms.Their errors in the percent area have to be added to the meter's. In principle also AC current probes can be used, but the danger of false results is higher because a DC content will saturate them. It is advisable to connect current probes to a RMS meter only after the probe was first connected to a scope, and it was checked that the signal was undistorted. Watch out: DC/AC current probes with their own amplifiers usually have a vertical position control on that amplifier. First the scope's position control has to be set exactly to zero, then the probe amplifier is connected to the scope, and from then on only the position control on the amplifier must be used for positioning the trace vertically which is necessary if the signal has a DC content which would drive the signal off-screen.

This means that the vertical position control of the current probe amplifier can add an arbitrary DC level to the output, if this is disregarded and the output applied to a True RMS meter, absurd results will be obtained, because the True RMS meter can not differentiate between the true signal DC content and the DC added by the amplifier.

In order to achieve correct results, it is thus necessary to follow this procedure: 1. With the probe disconnected set the scope's position control exactly to zero. 2. Then connect the current probe und adjust the probe's position control until the trace is again exactly in zero position. 3. Now clamp the probe around the conductor to be measured. The scope will display the True RMS value as long as the signal remains on-screen. If it goes off-screen the True RMS value can not be measured by the scope. Do not touch any vertical position control. 4. Then disconnect the probe amplifier output with its termination from the scope and connect it to the True RMS meter. Due to the fact that even small DC contents will affect the result, don't expect a much more precise True RMS result than from the scope. If only the AC RMS value is to be measured, the meter will yield indeed a more accurate result. Alternatively, one can measure the AC RMS content and the DC content with an average responding meter separately and calculate the total RMS current.

All DC/AC current probes are based on the Tektronix invention to place a Hall a sensor in the air gap of an AC probe's core; the Hall sensor output is amplified, and a current is sent through the winding of the probe such that the DC content of the signal current will be cancelled, and the DC flux in the core returns to zero. This amplified Hall sensor output signal extends from DC to about 3 KHz, it is combined with the output from the probe winding which has a lower cut-off frequency such that a total true DC + AC signal results. This is amplified by a wideband amplifier, the standard probe bandwidth is 50 or 100 MHz. The core is cut and lapped, a slider allows to retract one half so that the conductor to be measured can be inserted, the other core half is then pushed in place so that the air gap is minimized. Remanence in the core is another cause of DC shifts; all such probes feature a demagnetizing circuit, and it is necessary to demagnetize the core each time before low currents are to be measured and also after a high current was applied. These probes are delicate, exerting undue mechanical stress on the probe or the core can cause a DC shift, they are also sensitive to temperature. This is explained in order to show that only modest DC accuracies can be expected.

4.6 Shunts.
The alternative to a current probe is a shunt. Inductance-free precision shunts with 4-pole terminals offer the advantage of much higher precision like 0.01 % and complete freedom from parasitic DC contents, so they are ideal for True RMS measurements, but it is difficult to avoid ground loops. Shunts are always placed in the ground return path. A coaxial cable is used to connect the shunt from the 2 inner terminals to the scope or RMS meter; the inner terminal which is close to the outer one at ground potential is connected to the shield. In fast circuits the cable is terminated at the scope resp. RMS meter side into 50 ohms, using a feed-through 50 ohm termination. Termination at one side is usually sufficient to prevent reflections, in very fast circuits a 50 ohm resistor is inserted in series with the center conductor at the shunt side. It is important to avoid loops; in many SMPS and similar circuits cost reasons dictate the use of low-cost E and similar cores which radiate strongly. If there is a loop between shunt and cable, the stray magnetic field can induce a sizeable false signal which adds to the true shunt signal

4.7 Voltage probes.

4.7.1 Active voltage probes.
Active voltage scope probes can be used because of their minimal load on the test object and their 50 ohm output. Most of today's active probes use a 5:1 or 10:1 internal attenuator so they are not as easily damaged as earlier models, but the ground connection is always done first und removed last. Plug-on attenuators extend the voltage range x 10 and x 100. Note that their time constants are much shorter than those of passive probes, so higher square wave frequencies must be used for adjustment which requires a scope.

4.7.2 Passive probes.
Passive scope probes can only be used with scopes. Scope inputs are standardized: 1 MOhm in parallel with a capacitance usually in the range 10 to 50 pF. All passive probes constitute RC dividers together with the scope input and are of no use in any other configuration. Also all passive probes can only be adjusted to scope inputs within a small capacitance range, i.e. not any probe can be adjusted to any scope input. Every divider has to be adjusted. With scopes this is done by applying a 1 KHz square wave with perfect tops and of sufficiently short rise time and by adjusting a variable capacitor until the tops are perfectly flat. In addition to this basic adjustment capacitor hf probes have another up to 6 adjustment elements in the compensation box at the scope connector which must also be adjusted to the scope input. For these adjustments a 50 ohm pulse generator with a rise time < 1 ns,and a flat top is necessary; the probe is inserted into a special 50 ohm termination with a probe socket. Unless these adjustments are performed gross over- or undershoots at high frequencies will occur. Even if a RMS meter has the standard scope input, no adjustment can be done because the test pulse can not be displayed.

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www.members.aon.at/aseibt

IGBT Modules with Integrated Shunts

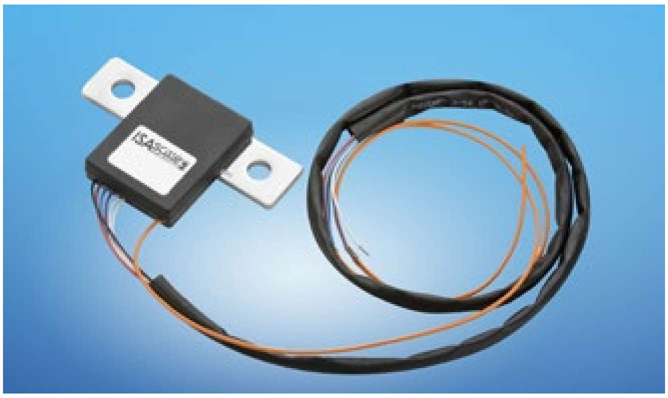
Infineon Technologies AG takes the EconoDUAL™ 3 modules to the next level of integration: They are now available with integrated shunt resistors for current monitoring in the AC path. Implementing these devices helps inverter manufacturers to reduce cost, improve performance and simplify the inverter designs. The EconoDUALTM 3 with integrated shunts can be used in a wide variety of applications, such as general purpose motor drives, uninterruptable power supplies, and solar. It is also a perfect fit for agricultural and commercial vehicles as well as for busses.

New inverter generations aim at cost reduction and increased power density at high lifetime levels. So far, constant improvements in this regard were restricted to the electrical performance of IGBTs, diodes, and the interconnection technologies. Integrating functionality into the IGBT module, the EconoDUALTM 3 enables further cost reduction. With its integrated shunts, external current sensors are no longer needed. This saves space in the system, reduces material costs and manufacturing efforts. In addition, the integration results in high current measurement accuracy across a wide temperature range leading to a very precise motor control.

www.infineon.com/EconoDUAL3

Measurement Technology in Formula E Racing Series

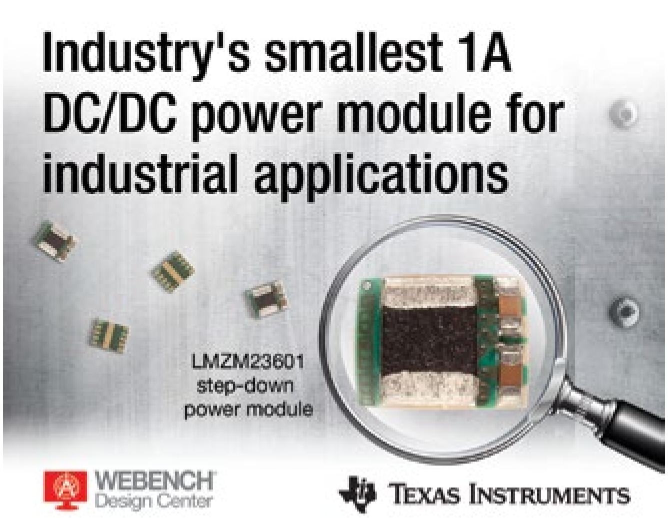
The shunt-based IVT-F measurement system is a custom-made production for the FIA. The device must meet elementary physical and technological framework conditions due to the regulations. In the racing trim, the sensor system used must be extremely precise and highly insulating. With a plastic potting that surrounds the IVT-F, the standard insulation used from the standard product IVT-S, which is between 600 and 800 volts, is therefore additionally amplified. In this way, the IVT-F achieves a real isolation electric strength of 1,000 volts. The very good linearity, the custom-made electronics, the quick sampling and the excellent calibration realize a precise measurement. The heat generated while racing is countered by the IVT-F with a high temperature resistance. The system designed from resistant special materials has a very low temperature coefficient. It protects the IVT-F from malfunctioning. The system ensures precise measurement results up to an operating temperature of +105°C. A microcontroller monitors the sensor status in order to meet the safety requirements. As with the standard product IVT-S, an AD converter in the IVT-F also ensures a precise transformation of the voltage drop into digital signals. A CAN bus interface was installed for the data transfer. It ensures the communication between IVT-F and the battery control unit.



www.isabellenhuette.de

36-V, 1-A DC/DC Step-Down Power Module Shrinks Board Space

Texas Instruments introduced two 4-V to 36-V power modules that measure just 3.0 mm by 3.8 mm and require only two external components for operation. The 0.5-A LMZM23600 and 1-A LMZM23601 DC/DC step-down converters achieve up to 92 percent efficiency, which minimizes energy loss, and feature tiny MicroSiP™ packaging that shrinks board space by up to 58 percent. The converters expand TI's power module portfolio to address up to 1-A performance-driven, space-constrained communication and industrial designs, including field transmitters, ultrasound scanners and network security cameras. TI has demonstrated the 1-A LMZM23601 power module at the Applied Power Electronics Conference (APEC) in San Antonio, Texas, March 6-8, 2018.



The LMZM23600 and LMZM23601 modules are offered with either fixed 5-V or 3.3-V output voltages, or with external synchronization and adjustable 2.5-V to 15-V output voltages. The LMZM23601 features a mode pin that allows flexibility to operate at a fixed frequency for low electromagnetic interference (EMI), or an automatic pulse frequency modulation control mode for high efficiency at light loads. Read the white paper, "Simplify low EMI design with power modules," to understand the EMI advantages of modules verses discrete converters.

www.ti.com

100V N-Channel Power MOSFETs for Industrial Applications

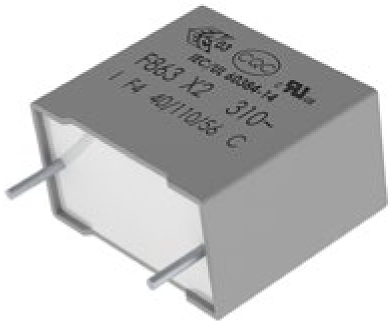
Toshiba Electronics Europe has started to ship two new 100V additions to its low-voltage U-MOS IX-H N-channel power MOSFET

series. The new devices are ideally suited to power supply applications in industrial equipment as well as motor control applications. Fabricated with Toshiba's latest low-voltage U-MOS IX-H trench process, which optimizes the element structure, the TPH3R70APL and TPN1200APL deliver the industry's lowest-in-class on-resistance of 3.7mΩ and 11.5mΩ respectively. The devices exhibit low output charge (QOSS: 74 / 24nC) and low gate switch charge (QSW: 21 / 7.5nC) and allows for a 4.5V logic level drive. Compared with current devices that the U-MOS VIII-H process, the new devices have lower key figures of merit for MOSFETs for switching applications including RDS(ON) Qoss, and RDS(ON) QSW. The TPH3R70APL is housed in a 5mm x 6mm SOP advance package and can handle drain currents (ID) up to 90A while the TPN1200APL is in a 3mm x 3mm TSON advance package and handles ID levels up to 40A.

www.toshiba.semicon-storage.com

Automotive Grade Film Capacitors for Use in Challenging Environments

KEMET announced a new family of automotive grade metallized polypropylene film capacitors. F863 class X2 miniature capacitors are specifically designed to provide robust performance in safety applications in harsh environments and severe ambient conditions. These new devices address applications in both the automotive and industrial segments. They provide across-the-line EMI and RFI filtering for the growing number of vehicle electronics applications, as well as in mains-connected indoor applications such as capacitive power supplies. The F863 series meets AEC-Q200 qualification requirements and is available in capacitance values ranging from 0.1 microfarads to 10 microfarads with rated voltages up to 310



VAC. The new, fully approved RFI X2 capacitors have an operating temperature range of -40 to +110 degrees Celsius. The metallized polypropylene film dielectric exhibits excellent self-healing characteristics. Additionally, KEMET's designers have enhanced the major components of this capacitor series to help resist traditional capacitance-loss mechanisms. With these improvements, the F863 series offers very high capacitance stability while meeting ENEC, CUL and CQC international safety requirements.

www.kemet.com/F863

Output Voltage Extension for 3W and 4W Smart Home and IoT AC/DC Converters

Designing energy efficient devices is not only about complying with the latest energy saving directives, but also about the needs of energy sensible systems. Sensor-rich modern IoT will benefit from using

energy efficient AC/DC power supplies of RECOM's RAC series. To cover more power-critical IoT and Smart Home systems, RECOM now offers its low-power 3W and 4W RAC-series with additional output voltages. RECOM's new RAC03-G and RAC04-G series were specially designed to supply modern smart homes as well as IoT systems, all of which require a high number of low power nodes, actuators and sensors to process information intelligently. These converters' high efficiency and no-load power consumption of only 75mW are ideal for energy-saving solutions which are needed in smart systems. With this extension, these series now offer 3.3, 5, 9, 12, 15 and 24V outputs to cover most required voltages. A universal input voltage range from 85VAC to 305VAC means they can be designed for worldwide mains requirements. SGA versions are certified to EN60335 and SGB versions to EN55022 Class B without the need of any additional components. All modules are also certified to EN/UL62368 and come with a three-year warranty. Samples are available from all authorized distributors.

www.recom-power.com

500 A AC/DC Current Sensor Delivers World-Class

Hioki has launched a high precision 500A AC/DC current sensor, Model CT6904, that delivers a world-class measurement band of 4 MHz, 40 times the previous design, and ±0.02% rdg. accuracy, making it ideally suited to applications such as the evaluation of inverters, where high-current, high-frequency designs are increasingly the norm. This extremely high level of accuracy is achieved via its high noise resistance characteristics thanks to a machined aluminum solid shield developed by Hioki to completely cover the sensor's magnetic core and winding, resulting in a common-mode rejection ratio (CMRR) of 120 dB or greater

at 100 kHz. The switching frequencies used in power conversion circuitry in the inverters and power conditioners found in environmentally friendly vehicles (EVs, PHVs, PHEVs, and HVs) have been increasing as those devices move toward higher-efficiency, more compact designs. However, the performance of existing current sensors is insufficient for measuring devices such as inverters that operate at increasingly high frequencies. The CT6904 resolves these issues.

Principal applications include the evaluation, design, and development of inverters and power conditioners for use in environmentally friendly vehicles and advanced power electronics research at R&D labs and universities.

www.hioki.com/en/information/detail/?id=410

Integrated, High Sensitivity, Current Sensor IC for <5 AMP Applications

Allegro MicroSystems Europe has introduced its first fully integrated, GMR-based current sensor IC with ultra-high sensitivity for applications that require <5 A current sensing. Allegro's ACS70331 current sensor IC incorporates giant magneto-resistive (GMR) technology that is 25 times more sensitive than traditional Hall-effect sensor ICs to sense the magnetic field generated by the current flowing through

the low resistance, integrated primary conductor. This new device has been designed to sense very small currents with 1 mA resolution in a very low series resistance package of only 1 mΩ. This QFN package has an industry best 3 mm x 3 mm solder footprint, providing a much smaller sensing footprint at a much lower resistance over competitive shunt and op-amp based solutions. Key applications include: handheld and laptop adaptor chargers, radios and walkie talkies, IoT load detection, small surveillance and other motor control applications.

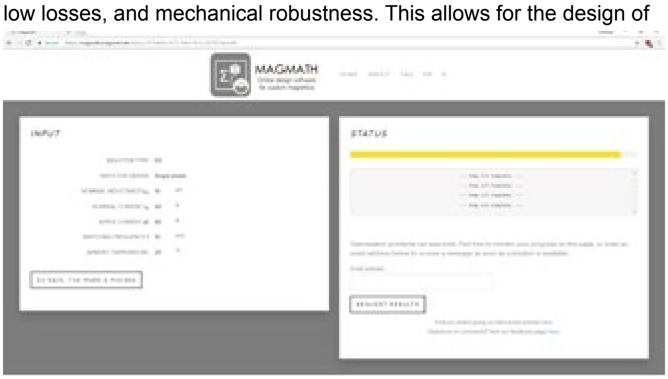
The analogue output provides a low noise high-speed signal, which is proportional to the current flowing through the primary conductor. The full scale bandwidth is 1 MHz and the response time of the device is typically 535 ns. The ACS70331 is offered in four factory-programmed sensitivity and offset levels to optimise performance over the desired current measurement range.

Allegro's ACS70331 current sensor IC operates from a single 3.3 V power supply and is qualified over the full commercial temperature range of -40°C to 85°C. It is offered in a low-profile surface mount QFN package.

www.allegromicro.com

Online Design Software for Custom Magnetics

Magment announced the launch of our new web application MAGMATH, which for the first time ever, allows users to design cost-optimised Magment inductors. Magment is an innovative, cost-efficient material: recycled magnetic particles are embedded in a cement matrix, yielding a flowable material with a high DC-bias capability, low losses, and mechanical robustness. This allows for the design of



rugged inductive components of any size and shape with a distributed air gap for minimized eddy current losses. MAGMATH brings the inductor design experience straight to the user: he inputs electrical, dimensional and loss or temperature data straight into the intuitive User Interface, and in a matter of minutes, receives an inductor tailored to his specifications, and optimised for cost. The many available inputs allow the user to specify his design to a high degree, but the algorithm can generate a solution with just three pieces of information: nominal inductance and current LN and IN, and switching frequency f. This is due to a complex genetic global optimisation routine that runs in the backend, which dynamically generates dimensions and other electrical specifications, while striving to keep losses and operating temperature low. Our promise is that this tool will be the next step forward in magnetic design.

www.magment.de

MxC200 DC-DC Power IC in Production

Fabless power semiconductor company Helix Semiconductors announced the start of mass production of its MxC200, a configurable high-efficiency 15W DC-DC power IC. Previously known as the HS200, the MxC200 takes voltage input ranging from 12-48V and converts it to selectable lower voltages. For example, when configured as a 48V input to 12V output, the IC offers greater than 97 percent peak efficiency and greater than 90 percent efficiency at full load.

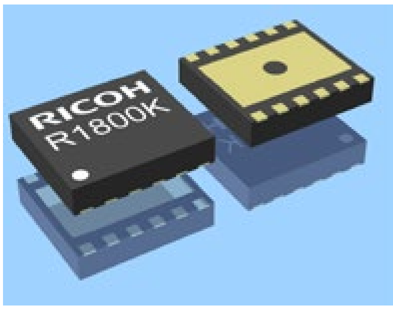
According to Harold A. Blomquist, president and CEO of Helix Semiconductors, "With the MxC200 and other MuxCapacitor-based products, Helix Semiconductors is answering the demand for more energy-efficient power ICs in the burgeoning AC-DC and DC-DC markets. The MxC200 features a unique three-stage process, each of which divides its input in half. Power can be pulled from any of its three outputs simultaneously up to 15W. The company's MuxCapacitor technology enables the MxC200 to achieve unprecedented high efficiency and to stay nearly flat from full load down to 5 percent load."

Target applications for the MxC200 include a wide variety of products such as wireless access points, security cameras, IoT gateways, and VoIP phones – as well as 24V to 48V intermediate bus converter applications and 48V input telecom and other Power-over-Ethernet applications. The MxC200 also targets products with 24V inputs, such as HVAC systems and industrial controllers. In fact, the device is very flexible and can perform voltage conversions on input voltage ranging from 12-48V with output voltage as low as 3.0V.

www.helixsemiconductors.com

Buck DC/DC Converter with 144 nA Quiescent Current for Energy Harvesting

Ricoh Electronic Devices Co., Ltd. in Japan has launched the R1800 Buck DC/DC Converter, designed for use in energy harvesting devices which are able to collect and store energy obtained from sources such as solar or vibration energy. Target applications include wearables for sports and healthcare, wireless sensors and IoT devices. This is a DC/DC converter collecting energy generated from a photovoltaic or vibration energy harvester cell and stores it in a super capacitor or rechargeable battery. An ultra-low quiescent current of 144 nA even allows to use the harvester circuit in a low-illumination environment and when the generated level of energy is moderate.



The R1800 enables the development of batteryless applications, which neither need battery replacement maintenance nor need power from mains to recharge. Instead, the application will operate as long there is sufficient light or vibration available.

A reverse current protection circuit prevents that a current flow will occur from output to input as soon the energy harvesting cell does not provide energy, the circuit is triggered when the input voltage drops below the output voltage.

www.ricoh-europe.com

GaN Power ICs Deliver Dramatic Size & Power Capability in only 14mm Profile

Navitas Semiconductor announced that GaNFast™ power ICs enable the 'Mu One', a universal 45W power adaptor with an unprecedented 14mm ultra-slim profile. GaN power IC technology is combined with the new USB-PD power delivery protocol and an advanced Type C connector to deliver a single, world-wide, slim adapter that can just as easily slide into your pocket as it can charge your laptop or fast-charge any smartphone.

High-speed Gallium Nitride (GaN) power integrated circuits have up to 20x the performance of old silicon chips. By operating at high frequency and simultaneously increasing efficiency, GaNFast power ICs reduce the size, weight and cost of components such as transformers, heatsinks, and printed-circuit boards.

"At Made in Mind, we are pre-programmed to challenge industry norms, we seek the finest of partners who share our beliefs. The Navitas GaNFast chips in the Mu One gave us a tremendous edge on speed-of-charging, efficiency and size". Commented Mathew Judkins, CEO of Made-in-Mind. "These and other technical advances allowed our new product range to push the envelope of consumers' expectations for performance and convenience in their humble power supply".

"This is a significant achievement for the industry to pack this much power in such a low-profile outline" said Gene Sheridan, Navitas CEO. "Consumers can anticipate a wide range of fast-charging, high-density solutions in the coming months as our customers deliver a new class of power adapters with our GaNFast power IC technology."

As recently featured on engadget, the Mu One 45W adapter is available now via Kickstarter, and will be listed in airport, main-street and online stores following production ramp-up.

www.navitassemi.com

Digital Control Meets Intelligent Analog to Streamline Design

Microchip Technology Inc. has introduced two microcontroller families designed with customer innovation in mind. The PIC16F18446 family of microcontrollers are ideal components for use in sensor nodes. Designed with flexibility in mind, the PIC16F18446 and its integrated Analog-to-Digital Converter with Computation (ADC2) runs from 1.8V to 5V, providing compatibility with the majority of both analog output sensors and digital sensors. The 12-bit ADC2 does its filtering autonomously, providing more accurate analog sensor readings and ultimately higher-quality end-user data. Because the ADC2 has the ability to wake the core only when needed, instead of on a pre-determined schedule, the power consumption of the system is lowered, making this MCU ideal for battery-powered applications. This power saving capability also enables sensor nodes to run on small batteries, decreasing end-user maintenance costs and the overall design footprint. The introduction of the ATmega4809 brings a new series of megaAVR® microcontrollers that were designed to create highly-responsive command and control applications. The processing power of the integrated high-speed Analog-to-Digital Converter (ADC) enables faster conversion of analog signals resulting in deterministic system responses. As the first megaAVR device to include Core Independent Peripherals (CIPs), the ATmega4809 can execute tasks in hardware instead of through software.

This decreases the amount of code and can tremendously reduce software efforts for faster time to market.

www.microchip.com

High-Performance Buck Converter Evaluation Board

GaN Systems announced the availability of its 5MHz buck converter evaluation board (GS61008P-EVBHF) using GaN Systems' 100V E-Mode GaN transistor and pSemi's PE29101 integrated high-speed driver. The outputs of the pSemi driver can provide switching transition speeds in the sub nano-second range.

This evaluation board allows customers to benefit from higher switching speeds, enabling smaller peripheral components in a variety of applications including DC–DC conversion, AC–DC conversion, wireless power charging, and LiDAR. This product has been showcased at the Applied Power Electronics Conference & Exposition (APEC).

"GaN has a robust ecosystem of quality partners like pSemi," said Peter Di Maso, Director, Product Line Management at GaN Systems. "Working with pSemi, we've been able bring faster switching, higher frequencies, and higher power density solutions to customers so they can leverage the numerous and irrefutable benefits of our industry leading GaN E-HEMTs. These benefits come together to reduce power losses, size, weight, and system costs."

www.gansystems.com

Powerful Transformers for PoE++

TDK Corporation presents a series of EPCOS transformers designed for an output of up to 60 W, which are therefore suitable for PoE++ according to IEEE 802.3bt. The new B82806D0060A** series comprises four types with different turns ratios for output voltages of 3.3 V, 5 V, 12 V, and 24 V. The SMD components have dimensions of 30 mm x 22 mm x 11.4 mm and are designed for a wide range of operating temperatures from -40 °C to +125 °C.

The electrical insulation of the RoHS-compatible transformers complies with UL 1446 class 130 (B) and can withstand a high-voltage test between the primary and secondary sides at 1500 V AC, 50 Hz for one second. Particularly worth highlighting are the low DC

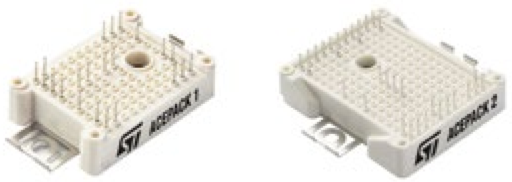
resistance values that – depending on the type – can be as low as 3.5 mΩ. This results in a higher efficiency, thus making the new transformers also suitable for active clamp forward converter topologies. The typical switching frequency is 250 kHz.

An increasing number of devices offer LAN connectivity for communication purposes. The obvious solution therefore is to power them via the LAN cable as well (Power over Ethernet), so that no separate power supplies are necessary. Existing systems with two pairs of cables compliant with IEEE 802.3af (PoE) and IEEE 802.3at (PoE+) are designed for outputs of 15 W and 30 W, respectively. The IEEE 802.3bt (PoE++) standard, which is designed for four pairs of cables, has been developed in order to supply devices with a higher power demand.

www.epcos.com

ACEPACK™ Power Modules

STMicroelectronics' new ACEPACK™ (Adaptable Compact Easier PACKage) modules provide cost-effective and highly integrated power conversion for 3-30 kW applications including industrial motor drives, air conditioners, solar generators, welders, battery chargers, UPS controllers, and electric vehicles. ST's space-efficient, low-profile ACEPACK technology combines high power density with reliability in economical plastic package. Features include optional solder-free



press-fit connections, which simplify assembly as an alternative to conventional soldered pins, and metal screw clamps that enable fast and reliable mounting.

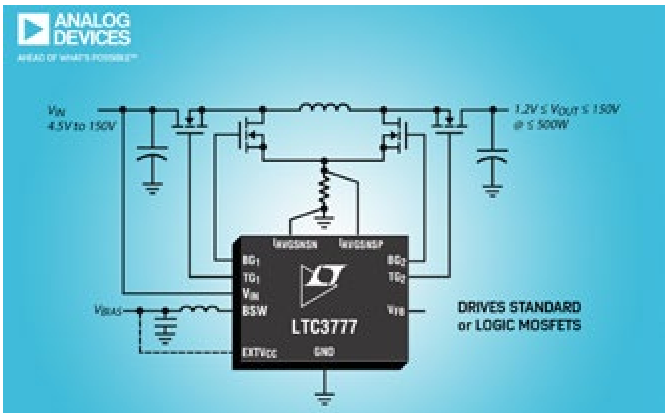
Inside, ST's third-generation field-stop trench IGBTs deliver today's best combination of low on-resistance and high switching performance. Two configurations are available, giving a choice of sixpack modules that contain six IGBTs with freewheel diodes as a three-phase inverter, or Power Integrated Modules (PIM) that provide a complete driver power stage. The PIMs are Converter-Inverter-Brake (CIB) devices that integrate a three-phase rectifier, a three-phase inverter, and a braking chopper for handling energy returned from the load. Both types also contain an NTC thermistor for temperature sensing and control.

Various PIM/CIB and sixpack devices are available in ACEPACK 1 or larger ACEPACK 2 sizes, featuring either 650V or 1200V IGBTs and current ratings from 15A to 75A. The internal layout of the modules is optimized for low stray inductance and low EMI emissions, which simplifies meeting EMC regulations, and 2.5kV isolation ensures robust performance under harsh operating conditions. All modules are specified up to 175°C maximum operating temperature, giving designers extra freedom to optimize heatsink size and power dissipation.

www.st.com/acepack

150V$_{IN}$ & V$_{OUT}$ Synchronous 4-Switch Buck-Boost Controller

Analog Devices announces the Power by Linear™ LTC3777, a 150V high efficiency (up to 99%) 4-switch synchronous buck-boost DC/DC controller, which operates from input voltages above, below or equal to the regulated output voltage. Its 4.5V to 150V input voltage range operates from a high input voltage source or from an input that has



high voltage surges, eliminating the need for external surge suppression devices, ideal for transportation, industrial and medical applications.

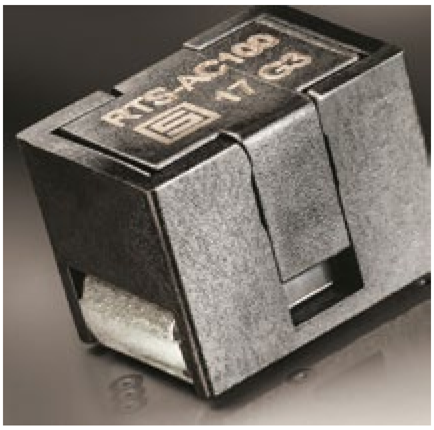
To prevent high on-chip power dissipation in high input voltage applications, the LTC3777 integrates a low quiescent current high efficiency switching bias supply for its internal power consumption. The output voltage of the LTC3777 can be set from 1.2V to 150V at output currents up to tens of amps, depending on the choice of external components. Output power up to 500W can be delivered with a single device. Higher powers can be achieved when multiple circuits are configured in parallel. The LTC3777's powerful 1.5Ω N-channel MOSFET gate drivers can be adjusted from 6V to 10V, enabling the use of logic-level or standard-threshold MOSFETs.

The LTC3777 employs a proprietary current mode control architecture for constant frequency in buck, boost or buck-boost modes. The operating frequency can be synchronized to an external clock from 50kHz to 600kHz.

www.linear.com/product/LTC3777

Reflowable Thermal Switch

RTS stands for “Reflowable Thermal Switch”. It was developed to protect highly integrated power semiconductors like MOSFETs, ICs, IGBTs, Triacs, SCRs, etc. from overheating. Before mechanical activation, the RTS can be mounted using conventional reflow soldering techniques with temperature profiles up to 260 °C. After having the RTS reflow soldered on a PCB, mechanical activation arms the RTS for tripping at 210 °C. This activation can be done manually or by fully automated means. In contrast to electrical activation, the RTS activation status is clearly and immediately visible to the installer. Furthermore, the third additional contact required for electrical activation is thereby eliminated. The new type of overtemperature protection shines with the smallest dimensions and highest load capacity. Operating currents up to 100



A at rated voltages of up to 60 VDC can be handled by the RTS, which is just 6.6 x 8.8 mm in size. Customer-specific variants are available with an integrated shunt or an additional overcurrent fuse. These further integrated functions are resulting in less space consumed on the printed circuit board. The Reflowable Thermal Switch meets the high reliability requirements of AEC-Q200 and MIL-STD. Thermal runaway refers to the overheating of a power semiconductor due to a self-reinforcing, heat-producing process. The reasons for this are the ever increasing power density and the trend towards miniaturization of electronic circuits.

www.schurter.com

Advertising Index

CoolSiC™ MOSFET

The perfect match for efficient and compact converter designs

CoolSiC™ – Revolution to rely on

Infineon CoolSiC™ semiconductor solutions are the next step towards an energy-smart world. Combining revolutionary SiC technology with extensive system understanding, best-in-class packaging and manufacturing excellence, Infineon CoolSiC™ enables you to develop radical new product designs with best system cost-performance ratio.

Infineon CoolSiC™ MOSFETs have unique advantages

- Superior gate oxide reliability
- Threshold voltage, Vth > 4 V
- IGBT compatible driving (+15 V)

SiC characteristics offer unbeatable performance

- More than twice the power density
- Boosted efficiency
- Reduction of total system cost

www.infineon.com/CoolSiC