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Electronics in Motion and Conversion

January 2020

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Speeds Adoption of Three-Phase Motors

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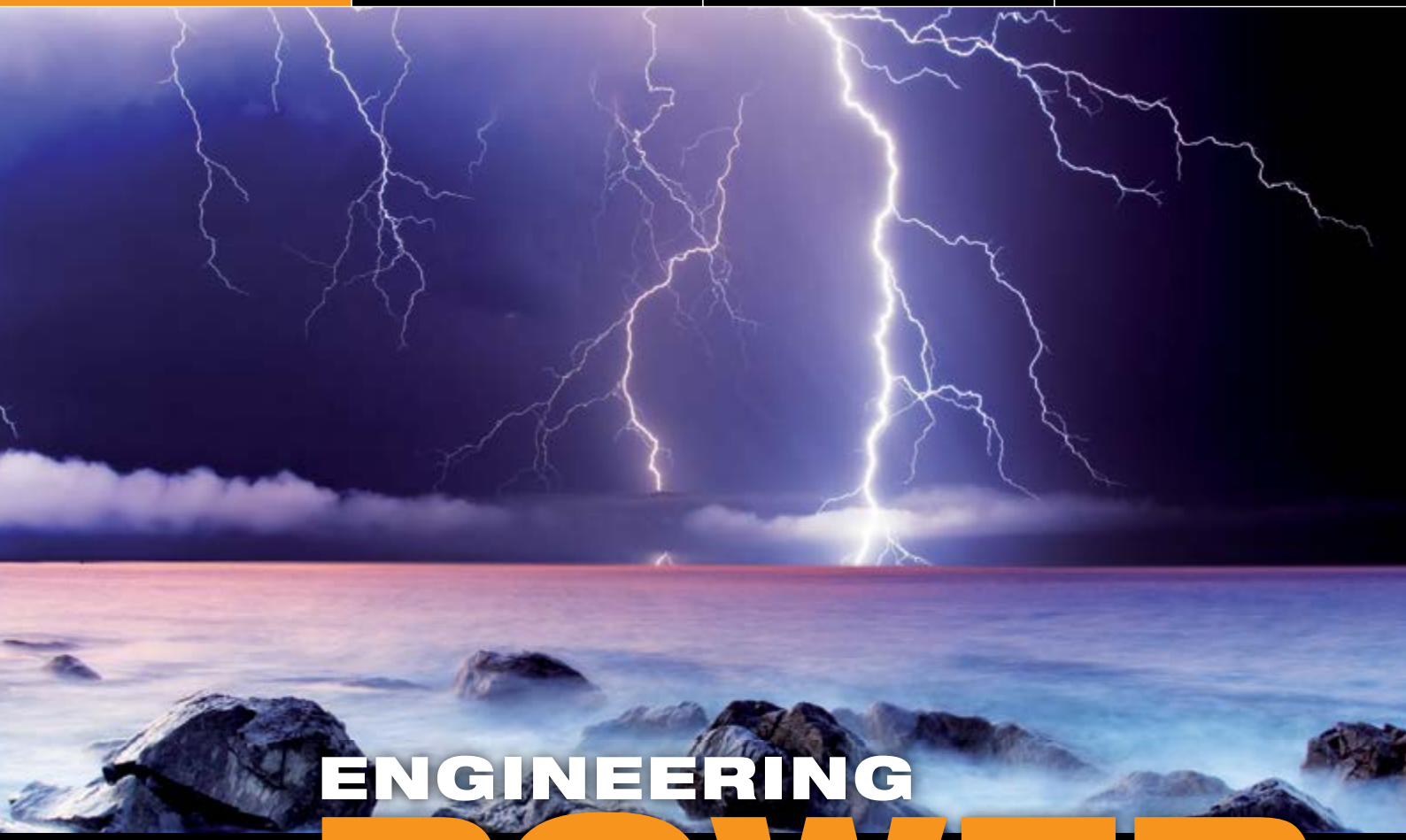

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GvA Power Electronics

CONTENT

The Gallery

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- Long term availability
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www.bodospower.com

New Year, Same Mission

A Happy New Year to all of our readers. May your wishes come true and those good intentions last into the coming year. You have in your hands the first issue of the New Year, eleven more will follow. I can proudly announce that the vast majority of our supporters will continue with us into 2020. We thank you for your continued support, without you it would not be possible for us to complete our mission – to distribute a magazine with well-founded articles and the latest news to the industry.

At the beginning of December our third WBG Power Conference took place in Munich, for the first time spread over two days. The first day included a panel discussion with highly interesting lectures by four well respected experts on the achievements in Wide Bandgap applications and an outlook for the future. Afterwards there was a lively one hour question-answer session, followed by a networking get together. The second day was filled with presentations on the core topics of SiC and GaN, with a tabletop exhibition, excellent networking opportunities and catering. If you were unable to attend, you'll be happy to know that all presentations have been recorded and will be available online shortly. Read more on the event-page at www.power-conference.com. A big thank you goes to our partners at AspenCore for the perfect arrangements, you did a great job. As did all of the presenters who made this event what it was: a big success. And for everyone who attended, our appreciation - you "made the day".

During a team meeting, we decided to change our Christmas practice for 2019. Instead of the Christmas cards that we have sent in the past, we decided to donate to UNICEF, as we believe that thinking about needy children is a better idea.

Other exciting news is that our new website has been online for a month now, and what can I say - positive feedback again. In addition to the well-known sections - like the archive, the news, and our event calendar - there's some interesting information about the team and guidelines for publishing articles in the magazine. If you have a minute, take a look, it's worth it.

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

My Green Power Tip for the Month:
Did you know that in Germany for the first time, shops have banned fireworks from their assortment of New Year's Eve trinkets ? Personally, I like this decision a lot, partly because I'm a pet owner. Maybe less fireworks are something that you might consider when celebrating the New Year too.

Best regards

Events

NEPCON 2020
Tokyo, Japan January 15-17
www.nepconjapan.jp/en

India Electronics Week 2020
Bangalore, India February 13-15
www.indiaelectronicsweek.com

APEC 2020
New Orleans, LA, USA March 15-19
www.apec-conf.org

DesignCon 2020
Santa Clara, CA, USA January 28-30
www.designcon.com

Embedded World 2020
Nuremberg, Germany February 25-27
www.embedded-world.de/en

AMPER 2020
Brno, Czech Republic March 17-20
www.amper.cz/en.html

APEX 2020
San Diego, CA, USA January 1-6
www.ipcapexexpo.org

Satellite 2020
Washington, DC, USA March 9-12
www.satshow.com

EMV 2020
Cologne, Germany March 17-19
https://emv.mesago.com

E-World 2020
Hall 5 / Stand 211

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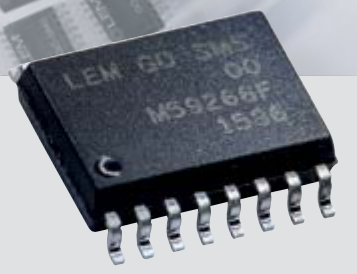

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LEM

Life Energy Motion

Bernd Hops to Take Over as Head of Corporate Communications

From January 2020, Bernd Hops (46), currently Head of External Communications, will take over as Head of Communications and Public Authorities & Associations at Infineon Technologies. He will succeed Klaus Walther, who held this position from 2013. In this capacity, Mr. Hops will report to Chief Executive Officer Dr. Reinhard Ploss and have global responsibility for internal, external and political communication.

"I am delighted that Bernd Hops is taking on this important and challenging task. He knows our company extremely well and has already made an important contribution to demonstrating Infineon's relevance for the economy and society. I wish him all the best and every success in his new role," says Dr. Reinhard Ploss, Chief Executive Officer of Infineon. "I personally thank Klaus Walther for his tireless commitment to sustainable enhancing our company's reputation. In the past years he has made a significant contribution with his strong strategic expertise and extensive network to positioning Infineon successfully in a challenging environment."

Bernd Hops has held management positions within Corporate Communications at Infineon since 2013. The graduate of the Georg-von-Holtzbrinck School for Business Journalists previously worked, among other things, as an editor for the "Tagesspiegel" and "Financial Times Deutschland" newspapers and at the consulting firm Roland Berger Strategy Consultants.

www.infineon.com

Strategic Partnership with Mycronic

Indium Corporation and Mycronic have formed a strategic partnership for the development of no-clean and water soluble solder pastes for jetting applications. The partnership with Mycronic will expand Indium Corporation's portfolio of proven products designed to address evolving industry challenges. The collaboration will also ensure that new products are fully vetted and tested before users begin evaluations, testing, and ultimately high-volume production.

"At Indium Corporation, we believe that materials science changes the world," said Ross Berntson, Indium Corporation President and Chief Operating Officer. "Through this partnership and by collaborating with Mycronic's engineers on our new PicoShot™ solder product offerings, we're able to bring to market new and innovative solder paste solutions to fit our customers' needs."

Mycronic's MY700 platform is a leading technology for jet printing in the electronics industry, providing solutions to most production- related difficulties of applying solder paste. The solder paste coming out of this partnership will also be compatible with the previous-generation jet printer, MY600, and support existing Mycronic customers.

"It is important for Mycronic to mutually develop solder paste solutions with key players like Indium Corporation," said Clemens Jargon, Vice President Global SMT at Mycronic. "This partnership will enable us to reach out to a much broader customer base all around the globe, and support them on enhanced jet printing applications."

www.indium.com

PCS for Photovoltaic Power Generation

Since Japan introduced a feed-in tariff (FIT) system in 2012, the generated electricity has mainly been sold, but recently there has been an increase in the use of electricity by companies that generated it for their own production activities, and the need for photovoltaic power generation for self-consumption is increasing. For such self-consumption, power generators are often installed on the rooftops of factories and other buildings. There is demand to reduce the weight of power conditioning sub-systems (PCS) and other ancillary equipment to facilitate transport and installation. Fuji Electric has recently launched a medium-capacity PCS line suitable for self-consumption that achieves the world's lightest weight in the 30 to 50 kVA capacity range. FE has achieved a conversion efficiency of 98.6%, the industry's highest level, using its own power semiconductors. The company aims to increase orders landed in Southeast Asia, where photovoltaic power generation for self-consumption is being introduced because of the preferential tax system. It is currently obtaining product certification in the Philippines, Thailand, Vietnam, and Malaysia. In general, forced air cooling with fans is adopted in order to cool the heat generated by the power loss of the mounted power semiconductors. This product uses FE's SiC power semiconductors to reduce the loss, and in combination with the optimum distribution of power semiconductors, it has made natural air cooling (fanless structure) possible. This has enabled long-term maintenance-free operation of 10 years, thereby improving customer convenience.

www.fujielectric.com

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SiC: FROM NICHE TO MASS MARKET

As technology driver ROHM has pioneered in SiC development. Meanwhile, SiC power semiconductors have a high acceptance in the mass market. We produce SiC components in-house in a vertically integrated manufacturing system and thus guarantee the highest quality and constant supply of the market. Together with our customers in the automotive and industrial sector, we are shaping the power solutions of the future.

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STRONGER performance
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AUTOMOTIVE

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www.rohm.com

Collaborate to Drive Electrification of Europe's Buses

In a major step forward in the electrification of Europe's public transport networks, BMZ, HORIBA MIRA and ZIEHL-ABEGG have teamed up to offer a unique turnkey service for converting existing bus fleets to e-Buses. As part of its environmental policy to reduce CO2 emissions from public vehicles, the EU has released a new vehicle directive that mandates the percentage of buses that must be emissionfree by 2025 and 2030. It lays out targets for each EU member, with Germany for example, targeted with having 22.5% of all buses as zero emission, increasing to 32.5% by 2030. This will drive huge demand for the development of new electric buses to meet these targets.
In addition, cities including Paris and Berlin have already committed to higher volumes of electrification at earlier dates than the mandate requires. While the onus has traditionally been on bringing new electrical buses to market, not to be overlooked is the role retrofitting existing buses will play in meeting these crucial targets. In order to achieve this, existing bus, owner, operators and manufacturers will need to act now to invest in retrofitting. Bringing together several decades of combined experience and expertise in the development and integration of electric drives for buses, BMZ, HORIBA MIRA and ZIEHL-ABEGG will develop and supply highly efficient, safe and reliable, electric powertrain solutions to electric bus manufacturers, operators and owners, with the option of a complete retrofit service for customers that need it.

www.bmz-group.com

Course for Growth

The independent technology group Rohde & Schwarz closed its 2018/2019 fiscal year (July to June) with strong results. At EUR 2.14 billion, revenue was 4.9 percent higher than in the previous year, while incoming orders rose by 10.6 percent to EUR 2.45 billion. The number of employees worldwide climbed from 11,500 to around 12,100 by June 30, 2019. In mobile communications, the commercial introduction of 5G has begun. Rohde & Schwarz was able to take advantage of the necessary infrastructure investments and did very well with its test and measurement solutions, especially with its products for base station testing. For testing 5G devices, the company launched a new generation of testers and over-the-air test chambers that are attracting a lot of interest from manufacturers. The upgrading of mobile networks is also fueling a significant increase in the demand for solutions that measure network quality. Rohde & Schwarz is meeting this demand with a comprehensive product portfolio for all phases in the lifecycle of a mobile network. The test and measurement business also profited from the automotive industry, whose substantial R&D expenditures for driver assistance systems and autonomous driving are boosting the demand for test and measurement solutions.

Rohde & Schwarz offers a broad portfolio of T&M solutions for V2X, radar, eCall, connectivity and automotive buses, for example a unique tester for radar sensors.

www.rohde-schwarz.com

Deputy Director of the European Technical Center

ROHM Semiconductor appointed Mr. Andreas Thamm as new Deputy Director of the European Technical Center (EUTC). Andreas Thamm has more than 20 years of experience in high-tech companies, where he held various positions in engineering and management.
The European Technical Center provides customer support excellence through specialized FAEs that assist customers from product selection, to response on technical questions, to system-level design support. "It is a critical interface between customer requirements and product development in Japan," comments Toshimitsu Suzuki, President ROHM Semiconductor Europe. "The appointment of Andreas Thamm underlines the importance of the European market for ROHM. His expertise in industrial automation and his international experience in segment marketing will certainly help to focus on the products of our local customers and to pass on the needs of the industry to our engineering departments in order to emphasize products for the European market."
"ROHM Semiconductor is a technology leader in power management applications for growth markets such as Industry 4.0, Smart Home or ADAS and supports its customers in successfully achieving their development goals," says Andreas Thamm. "I see great growth potential in the industrial sector in Europe. My mission is to contribute to this growth by further expanding the EUTC's system and application-oriented customer service."

www.rohm.com

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Acquisition of Silicon Carbide Wafer Specialist

STMicroelectronics announced the closing of the full acquisition of Swedish silicon carbide (SiC) wafer manufacturer Norstel AB ("Norstel"). ST exercised its option to acquire the remaining 45% stake, following the initial transaction announced in February 2019. The total consideration for the acquisition of Norstel was $137.5 million, funded with available cash.

"At a time of constrained global capacity for silicon carbide, the full acquisition of Norstel will strengthen our internal SiC ecosystem: it will boost our flexibility, allow us to control better the improvement of yield and quality of the wafers, and support our long-term silicon carbide roadmap and business," said Jean-Marc Chery, President and CEO of STMicroelectronics. "This acquisition comes in addition to wafer supply agreements signed with third parties, with the overall goal to secure the required level of wafers to manufacture MOSFET and diodes for the automotive and industrial customer programs that will ramp up over the next years."

Norstel will be fully integrated into ST's global R&D and manufacturing operations. It will continue growing its activities covering both the production of 150mm bare and epitaxial silicon carbide wafers and R&D on 200mm production as well as, more broadly, on wide band-gap materials.

www.st.com

APPLAUSE – an ECSEL Joint Undertaking Project

Würth Elektronik is part of a consortium of 31 European electronics packaging, optics and photonics key players, leading equipment suppliers and testing experts launched a new project, "Advanced packaging for photonics, optics and electronics for low cost manufacturing in Europe," simply called APPLAUSE. The project fosters the European semiconductor value chain by building new tools, methods and processes for high volume manufacturing. The 34M€ total budget for the three-year project is co-funded by Horizon 2020 and national funding agencies and industries, as a part of the Electronics Components and Systems for European Leadership Joint Undertaking (ECSEL JU). The APPLAUSE project is an innovation activity (IA) of the European Commission in the field of electronics research.

The APPLAUSE project is coordinated by ICOS Vision Systems N.V. (Belgium), a division of KLA Corporation, and has partners from 11 countries, including 10 large enterprises, 11 small and medium-sized enterprises (SMEs) and 10 research and technology organisations.

"In addition to achieving the overall goals of APPLAUSE, Würth Elektronik has focused on further developments in the areas of electronic packaging and individual sensor systems", explains Dr. Jan Kostelnik, Head of Research and Development at Würth Elektronik Circuit Board Technology (CBT). The topics will be piloted in six use cases, each having an industrial end user.

www.we-online.de

Sales Manager for Americas

In order to optimally serve the growing market for thermal process solutions in North and South America, SMT Thermal Discoveries, has won Jens Saalmann as a new employee who will provide competent and reliable support in this area. "Jens Saalmann will enable us to further expand our sales network, react more quickly to requirements and optimally exploit the market potential," explains Florian Graf, Head of Sales & Marketing at SMT. Jens Saalmann is SMT's new contact person for North and South America since November 1st. He has worked as Key Account Manager for the electronics and automotive supplier industry in the past, through this position he has already gained experience with thermal processes. "SMT is a company with innovative products and individual solutions in the machine area for thermal processes. I am looking forward to my new challenge and the upcoming customer projects that I can implement at SMT", says Jens Saalmann. SMT Thermal Discoveries, based in Wertheim, Germany, was founded in 1987 and is a manufacturer and global supplier of machines for thermal processes from -50 °C to +450 °C.

www.smt-wertheim.com

ECPE Events

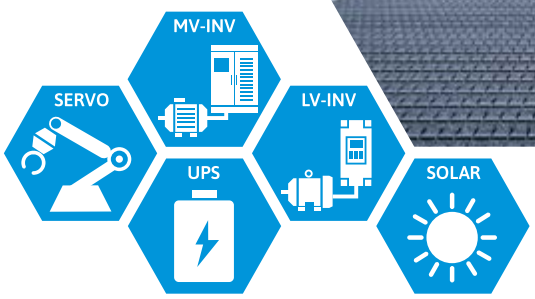
ECPE Workshop 'Power Semiconductor Robustness - What Kills Power Devices?'
13 January (afternoon) - 14 January 2020, Munich, Germany

ECPE Tutorial 'Drivers and Control Circuitry for IGBTs and MOSFETs' - further information published soon
18 - 19 February 2020, Barcelona, Spain

ECPE Workshop 'Magnetic Components in Power Electronics'
19 - 20 February 2020, Grenoble, France

ECPE Tutorial 'EMC in Power Electronics' - further information published soon
22 - 23 June 2020, Eindhoven, Netherlands

www.ecpe.org



The 7th Generation Modules

DualXT & Premium DualXT

DualXT – Main features

- 7G IGBT & FWD
- New internal layout
- Higher reliability
- Improved silicone gel
- Solder or mini press-fit pins
- More power, lower losses

Premium DualXT – Additional features

- Advanced bond wire design
- High thermal conductive ceramic substrate
- Package material with CTI > 600
- V_{iso} = 4 kV
- High power density

www.fujielectric-europe.com
www.americas.fujielectric.com/semiconductors

Fuji Electric
Innovating Energy Technology

Europe’s Booming Solar Market

The upward trend in the European solar market continues: A 20.4-gigawatt increase in photovoltaics (PV) in Europe is expected for this year, as recently outlined by SolarPower Europe in the intermediate scenario of its Global Market Outlook. This would represent an over 80-percent increase in comparison to the previous year. The

trade association estimates further growth of 18 percent in 2020. The rapid growth of the European PV market is reflected in the number of tickets already booked for Intersolar Europe,the world’s leading exhibition for the solar industry. Seven months before the start of the exhibition, more than 90 percent of exhibition space has already been booked. This includes a number of new exhibitors who will be there for the first time next year. Intersolar Europe will be held in conjunction with three other energy exhibitions from June 17 to 19, 2020 in Munich as part of The smarter E Europe, the continent’s largest platform for the energy industry.

The outlook is sunny for the European solar market in 2020 and beyond. SolarPower Europe’s five-year outlook shows two-digit annual growth rates through 2023 as well as a rise in the total installed PV capacity to 255 GW. Germany has been ranked in first place with an expected increase in photovoltaics of 26.69 GW by 2023 and an annual growth of 10 percent, followed by Spain, the Netherlands and France.

www.intersolar.de

Multifaceted Conference Program

Parallel to the international EMV trade fair, the conference in Cologne from 17 - 19 March 2020 will offer a varied program of current developments and research findings as well as the basics of electromagnetic compatibility. The participants can look forward to three days of conference with 66 highly relevant scientific contributions in

German. In addition, they will be offered three hours of compact basic knowledge as well as user and practice-oriented content in 20 parallel workshops in German and English. In their lectures, 90 speakers from industry and science will convey current knowledge on the entire spectrum of electromagnetic compatibility, such as legal regulations, 5G, measuring and interference suppression for motor vehicles, but also basic principles. They represent numerous institutions such as BMW AG, Miele & Cie. KG, SGS Germany GmbH, EMC Test NRW, AUDI AG, TDK Electronics AG, Otto-von-Guericke University, Robert Bosch GmbH, University of Stuttgart and many more. The experts will provide a platform for discussions and will be available to answer participants' questions. "The EMV Conference in Cologne offers EMC experts the opportunity to get ideas and suggestions from users and specialists in personal contact. The program committee has again compiled interesting and varied conference lectures. The workshops also offer newcomers a good opportunity to acquire or refresh basic knowledge," comments committee chair Prof. Heyno Garbe from Leibniz University Hannover, summarizing the program.

https://emv.mesago.com

Purchase of CUI Power Assets

CUI INC

Bel Fuse Inc. announced that the Company has entered into an asset purchase agreement with CUI, in which CUI will sell the majority of its Power business to Bel for $32.0 million, plus the assumption of certain liabilities and subject to closing working capital adjustments.

Based in Tualatin, Oregon, the CUI Power Business, a division of CUI Global Inc., had TTM sales of approximately $37 million with products and distribution that offer strong opportunities for growth.

Daniel Bernstein, CEO of Bel, said, "The CUI Power Business' extensive product portfolio and distribution channel fits squarely within our growth strategy. Their product portfolio will round out Bel's current Power Products offering, allowing us to better address all our customer power needs. In addition, we look forward to utilizing CUI's success with the electronic catalog distributors throughout the Bel\Cinch product groups and capitalizing on CUI’s enviable strong relationship with these distributors. Electronic Catalog Distributors are playing a vital role in demand creation, and over the past four years this segment has been our fastest growing business. The combination of Bel and the CUI Power Business will substantially strengthen our Power Group and unite complementary capabilities, sales channels and customer relationships.” The all-cash transaction is expected to close in the fourth quarter of 2019, and will be funded with available cash on hand, some or all of which may be sourced from our revolving credit facility.

www.belfuse.com

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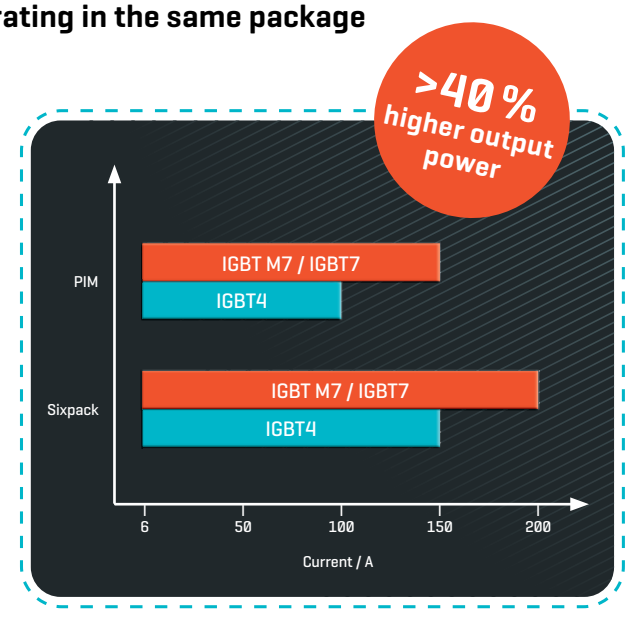
EMBEDDED

MiniSKiiP® FEATURING LATEST CHIP GENERATIONS

Vincotech now offers IGBT M7 and IGBT7 across its complete MiniSKiiP® portfolio of sixpack and PIM topologies. This delivers the dual benefits of superior performance and multiple sourcing to minimize customers´ supply chain risks. These modules enable manufacturers to offer flexible, scalable inverter designs for motion control applications with a nominal current range from 5 A up to 200 A.

The choice is yours to go either for a higher power rating in the same package or for the same power rating in a smaller package.



Main benefits

- Multiple sourcing through the complete MiniSKiiP® component chain for enhanced supply chain security
- Improved efficiency with 20 % lower V_{cesat} than the competition
- Increased power density to help drive down system costs

www.vincotech.com/MiniSKiiP-IGBTM7-7

EMPOWERING **YOUR IDEAS**

Power Magnetics at High-Frequency Workshop

The Power Sources Manufacturers Association (PSMA) and the IEEE Power Electronics Society (IEEE PELS) are jointly sponsoring the fifth high-frequency magnetics workshop, “Power Magnetics @ High Frequency,” on Saturday, March 14, 2020. The workshop will be conducted on the day before and in the same venue as APEC 2020 at the Ernest N. Morial Convention Center in New Orleans, LA.
This day-long event will continue the focus on identifying the latest improvements in magnetic materials, coil (winding) design, construction and fabrication, evaluation and characterization techniques and modelling and simulation tools to satisfy the technical expectations and requirements of higher application frequencies. This year’s workshop will address two specific issues of interest: improving models of power magnetic components based on characterization and performance data and associating then advantages of different winding techniques for different applications. The target audiences for this workshop include anyone working to achieve higher power densities, low profile aspect ratio, higher efficiencies and improved thermal performance. Continuing Education Units (CEUs) will be available to workshop attendees. Previous workshops have completely sold out, so individuals interested in attending this year’s event are encouraged to register early. The workshop will consist of morning (modelling and characterization) and afternoon (survey winding techniques) technical lecture presentation sessions and a lunchtime interactive technology demonstration session. The two technical presentation sessions will each be followed by a panel with a Q&A period.

Power Sources Manufacturers Association
The Multinational Power Electronics Association

www.psma.com/technical-forums/magnetics/workshop

Awarded Korea’s Prestigious Industrial Service Medal

MagnaChip announced that CEO YJ Kim was awarded the Industrial Service Medal by the Korean Government in acknowledgement of his efforts to attract investment and encourage job development in Korea. The medal was presented today at the annual ‘Foreign Company Day’ ceremony hosted by the Korea Ministry of Industry, Trade and Energy, and the Korea Foreign Company Association (FORCA). The ceremony, held at the Grand InterContinental Hotel in Seoul, Korea, was attended by 500 CEOs, executives, employees of global companies and government representatives.

Mr. Kim, a 30-year veteran in the high-tech industry, has held executive positions at leading semiconductor companies, including Intel, Samsung and Cavium. He joined MagnaChip in 2013 and was appointed as CEO in 2015. Under his leadership, MagnaChip’s revenue and profit have shown significant improvement, and the Company’s Display, Power and Foundry businesses each have achieved substantial market success. The Company is widely recognized as one of the leading independent suppliers of OLED display drivers used in smartphones, and as an acknowledged leader in the design and production of Power semiconductors. “I am very proud of the fact that MagnaChip Semiconductor has made a significant contribution to the Korean semiconductor industry and to the economy of Korea,” said YJ Kim, CEO of MagnaChip. “I want to thank all of MagnaChip’s employees throughout Korea for their hard work and dedication.”

www.magnachip.com

Power Grid Protection System Starts in Poland

The New Energy and Industrial Technology Development Organization ("NEDO") announced that the Smart Grid Demonstration Project, aimed at the expansion of renewable energy in Poland, entered power grid protection system (“SPS: Special Protection Scheme”) operational demonstration phase. The solution implementation was executed by Hitachi, Ltd., Hitachi Chemical Co., Ltd. and Sumitomo Mitsui Banking Corporation in cooperation with Polish partner companies. The project was supported by the Ministry of State Assets of the Republic of Poland (formerly the Ministry of Energy). This important milestone achievement was commemorated with an opening ceremony held in Poland, on December 2. The SPS is a next generation grid automatics system preventing overloading of transmission lines. The system plans optimal countermeasure actions for specific accidents on the power network based on the real-time network status. If an accident actually occurs, the SPS carries out controls automatically (primarily for the automatic control of wind generation) in order to prevent overloads in the power grid. The demonstration is also being carried out to examine how much the amount of connectable capacity of the existing transmission lines can be raised with the use of the SPS allowing as a result for the optimization of power infrastructure investments in Poland and better integration of renewables. Moreover, Hitachi, Hitachi Chemical, and SMBC have been cooperating on financing schemes and business models for this system development and expansion.

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www.hitachi.eu

Highest power density and performance

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Leading IGBT technology for 1200 V, 900 A with emitter controlled 7 diode, NTC and PressFIT contact technology, ideal for general purpose drives, electric busses and trucks, as well as solar applications.

Summary of Features

- Highest power density
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- PressFIT control pins and screw power terminals
- Integrated NTC temperature sensor
- Isolated baseplate
- Compact and robust design with molded terminals

Benefits

- Higher inverter output current for the same frame size compared to the previous generation
- Avoidance of paralleling of IGBT modules
- Reduced system costs by simplification of the inverter systems
- Easy and most reliable assembly
- High interconnection reliability

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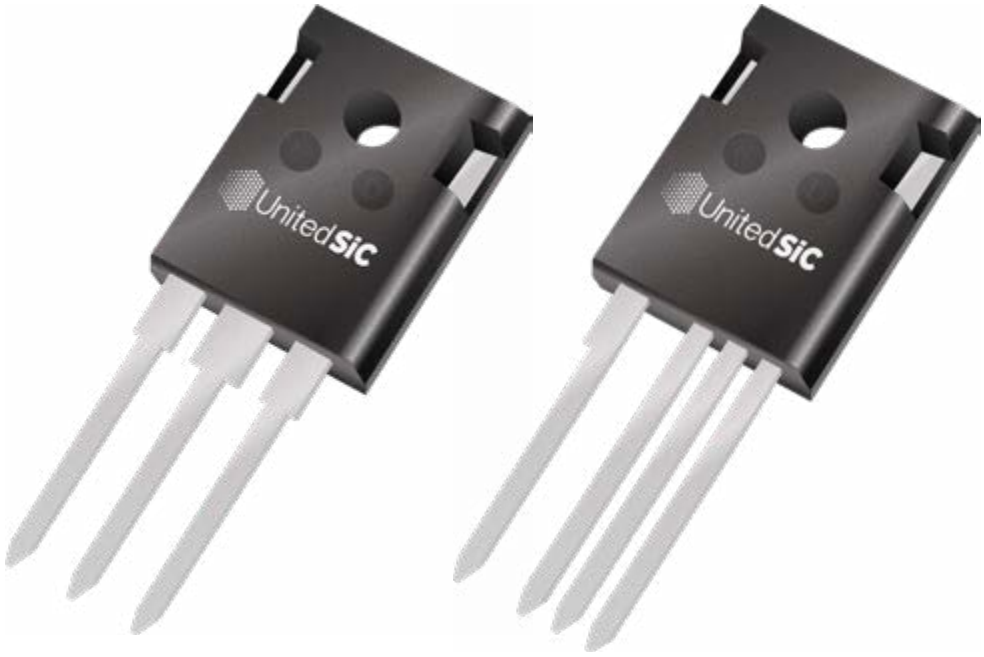
Ultra-low, 7- and 9-mohm RDS(on) SiC FETs for EV Inverters, Battery Chargers and Circuit Protection



The latest product release from UnitedSiC are 7mohm, 650V and a 9mohm, 1200V Silicon Carbide FETs in a TO247-4L package. The UF3SC devices set a new benchmark for low, on-state losses from room temperature to the rated 175C. The 5V threshold voltage coupled with the +/-20V Vgs rating means these devices are compatible with standard Si as well as SiC gate drivers and can be successfully driven 0 to 12V.

The ultra-low conduction losses are combined with low switching losses, which makes these devices useful in >99% efficient EV traction inverters, EV fast chargers, UPS and Solar applications. Solid-state breakers can now be implemented with very low conduction losses. Many designs, previously requiring paralleled devices, now need just one. Similarly, designs needing expensive power modules could now be implemented with these discrete devices.

These SiC FETs combine a high-performance Gen 3 SiC JFET and a cascode-optimized Si MOSFET. This circuit configuration creates a fast, efficient device in an industry standard package that can be driven with the same gate voltages as Si IGBTs, Si MOSFETS and SiC MOSFETs.

UnitedSiC offers the UF3SC series with cost effective pricing to complement its unmatched performance, driven by the inherent advantages of our silver sintered stack cascode technology, using low RdsA Gen 3 SiC JFETs.

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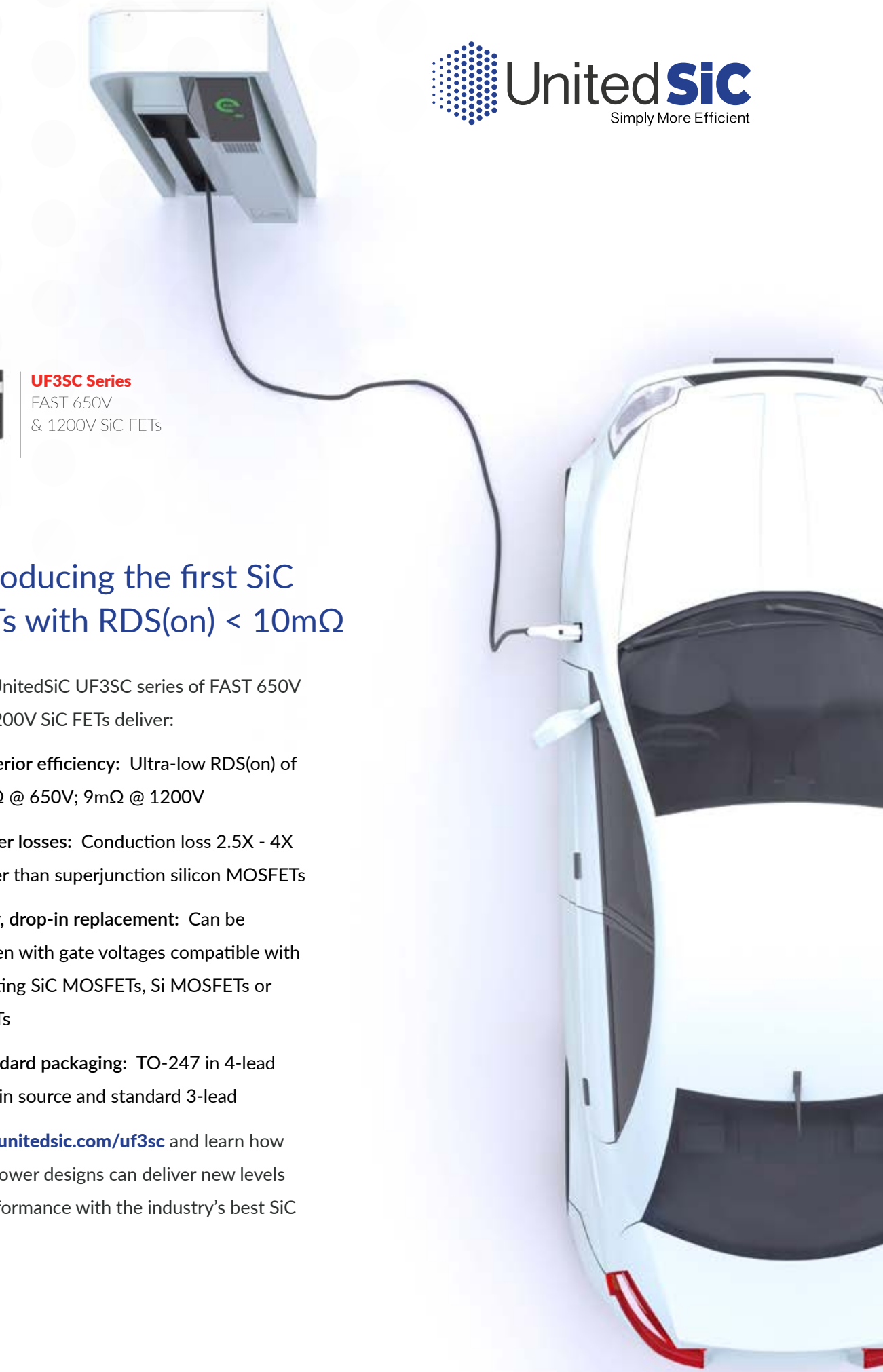
Go to **unitedsic.com/uf3sc** and learn how your power designs can deliver new levels of performance with the industry's best SiC FETs.



Partnering in SiC-MOSFETs to Deliver Automotive and Industrial Solutions

Interview with Dr. Rainer Käsmaier, ABB

To accelerate market entry into the high-growth electric vehicles (EV) sector, Dr. Rainer Käsmaier, Managing Director of Semiconductors at ABB's Power Grids business, and Gregg Lowe, CEO of Cree, the leading US-based manufacturer of silicon carbide power semiconductors, have announced a partnership to jointly expand the rollout of SiC-based products in the rapidly growing power semiconductor market. This contract is to enable Cree to broaden its customer base, leveraging ABB's extensive power semiconductor portfolio.

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

By incorporating Cree's silicon carbide semiconductors into its product portfolio, ABB accelerates its entry into the fast-expanding EV sector.

For Cree, the partnership enables the company to broaden its customer base. Cree's products will be included into ABB's power semiconductor product portfolio, across power grids, train and traction, industrial, and e-mobility sectors. Cree's high-end silicon carbide devices will be assembled into power modules in ABB's award-winning automated power semiconductor factory in Lenzburg, Switzerland.

We have asked Dr. Käsmaier some questions about the partnership with Cree:

What was the main reason for you to make this arrangement with Cree?
The main reason was essentially: We at ABB decided some time ago that the expertise we have in the high-voltage (HV) area of semiconductors would enable us to open new business areas. This is exactly in line with the trend in electric cars, requiring HV power semiconductors to drive electric motors and to charge HV battery systems. In this market – in addition to industrial and rail markets in which our semiconductors have already been in use so far – we have exactly the appropriate experience to use and apply our expertise, and wide bandgap (WBG) technology, in this case SiC, is an efficient base material option for the EV applications.

We have been developing power components for quite some time that are also well suitable for use in vehicles. It was also foreseeable that silicon carbide would bring significant advantages in the electric vehicle power train and that we would therefore have to deal with it. And here Cree virtually offers itself as a strong partner.

But you already had power modules in your portfolio?
That's right. Power modules are the main products in our Semiconductors product group, and they go into various markets. Essentially, we have been providing our power modules in all industrial segments requiring voltage source converters. We are particularly well on our way in the large traditional "mobility" segment of traction inverters for trains.

And, of course, we are very active delivering semiconductor modules for Power Grids, our home division. With renewable power grids, it's becoming extremely important to transport bulk electricity from wind or solar power plants – which are located somewhere, but not exactly where the cities are – over long distances. Highly efficient substations are needed for that purpose (which my colleagues in another ABB division will then build).

And it's precisely this know-how that we have that can also be used very well in the automotive sector. Automotive power modules naturally look different from that of a train or an HVDC converter station. Requirements in terms of size, form factor and converter integration are different in a car. We believe that we have understood these requirements very well and we presented such a module at this year's PCIM (see the description in the box on page 20).

Your move in the direction of wide bandgap silicon carbide in this respect is also beneficial for the environment because of its smaller dimensions, higher efficiency and reliability, and lower consumption?
At ABB, we are not on the road with lower voltage silicon MOSFET or gallium nitride, but in the higher voltage segment. We see the need to use SiC in order to contribute to environmental friendliness and reduced battery sizes. Compared to a standard silicon-based semiconductor, a silicon carbide semiconductor allows energy conversion with almost no losses, thus reducing power conversion losses and carbon dioxide emissions.

But this can in future also open options for the rail sector, where our modules are used in high-speed trains all over the world offering an attractive alternative to flight operations – a considerable contribution to the increased cleanliness of our planet. This has an even greater effect in Asia with its long distances, but it´s also becoming more and more important in Europe.

For EVs, whose customers are the end consumers, you need a small power electronics unit that consumes little electricity allowing to maximize the driving range with the existing battery, or – which is a burning issue – use a smaller battery with a correspondingly lower weight and cost. If you can then make everything that consumes electricity and is necessary for electricity conversion more efficient, then you can also achieve the desired longer range, which is still a decisive purchase criterion for any electric car.

Were you already active in the wide-bandgap business before this partnership announcement?
Yes. We have been developing silicon carbide as a research topic for several years now and presented the above-mentioned first prototypes of a SiC-based module for electric cars at the PCIM this year. Of course, you must always distinguish between the module and the SiC chip, which represents only one, albeit essential, step in the entire module.
This presentation in the lecture by your colleague Jürgen Schuderer also received the Best Paper Award there.
Yes, I am very proud of Jürgen Schuderer and the whole research team, and it was essential that we started this research topic just in time a few years ago. With these results, we can now move into the industrialization phase and apply our know-how. If we were to start research now, we would be very late, if not too late.

Does this already go into packaging?
Yes, we now do the assembly part at our plant in Lenzburg, Switzerland. When we discovered that the research results were so promising, we started building up the capability to produce the module we presented at PCIM.

Is your agreement with Cree limited to SiC-MOSFETs, or does that go further into the basic development of WBG semiconductors?
It is well known that Cree not only makes MOSFETs, but also the step before, where they provide the wafer. They're really at the forefront of that – remember the announcement of a large investment in a SiC wafer factory by Gregg Lowe in Nuremberg in May. This proofs that Cree is a player who is very serious about all this: exactly the kind of partner we want.

Our partnership includes both wafers and MOSFETs: What Cree is also interested in is that we have know-how both for the MOSFET chips and for the next step, the modules. But we don't start from scratch. We had joint development projects even before this announcement.

It is quite possible that we will not only maintain the status quo that everyone has, but also look at how we are progressing in the partnership in the future. Especially for our industry, you need to do developments constantly to stay competitive. And this is probably even more extreme in the semiconductor industry than in other industries because of the short cycle times.

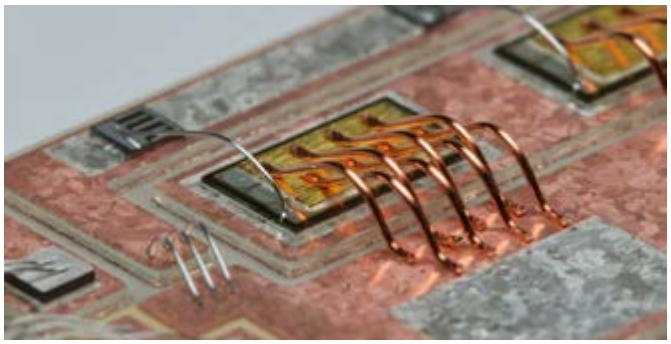
This has been the case for decades. And if you then have a partner who is travelling a lot around the world, then it's also clear that you're

tuning the development plans of both sides. The definition in detail is always a matter of alignment, but joint progress is very well planned.

Are there any links to other Cree contract partners such as ZF or Danfoss?
In general, companies like Cree cannot afford to cooperate with only one supplier in the high-voltage power semiconductor sector. The only important thing is that you know exactly that what you are discussing with this partner is separated from what is discussed with others. Of course, this professional behaviour applies to both sides.

The exciting thing about this market is that many people are just starting out and it is not clear who is setting which focus where and who has to enter into partnerships with whom. For some, this is already apparent, for others it will only become apparent in the future.

So, it´s all still in the flow?
The supply chain Wafer – MOSFETs – Modules – Inverters must be built up first. For me, the best classic customer is one who builds an inverter. As a side remark irrelevant for our topic, just think of the area of autonomous driving - there are old players and newcomers, and nobody can say today who will have long-term success, who will be a customer and who will be a competitor.



Are you also contributing to ABB`s "Ability" platform?
Not directly. But we use it, we are internal customers, so to speak. And that's what I am happy to tell you: I'm sure you've noticed that our facility won the "Factory of the Year" award for automation last year because we fully automated the backend module line, of course with ABB robots. There are software solutions from ABB in use, and that has already helped us a lot to be able to access in-house solution offers.

The industrial sector is also an important area of application for the modules you offer, isn't it?
Of course. Since a few years we focused on Industry 4.0, on two tracks: As a self-user of Industry 4.0 as well as a provider of solutions for Industry 4.0. As a semiconductor manufacturer, we need both tracks, one of which is automation, for which we were awarded because we are able to fully control the module manufacturing from outside of the line.

The other area is the semiconductor in itself. As it becomes more intelligent, it can also enable intelligent and autonomous systems that are controlled, powered and moved. We are focusing on both and are organized accordingly to always stay up to date at the cutting edge. Else we would miss the train!

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Brief Summary of the award-winning paper mentioned in the interview with Dr. Käsmaier:

High-Power SiC and Si Module Platform for Automotive Traction Inverter

Jürgen Schuderer et al. from ABB Corporate Research and Andreas Apelsmeier from AUDI AG, Germany

Abstract: A novel power semiconductor module platform for the automotive powertrain is presented in this paper. Mold modules are designed for symmetric and minimized parasitics by applying alternating and multilayer current routing. All interconnects are solder-free to provide superior reliability, and to meet present and future automotive requirements, e.g., passing 1000 temperature shock cycles in the range of -40 to 150 °C. SiC or Si devices are packaged in the same external outline offering a simple scalability for inverter classes in the 150 – 350 kW power range. A screw-less and O-ring-less 3-phase inverter module is achieved by a laser welding of the mold modules to a low-cost Al cooler enclosure.

Rapid growth of electric vehicles presents the need for cost-effective and reliable power electronics inverters in the drive train of passenger and commercial vehicles. At the heart of the traction inverter are power semiconductor modules that control motor torque and speed via pulse width modulation. These modules must fulfill specific requirements:

- Cost reduction is a key development target.
- Modules must be optimized for mechanical integration into highly compact inverters that are mounted in space-restricted engine compartments.
- Modules must be optimized for harsh environmental conditions.

To address these performance requirements, ABB has developed a SiC/Si power module platform with the following key features:

- A mold module approach is selected that does not require any housing (cost benefit) and that provides excellent environmental protection, cycle reliability and protection against shock, vibration and handling damage.
- A completely solder-free power module is realized for the highest cycle reliability and robustness standards. All interconnections are either sintered or welded. In addition, the device topsides are bonded by copper wire.
- To allow for SiC fast switching, power and gate loop parasitic inductances and coupling coefficients are rigorously minimized.
- A low-cost cooler enclosure is realized by laser welding of mold modules into a cooler structure based on embossed aluminum sheets. In this manner, a compact three-phase inverter module is achieved without the need for screwing or clamping of O-ring sealings.
- The module offers several aspects of scalability. Two different substrates are applied to assemble either a high-power SiC, or a lower-power Si version for the identical external outline. This allows for output power scaling in the range of 150 – 350 kW. In addition, the module cost can be scaled by applying different power module component materials (substrates, baseplates, bond materials) to optimize for the right cost-performance ratio for the specific target vehicle.

Module characterization and accelerated stress tests are conducted to validate the performance and to demonstrate high-temperature operation up to junction temperatures of 200 °C.

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Rugged 600V 3-Phase Gate Driver with Integrated Bootstrap Diode and Fast Overcurrent Protection Speeds Adoption of 3-Phase Motors

Ruggedness and low cost of ownership over a long service life make three-phase motors, whether they're induction or permanent-magnet brushless motors, favorites for industrial use. Simpler and cheaper brushed and single-phase motors are increasingly being replaced by three-phase motors in home appliances, boosted by the ongoing demand for high efficiency, clean and quiet operation, and smaller size and lighter weight.

By Michele Lauria and Massimiliano Magni, STMicroelectronics

Three-phase motors require a three-phase inverter, which is generally composed of 6 power transistors (MOSFETs or IGBTs), one or more gate drivers to control each power transistor, and control logic (a microcontroller or microprocessor) that implements the control algorithm (speed control, torque control etc.).

The gate driver is the analog bridge between the digital control and the power actuators and must be reliable, robust against noise and disturbances, accurate (to make the control algorithms and the pulse-width-modulation effective), and in some cases implements protections and safety functions to guarantee safe operation even in unusual conditions or during failures of some parts of the system.

Introduction

The STMicroelectronics STDRIVE601 is a monolithic device embedding three half-bridge gate drivers for N channel power MOSFETs or IGBTs. It is fabricated using ST's BCD6s-OFFLINE technology process, which integrates Bipolar, CMOS, and DMOS devices on the same chip, along with floating sections with breakdown voltage in excess of 600 V that can drive the high-side transistors., The new generation BCD6s technology also assures best-in-class ruggedness of the device.

The device includes several auxiliary functions and features to accelerate the design of the system, minimize the need for external components and circuits, avoid using complex and delicate protection schemes against noise and disturbances, and keep the overall application simple and cost effective.

The STDRIVE601 is housed in a space-efficient SO28 package and replaces three half-bridge drivers, enabling a compact PCB layout. Its 6 outputs can each sink 350 mA and source 200 mA, with gate-driving voltage ranging between 9 V and 20 V.

The 3 high-side bootstrapped sections can operate as high as 600 V and can be supplied through the integrated bootstrap diodes, which save PCB area and reduce the bill of materials. An under-voltage lockout (UVLO) on the low-sides and each of the high-side driving sections prevent the power switches from operating in low-efficiency or dangerous conditions.

Thanks to technology evolution and design optimization, the STDRIVE601 provides state-of-the-art ruggedness against negative voltage spikes in excess of 100 V and responds quickly to logic inputs in a class-leading 85 ns. Matched delays between the low-side and high-side sections eliminate cycle distortion and allow high-frequency operation, while interlocking and deadtime insertion prevent cross conduction under unforeseen conditions.

Effective overcurrent protection is assured by the smart ShutDown circuit, high-speed protection that turns off the gate-driver outputs just 360 ns after detecting an overload or short-circuit condition. Designers can set and adjust the duration of the protection OFF-time by changing the value of an external capacitor, without affecting the turn-off reaction time. An active-low fault indicator pin is provided.

ST also offers the EVALSTDRIVE601 evaluation board to help users explore the features of the STDRIVE601 and quickly get first prototypes up and running.

The below-ground voltage phenomenon

The negative spike voltage of a half-bridge output is often found in power applications, especially if space or mechanical constraints do not allow an optimized PCB layout. The below-ground spike can lead to unwanted phenomena such as the over-charging of the bootstrap capacitor and the incorrect operation of the output stage if devices with insufficient ruggedness are used.

In half-bridge topologies, especially when driving highly inductive loads, the output of the power half-bridge could experience a negative voltage, with an initial dynamic spike followed by a static component (Figure 1b). This phenomenon occurs when the bridge makes a hard switching transition towards the low voltage level and the load current is outgoing (from the bridge to the load). When the high-side switch

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turns off, the inductive component of the load tries to keep the output current constant. The output voltage drops and when it reaches the "ground" value the current starts flowing through the low-side free-wheeling diode, which gets forward biased. The main contributors to dynamic below-ground voltage are the spikes due to the high dI/dt experienced by the PCB parasitic inductances in series with the free-wheeling diode located along the low-side current path of the half-bridge. Other contributors are the forward peak voltage of the low-side freewheeling diode, which passes from a high voltage reverse condition to a forward condition in a short time, and by the parasitic inductance of the shunt resistors.

The static below-ground is mainly due to the voltage drop on the sense resistor (if present) and the forward voltage of the free-wheeling diode (Figure 1a).

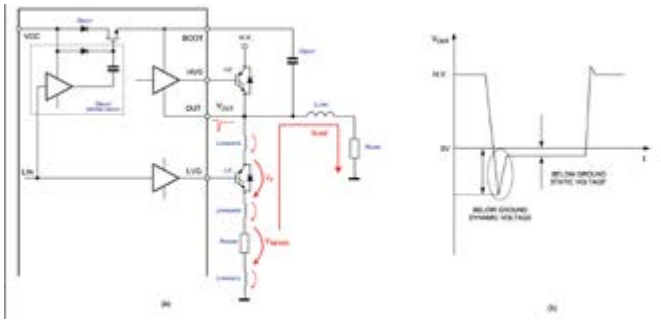

Figure 1: Below-ground phenomenon in half bridges.

Gate driver ruggedness

A key feature of the STDRIVE601 design is its exceptional ruggedness against noise, disturbances and below-ground phenomena. Thanks to the innovative level-shifter architecture and ST's advanced fabrication process technology, the driver achieves unsurpassed immunity to deep below-ground spikes, and properly operates in presence of very steep common-mode transients.

Immunity to below-ground spikes has been tested and confirmed in a dedicated test setup (Figure 2), designed to artificially produce negative spikes much larger than those found in actual applications.

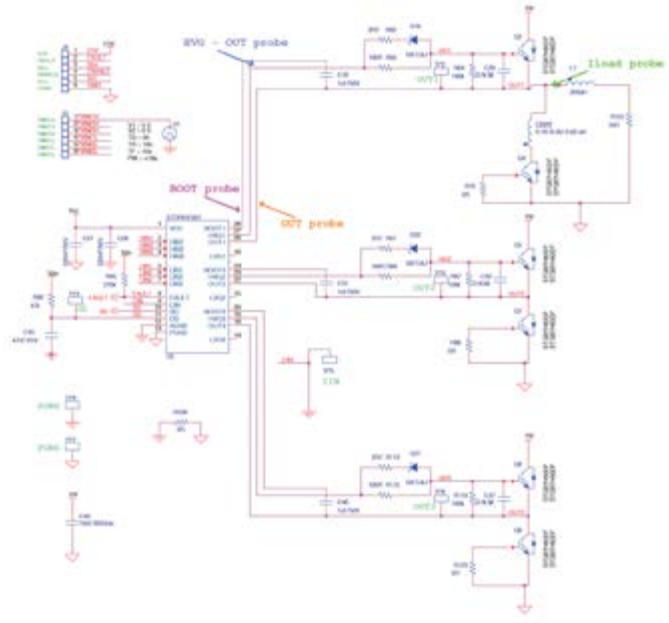

Figure 2: Setup used to analyze below-ground phenomenon.

We've driven an RL load (200 µH, 16 Ω) while putting an inductor with several selectable values (0.19 µH, 0.45 µH, 0.82 µH) in series with the low-side IGBT, to simulate a stray inductance that can be due to very bad PCB layout.

Figure 3 shows the case of a stray inductance of 0.82 µH: the output swings from 300 V to 0 V and the below-ground spike has a minimum peak at -127 V and remains negative for about 148 ns.

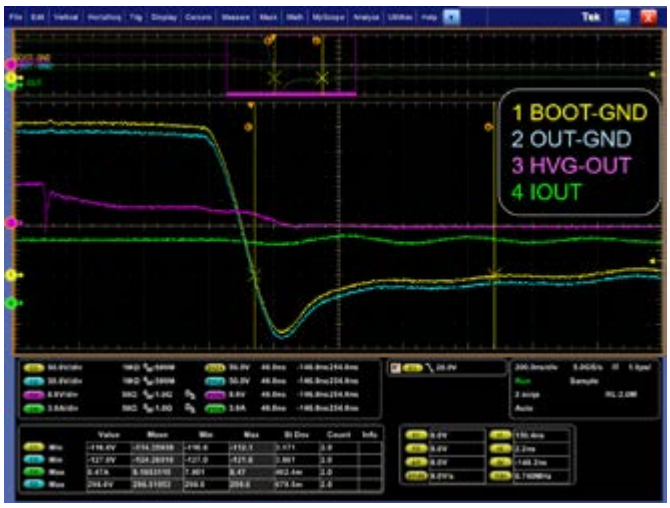

Figure 3: 127 V Below-ground observed on channel 1 output with a stray inductance of 0.82 µH.

Several commutations have been repeated and no damage or malfunction affects the driver.

Bootstrap diode

The STDRIVE601 internal bootstrap diodes, implemented with 600 V rated MOSFETs, charge the bootstrap capacitor of each channel from the main supply voltage (VCC) each time the LVG output is turned on. This avoids expensive and big external high-voltage diodes.

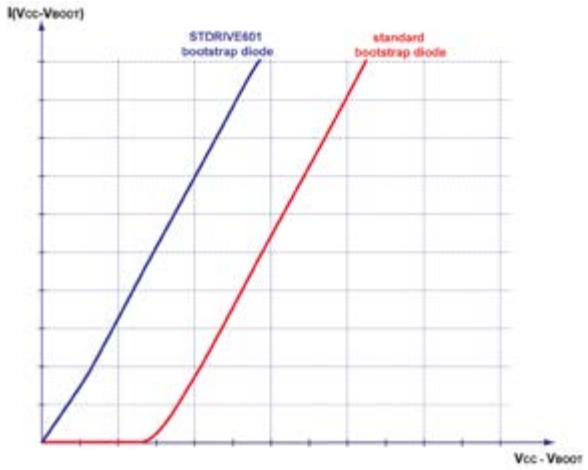

Figure 4: STDRIVE601 bootstrap diode vs standard bootstrap diode.

The integrated bootstrap structure starts conducting immediately on forward bias, without the typical offset voltage given by actual diodes. This difference is visible from the I-V curve in Figure 4, which shows the transfer curve of an STDRIVE601 bootstrap diode compared with a traditional bootstrap diode. This characteristic gives an immediate benefit in residual voltage drop for a given current, and results in charging the bootstrap capacitors even when the voltage drop is small, where the traditional diodes show their limit.

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Smart ShutDown overcurrent protection

STDRIVE601 integrates a comparator committed to fault protection through a smart ShutDown (SmartSD) circuit.

The SmartSD architecture turns off the gate driver outputs in case of overload or overcurrent conditions, with just 360 ns delay between fault-detection and the actual output switch-off. The protection intervention time, which is about two times faster than other gate drivers in the market, is independent of the duration of the disable time after the fault.

This allows the designer to increase the duration of the output disable time after the fault event up to very large values without increasing the delay time of the protection. The duration of the disable time is determined by the values of the external capacitor C_{OD} and of the optional pull-up resistor connected to the (OD) pin (see Figure 5).

The comparator for smart ShutDown has an internal voltage reference VREF connected to the inverting input, while the non-inverting input is available on the CIN pin. The comparator's CIN input can be connected to an external shunt resistor to implement a fast and simple overcurrent-protection function. The comparator's output signal is filtered from glitches shorter than a fixed time (t_{fCIN}, approximately 300 ns) and then fed to the SmartSD logic.

The VREF threshold typical value is 460 mV; the comparator input (CIN) has a hysteresis of about 70 mV. If the impulse on CIN pin is higher than VREF, the SmartSD logic is triggered and immediately sets all the driver outputs to low-level (OFF). At the same time the diagnostic pin (FAULT) is forced low to signal the event (for example to a microcontroller input) and OD starts to discharge the external C_{OD} capacitor used to set the duration of the output disable time of the fault event. As soon as the output disable time expires, the FAULT pin is released and driver outputs restart following the input pins.

The overall disable time is composed by two phases:

The OD unlatch time (t1 in Figure 5), which is the time required to discharge C_{OD} capacitor down to V_{SSDl} threshold. The discharge starts as soon as the SmartSD comparator is triggered.

The OD Restart time (t2 in Figure 5), which is the time required to recharge the C_{OD} capacitor up to the V_{SSDh} threshold. The recharge of C_{OD} starts when the OD internal MOSFET is turned-off, which happens when the fault condition has been removed (CIN < VREF - C_{INhyst}) and the voltage on OD reaches the V_{SSDl} threshold. This time normally covers most of the overall output disable time.

If no external pull-up is connected to OD, the external C_{OD} capacitor is discharged with a time constant defined by C_{OD} and the internal MOSFET's characteristic (Equation 1), and the Restart time is determined by the internal current source I_{OD} and by C_{OD} (Equation 2).

$$t_1 \cong R_{ON\_OD} \cdot C_{OD} \cdot ln\left(\frac{V_{OD}}{V_{SSDl}}\right) \quad \text{Equation 1}$$

$$t_2 \cong \frac{C_{OD} \cdot V_{SSDh}}{I_{OD}} \cdot ln\left(\frac{V_{SSDl}-V_{OD}}{V_{SSDh}-V_{OD}}\right) \quad \text{Equation 2}$$

Where V_{OD} = *OD floating voltage level*

In case the OD pin is connected to VCC by an external pull-up resistor R_{OD_ext}, the OD discharge time is determined by the external network R_{OD_ext} , C_{OD} and by the internal MOSFET's R_{ON_OD} (Equation 3), while the Restart time is determined by current in R_{OD_ext} (Equation 4).

$$t_1 \cong C_{OD} \cdot \left(\frac{R_{OD_{ext}} * R_{ON_{OD}}}{R_{OD_{ext}} + R_{ON_{OD}}}\right) \cdot ln\left(\frac{V_{OD}-V_{on}}{V_{SSDl}-V_{on}}\right) \quad \text{Equation 3}$$

$$t_2 \cong C_{OD} \cdot R_{OD\_ext} \cdot ln\left(\frac{V_{SSDl}-V_{OD}}{V_{SSDh}-V_{OD}}\right) \quad \text{Equation 4}$$

where

$$V_{on} = \frac{R_{ON\_OD}}{R_{OD\_ext}+R_{ON\_OD}} \cdot V_{cc}; \qquad V_{OD} = V_{cc}$$

Figures 6 show examples of Smart ShutDown operation, with two different capacitors connected to the OD pin. The triggering pulse on CIN has a width of 500 ns, with amplitude (peak to peak) of 1 V; the internal current source (I_{OD}) has been used to charge the external capacitor.

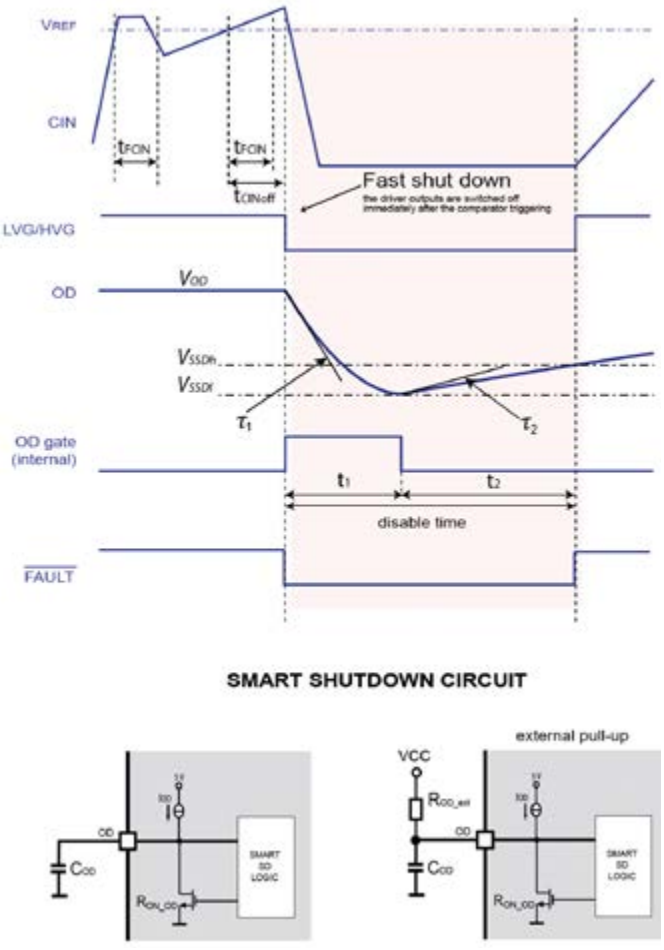

Figure 5: Smart ShutDown timing waveform.

$$disable\ time = \frac{C_{OD} \bullet V_{SSDh}}{I_{OD}} + R_{ON\_OD} \bullet C_{OD} \bullet \ln\left(\frac{V_{OD}}{V_{SSDl}}\right)$$

C_{OD} = 2.2 µF
⇒ disable time = 1.46 s
V_{SSDh} = 4 V
V_{SSDl} = 0.56 V
I_{OD} = 6 µA
R_{ON_OD} = 25 Ω
V_{OD} = 15 V

C_{od} = 330 nF
⇒ disable time = 220 ms
V_{SSDh} = 4 V
V_{SSDl} = 0.56 V
I_{OD} = 6 µA
R_{ON_OD} = 25 Ω
V_{OD} = 15 V

Other functions and characteristics

The STDRIVE601 has been designed to have fast and accurate propagation delays. From input toggling to output turn-on (or off) the delay is 85 ns for both Low and High-side drivers and the matching time is less than 30 ns, with a typical delay matching of 0 ns.

An UnderVoltage LockOut (UVLO) mechanism monitors the supply voltage of the output stage of the driver and turns it off when the voltage drops below a pre-defined threshold. This protection prevents the device from driving the power transistors when the supply voltage is so low that it would lead to high conduction losses or, even worse, transistor damage.

Figure 6: On the first figure C_{OD} = 2.2 µF, on the second figure C_{OD} = 330 nF.

The UVLO threshold has a hysteresis and a built-in filter to prevent unwanted activations from noise on the supply voltage. All 6 drivers in STDRIVE601 are protected by the UVLO mechanism.

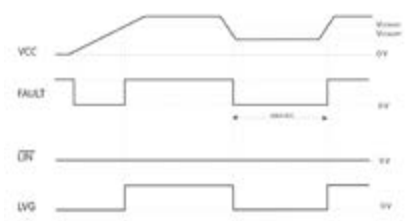

Figure 7: UVLO mechanism on VCC power supply.

Summary

With the many advantages of three-phase motors, they are rapidly displacing simple single phase and brushed motors. The ease of use, availability, and cost-effectiveness of three-phase inverters, like the STDRIVE601, which is a three-phase 600V-rated single-chip gate driver, is a valuable contributor to this progress. The STDRIVE601 delivers robustness, simplicity, and cost saving while assuring protected system and safety functions.

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When Performance Matters – Integrated Capacitors Reduce Commutation Loop Inductance

Designers pursuing the right balance of price and performance to satisfy today's demand for power-switching applications are cutting it close with inverters. And engineers are more likely to select parts with performance parameters in the neighborhood of the target specifications to gain a built-in design advantage. This is why margins between devices' maximum electrical value and the application parameters are shrinking.

By György Kovács, Sr. Development Engineer, Vincotech

Power modules are a big step forward for engineers seeking to boost efficiency. They have several advantages over discrete components, one being superior parasitic performance. Nonetheless, there is still room for improvement, particularly if we take the electric components connected to the power module into consideration. These connections are still the source of parasitic inductances that adversely affect switching performance. They may even jeopardize the switching elements if the design lacks the necessary voltage buffer.

Parasitic inductance in an inverter power bridge leads to inefficiencies. The voltage spikes during the power device's switch-off cycle (figure 1) at a high rate of dI/dt:

$$V_{CE(peak)} = V_{CE} + L_x \times \frac{di}{dt}$$

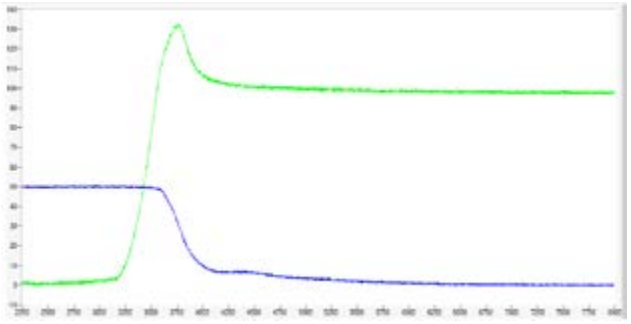

Figure 1: Switch-off curves (Uce and Ic) of a power switch

Switching time may have to be increased to prevent voltage spikes from damaging power devices. Increasing power devices' switching time would also increase turn-on and turn-off losses in each power switch. This adds to the switching losses, generating even more heat to be dissipated in the switching devices.

DC link capacitors can mitigate the effects of inductance from the DC voltage source and reduce the switching component's voltage overshoot. The key to good performance is a low-inductance design that connects these parts so as to minimize PCB and module pins' stray inductance. Even so, the decrease in parasitic inductances is unremarkable no matter how carefully the designer configures this electric circuit. It certainly cannot compare installing a capacitor with a snubber function in the module (figure 2). This integrated capacitor provides a low-inductive, high-frequency solution that closes the commutation loop.

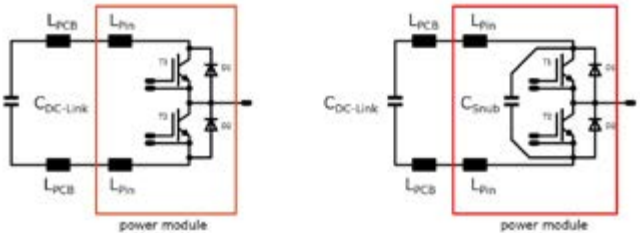

Figure 2: Position of the snubber capacitor as it relates to the parasitic inductances of a module design

It is standard practice at Vincotech to integrate MLCC SMD capacitors. High voltage (650 -1000 V) parts in case sizes 1206 to 2220 can be applied as snubber. Different types of capacitors may be used depending on the given specification. Devices with X7R (class2) dielectric materials have s higher capacitance in the same package as C0G/NP0 parts, but class 2 materials have a significant DC bias effect. This means that the part's capacitance value is significantly decreased at the rated voltage (figure 3).

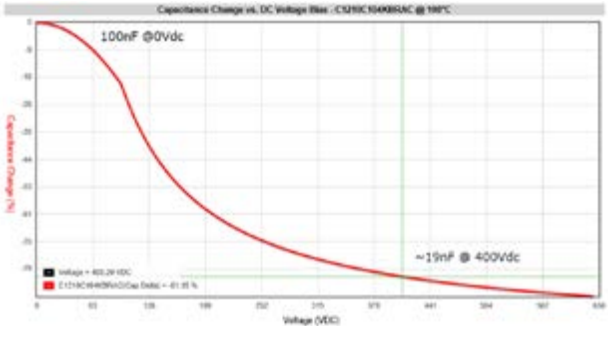

Figure 3: K-Sim (www.kemet.com) simulation of X7R capacitor showing the DC bias dependency

The comparative measurements of the SiC MOSFET booster configuration shown in figure 4 were taken to illustrate the behavior of the different setups, including one without a snubber capacitor. This test used a standard double-pulse measurement system and the MOSFETs' nominal current. The switching devices were encapsulated in a standard Vincotech package with the additional snubbers placed on the layout by design.

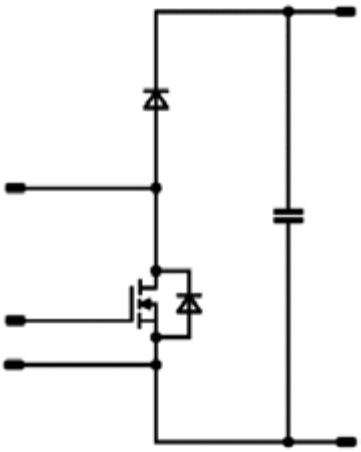

Figure 4: Booster configuration to test the integrated DC snubber effect

option	value	over shoot (absolute value)
no capacitor	-	205V (805 V)
X7R	100 nF	150V (750 V)
C0G	22 nF	121V (721 V)

SMD capacitor effect on overshoot voltage

Conclusion

The integrated capacitors significantly reduced the switching devices' voltage overshoot during turn-off. This test also underscored the differences between capacitors' dielectric materials. C0G/NP0 devices have significantly lower capacitances than their X7R counterpart, and exhibited even better performance. This is attributable to the X7R class 2 material's high DC bias effect.

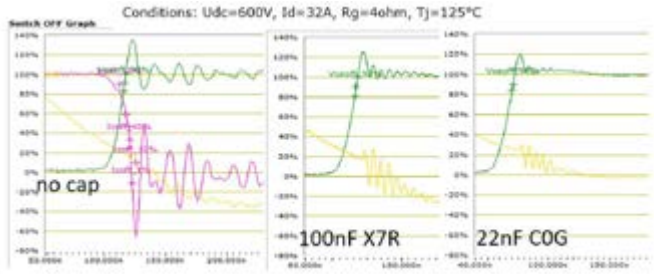

Figure 5: Switch-off waveforms of the DC snubber effect test circuit. Yellow = gate voltage; green = collector-emitter voltage; pink = collector current

C0G/NP0 capacitors' dissipation factor (DF) parameters are superior to those of the X7R, which results in less self-heating because of the dissipation factor's lower ESR (equivalent series resistance) component.

Another advantage of the C0G/NP0 material is that it is immune to the aging phenomenon that causes the capacitance and dissipation factor of X7R devices to decrease over time.

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To Increase Power Density, Look at Packaging As Well As Silicon

Both automotive and industrial applications are demanding ever-increasing power density. For example, for improved safety, new automotive power steering designs now require dual redundancy circuits; that's twice the number of components within the same space.

By Neil Massey, International Product Marketing Manager, Nexperia

Alternately, in server farms where every square metre costs money, commonly we are seeing requests to double the amount of output power in the same power supply housing every 18 months.

If discrete semiconductor suppliers are to meet the challenge, they can no longer simply concentrate on improving the silicon technology, they must also look to improve package performance at the same time. Nexperia, the leader in discrete and MOSFET components and analogue and logic ICs headquartered in the Netherlands, has pioneered full copper clip die mounting technology inside the power package (LFPAK Loss-free Package) in order to realise many technical benefits (current capability, RDSon, thermal characteristics etc).

LFPAK package family designed for power density

The LFPAK family of packages is used to improve power density. Its main feature is the use of a full copper clip inside the package and short gull-wing leads on the outside. Nexperia first introduced the package in 2002 with the LFPAK56 package - a power SO8 footprint (5mm x 6mm) that was designed to replace the larger DPAK package. Now, the company has a full range of sizes in both single and dual MOSFET configurations covering a wide range of applications. Most recently, Nexperia released LFPAK88, an 8mm x 8mm package designed for higher power applications that replaces the larger D²PAK and D²PAK-7 packages.

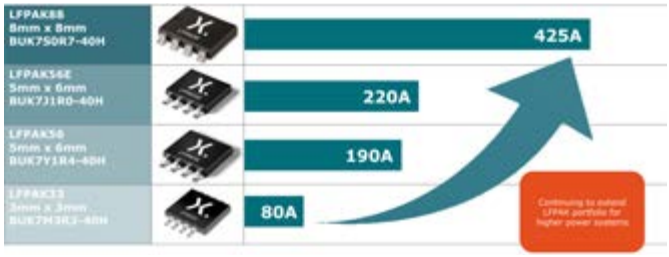
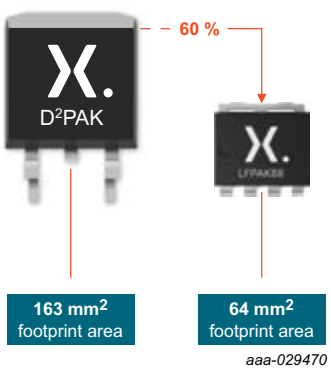


Figure 1: LFPAK discrete MOSFET family of packages



Clip-bond versus wire-bond packages: power density benefits

LFPAK devices are smaller than the older D²PAK and D²PAK-7 parts they replace, delivering an immediate improvement in power density.

Figure 2: LFPAK88 smaller footprint benefit over D²PAK

Figure 2 shows the relative footprint sizes of LFPAK88 devices which are 60% smaller than D²PAK parts; also LFPAK88 parts feature a reduced height, giving an overall volumetric reduction of 86%. However, the major difference that enables performance and power density improvements is the use of copper clip technology unlike the older wire-bond technology used within packages like D²PAK and D²PAK7.

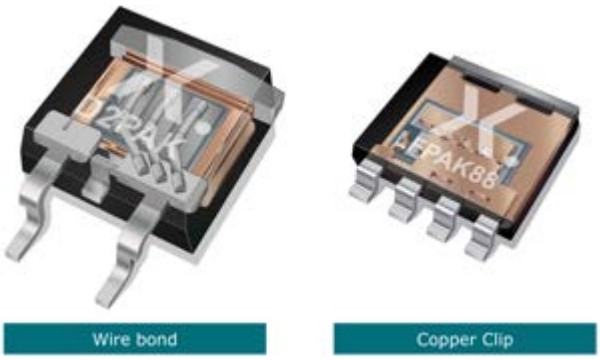


Figure 3: LFPAK88 with copper clip and D²PAK with wire-bond connections

Copper clip technology performance benefits include:

1. Current (Amps)

Wire bonds are the limiting factor that determine the amount of current the device can handle. In the case of the D²PAK the maximum diameter of bond wires used is 500µm (due to connecting T-post size).

The largest die that Nexperia can fit into the D²PAK using its latest Trench 9 super-junction 40V silicon is 120A. However, for the smaller LFPAK88 which has no limiting bond wires, the largest die Nexperia can currently include is rated at 425A - in future when the company releases larger silicon, the current rating will be even higher. [Note: the values shown are from measurement and not theory]

2. $R_{DS(on)}$ [in mΩ]

The three 500µm diameter bond wires used in the D²PAK add to the overall $R_{DS(on)}$ of the MOSFET.

For example, using the same Trench 9 40V technology platform in both devices (as above), the largest silicon die Nexperia can fit inside a D²PAK has an $R_{DS(on)}$ of 1.2mΩ. This reduces to 0.7mΩ with the smaller clip bonded LFPAK88 thanks to the elimination of the bond wire resistance. [Note: a 0.55mΩ LFPAK88 part is in development on the T9 platform].

3. Parasitic Source Inductance (nH)

Parasitic source inductance must be overcome at every switching event, as it reduces efficiency. This loss assumes greater significance in applications that need to switch at higher frequencies such as DC/DC converters.Source bond wires also add to the overall parasitic source inductance, and a combination of the longer legs of the D²PAK and the source bond wires give a value of 5nH. By comparison, the LFPAK88 has no source bond wires and has only small gull-wing leads, therefore the impedance is low at 1nH.

4. Current/thermal hotspots

When a high current flows through a device, it is concentrated at bottlenecks where the bond wires connect to the silicon. These current hotspots can lead to thermal/quality issues.

With the LFPAK88, the top copper clip covers significantly more area so hot spots do not occur.

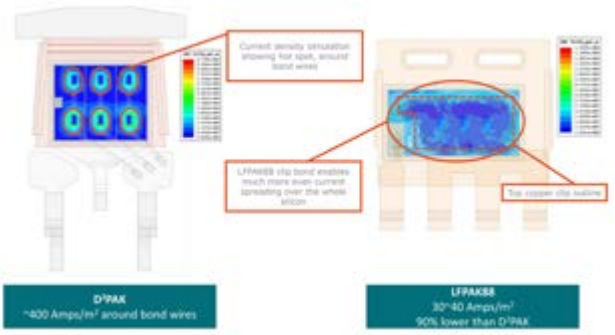


Figure 4: Simulation of D²PAK and LFPAK88 current density and hotspots on wire-bond

Thermal Resistance Rth(j-mb) (K/W)

The LFPAK88 has good thermal performance compared to older packages. For example, if we look at the thermal resistance from the silicon to the bottom of the package where it attaches to the printed circuit board (Rth_Junction to mounting base), then lower resistance values are better.

D²PAK largest die was measured at 0.43K/W; LFPAK88 measured at 0.35K/W.

The better Rth value is mainly resulting from the shorter thermal route with a thinner drain copper clip (0.5mm for LFPAK88 and 1.3mm for D²PAK)

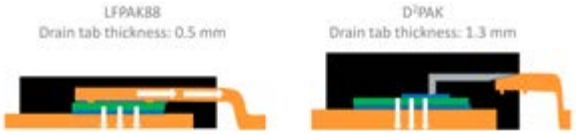


Figure 5: D2PAK and LFPAK88 thinner drain tab

Power Density >1W/mm³

The size benefits, with increased current capability and better $R_{DS(on)}$ all combine to give a better power density, as summarized in the table (using the same technology platform to give like-for-like performance)

	LFPAK88	D²PAK
Silicon	Automotive T9 40V	Automotive T9 40V
Type	BUK7S0R7-40H	BUK761R2-40H
Volume x*y*z mm³	8mm*8mm*1.7mm =108.8mm³	10.3mm*15.8mm *4.5mm=732.3mm³
Power I²R = W	(425A)² * 0.7mΩ = 126.4W	(120A)² * 1.2mΩ = 17.3W
Power Density W/mm³	126.4/108.8 = 1.16 W/mm³	17.3/732.3 = 0.024 W/mm³
LFPAK88 vs D²PAK	48x better power density	

Conclusion

In conclusion, the drive for power density means that not only are silicon improvements are needed, but also new package construction techniques must be utilised to get the most out of the discrete MOSFETs. The LFPAK full copper clip family of packages enhances the performance of the silicon and is an enabler of reduced footprint and improved power output.

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A Brief HowTo: Analyzing Control Loop Stability with Bode Plots Using Modern Oscilloscopes

Power supplies are an integral part of every electronic device. With the increasing complexity of devices, electronics become more sensitive, translating to higher requirements for the power supply and more stringent test needs. One of the important tests an engineer has to perform is to verify stability of the power supply.

By Dr. Markus Herdin, Market Segment Manager Industry, Components, Research & Universities, and Marcus Sonst, Application Development, both at Rohde & Schwarz

Traditionally, the method of choice has been to observe the step response and judge from the timing whether the control loop is stable and fast enough. However, judging the level of stability from a step response is more an art than a science. Mere observation of the step response makes it difficult to assess how changes in design improve the performance of a control loop.

Stability also depends on the operation point of a power supply. A control loop might be stable for heavy loads but become nearly instable for low loads. Consequently, verification of different operational points is essential.

Control loops have been researched for decades. A reliable method for verification of stability is the closed loop response (CLR) measurement, illustrated using a Bode plot graph (see below). In the past, measuring the closed loop response required special equipment such as vector network analyzer. The price of the equipment and the inconvenience of setting up an additional measurement instrument often prevented the engineers from using closed loop response measurement.

Nowadays, modern oscilloscopes feature signal generators and flexible, powerful signal processing capabilities. This makes it possible to perform automatic closed loop response measurements with the oscilloscope that an R&D engineer already has for everyday power supply tests. This capability is typically an optional software extension of the oscilloscopes, making it a cost-effective alternative to standalone solutions.

About Bode plot

A Bode plot is a graph depicting the frequency response of a system. It combines a Bode magnitude plot that describes the magnitude of the frequency response in dB, and a Bode phase plot that describes the phase shift.

With these two plots it is possible to measure whether a control loop is stable or instable and how big the “safety” margin is. At the crossover frequency, where the gain of the control loop goes down to 0dB, the phase margin can be measured. It is the remaining phase to -180° phase shift, the point where the control loop would get instable. The phase margin therefore measures the “safety” margin for the phase.

At the frequency where the phase of the control loop reaches-180°, the gain margin can be measured. The gain margin is the negative gain at this frequency, i.e. measuring the additional gain would be needed in order to reach the point of instability. Both phase margin as well as gain margin are therefore the safety margin for stability.

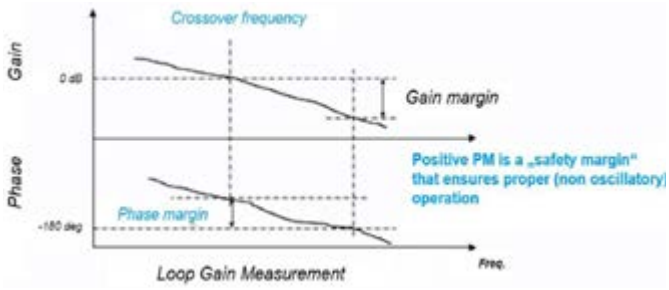

Figure 1: Loop Gain Measurement

In the oscilloscope, the Bode plot measurement is based on the built-in waveform generator and two measurement channels. The waveform generator is used to generate a disturbance signal that is fed into the control loop and the two measurement channels are necessary to measure both the disturbance signal itself as well as the reaction of the control loop. The ratio between both is the (complex) control loop gain containing magnitude gain and phase. The oscilloscope automatically sweeps through all measurement frequency and plots the gain and phase responses.

This article presents the most important topics to consider in order to make accurate Bode plots for control loops in switched mode power supplies.

A) Selecting the right injection point

To measure the control loop response, the loop has to be broken at a suitable point and a perturbation signal injected at this point. A simple method of performing this is to add in the feedback loop an additional resistor that is small enough not to influence the actual feedback loop

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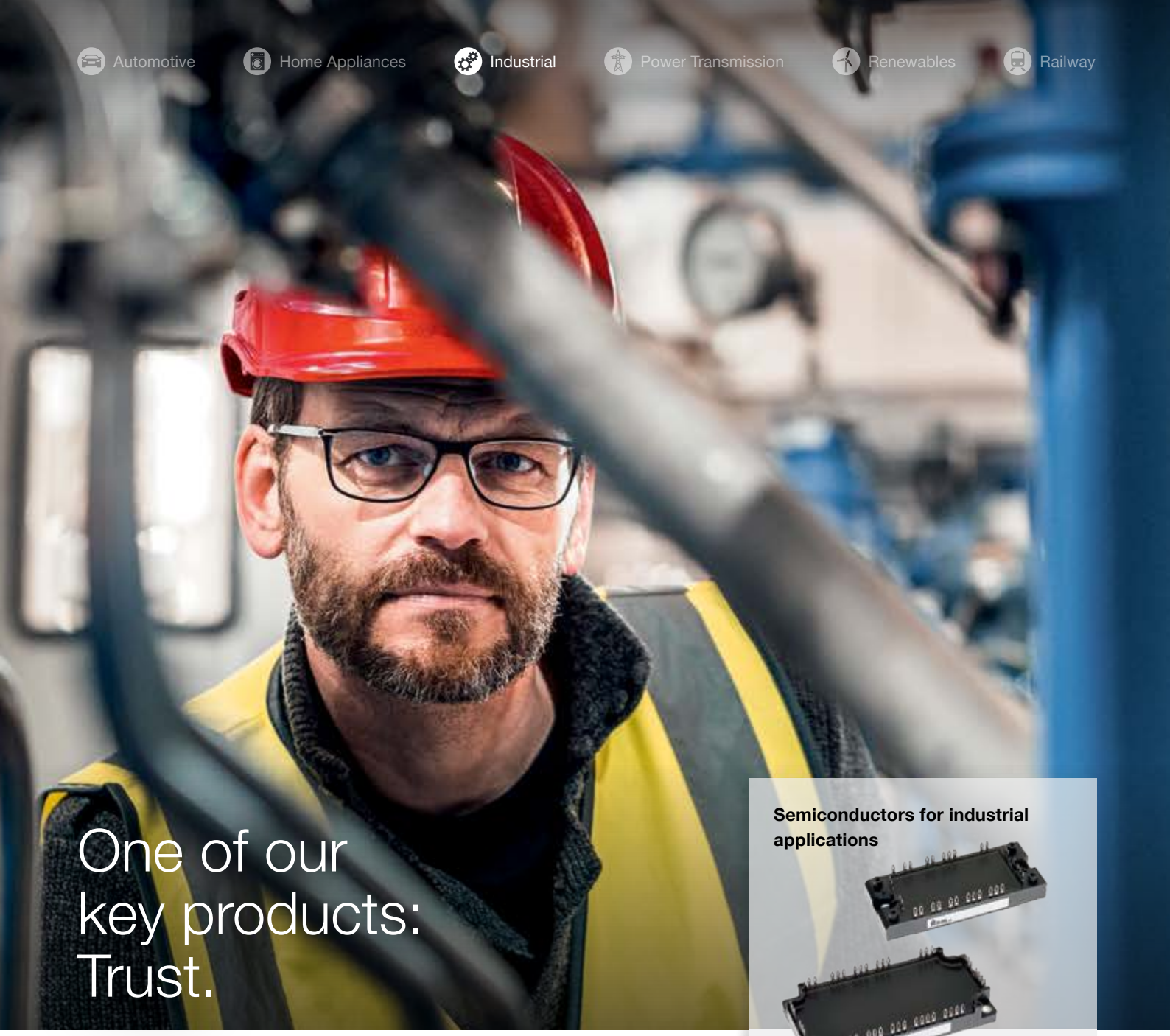

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significantly. Injecting a signal across the resistor makes it possible to insert a perturbation signal into the control loop and measure the response to this perturbation at the output of the power supply. This is called the voltage injection method. It is important to add the resistor at a point where the impedance in the direction of the feedback loop is much larger than the impedance looking backwards. Figure 2 shows how to correctly carry it out.

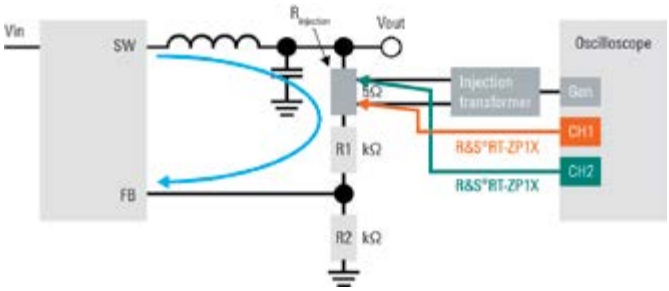

Figure 2: Choosing the correct injection point

B) Injection transformer

The injection transformer is connected between the signal generator and the power supply converter in order to inject a small error signal into the control loop. The measurement concept requires a connection to the DUT, and it is important to ensure that the transformer will not change the behavior of the loop. Therefore, the transformer has to provide galvanic isolation (safety, instrument protection, signal integrity), inhibit DC voltages from the generator and have a relative flat gain over the whole frequency range. When choosing a transformer, the permeability core and the parasitic capacitance between primary and secondary side should also be observed.

C) Amplitude profiling

A control loop is by nature very sensitive to a disturbance signal as it has the basic task of steering the control so that the effects of the disturbance signals (i.e. error signals) are minimized. When injecting a disturbance signal into a control loop to measure their response, it is therefore important to carefully choose the right amplitude. Basically, the following rules apply:

- The injection signal amplitude must be low enough that it provides only a small signal perturbation. This is important to avoid overdriving the active components.
- The injection signal level must be high enough above the noise level to allow an accurate measurement result.

Figure 3: Optimized amplitude profile of the injection signal (blue) and bode plot (red and blue)

As the gain of the control loop varies over frequency, so does the optimum injection signal level. This is what amplitude profiling does, i.e. allows definition of the amplitude level of the injection signal dependent on the measurement frequency.

D) Probing

Key to good measurements with oscilloscopes is choosing the right probe. Probes differ in voltage levels, attenuation ratios, bandwidth and many other parameters. Depending on the application, different parameters are important.

Standard passive probes typically supplied with an oscilloscope have an attenuation factor of 10:1 and a bandwidth in the range of 500 MHz. While the bandwidth of such a probe is totally sufficient for control loop measurements, the additional attenuation is a significant disadvantage.

For control loop response measurements, sensitivity and therefore low-noise probing is most important. For that reason, 1:1 probes are usually the best choice, in particular since the measurement voltage is often not too high and required measurement bandwidths are in the range of only up to a few MHz.

When using power supplies with higher output voltages, high-voltage passive probes or high-voltage differential probes are recommended.

E) Stability measurements over all conditions

In switched-mode power supply circuits, changes in line, load and temperature sometimes degrade phase margin markedly from the nominal value. A typical example is a low-load situation, where power supplies might go into discontinuous current conduction mode, with a different control loop characteristic than the characteristics of the control loop in standard load situations. In order to be sure that the power supply is stable in all scenarios, it is recommended to perform Bode plot measurements for all operation points.

Conclusion

Oscilloscopes have become all-in-one solutions for many measurement problems electrical engineers face. Having the capability of performing Bode plots using the built-in waveform generator extends the capabilities of the oscilloscopes to yet another application that is particularly important for power supply design. This saves space on the engineer's desk and eliminates the need of investing in a specialized testing solution for control loop analysis.

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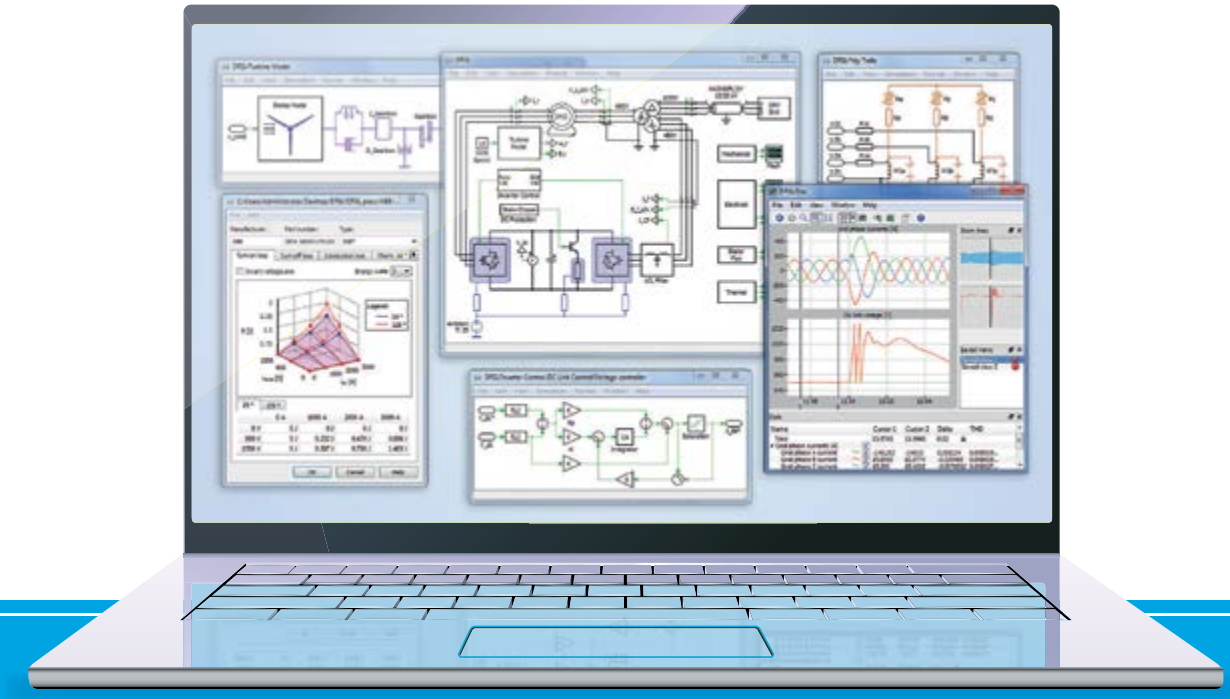

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Produce Negative Voltages Using the Buck Controller

Negative voltages are used to power an expanding number of LCD screens in automobile infotainment systems. Likewise, in industrial and railroad environments, negative rails satisfy the needs of instrumentation and monitoring applications. In all cases, the negative voltage rail must be produced from a positive source, but positive-to-negative ICs are not as readily available as buck controllers.

By Victor Khasiev, Analog Devices, Inc.

Manufacturers are unlikely to have tested and qualified negative output converters, but probably already have a number of approved buck controllers, such as the LTC3892 dual output controller. To avoid the extra time and cost of testing a dedicated negative output converter, the LTC3892 dual output buck controller can be used to produce a negative output voltage with a Ćuk topology.

Dual Output Converter: –12 V at 3 A and 3.3 V at 10 A

The LTC3892 is a dual output controller, where one output can be used for a positive voltage and the other channel for a negative voltage, as shown in Figure 1. The input voltage range of this solution is 6 V to 40 V, with VOUT1 equal to 3.3 V at 10 A and VOUT2 equal to –12 V at 3 A. VOUT1 is configured as a straightforward buck converter topology with power train components Q2, Q3, L1, and the output filter capacitors. No voltage divider is required at the VFB pin (tied directly to the output) to set the output to 3.3 V, as the LTC3892-2 features fixed 3.3 V or 5 V outputs set by the grounding or by tying VPRG1 to INTVCC, respectively.

VOUT2 is a negative output voltage relative to GND. The op amp U2 (LT1797) is wired as a differential amplifier that is employed to sense the negative voltage and scale it to the 0.8 V reference of the LTC3892 error amplifier (EA). In this approach, both the EA of the LTC3892 and the op amp are referenced to system GND, which simplifies power supply control and functionality. The seed formulas for setting the negative output voltage are:

$$KR = \frac{0.8\ \text{V}}{|V_0|}$$

$$R_{F1} = 5.11\ \text{k}\Omega$$

$$R_{F2} = \frac{R_{F1}}{KR}$$

$$R_{F3} = \frac{R_{F1} \times R_{F2}}{R_{F1} + R_{F2}}$$

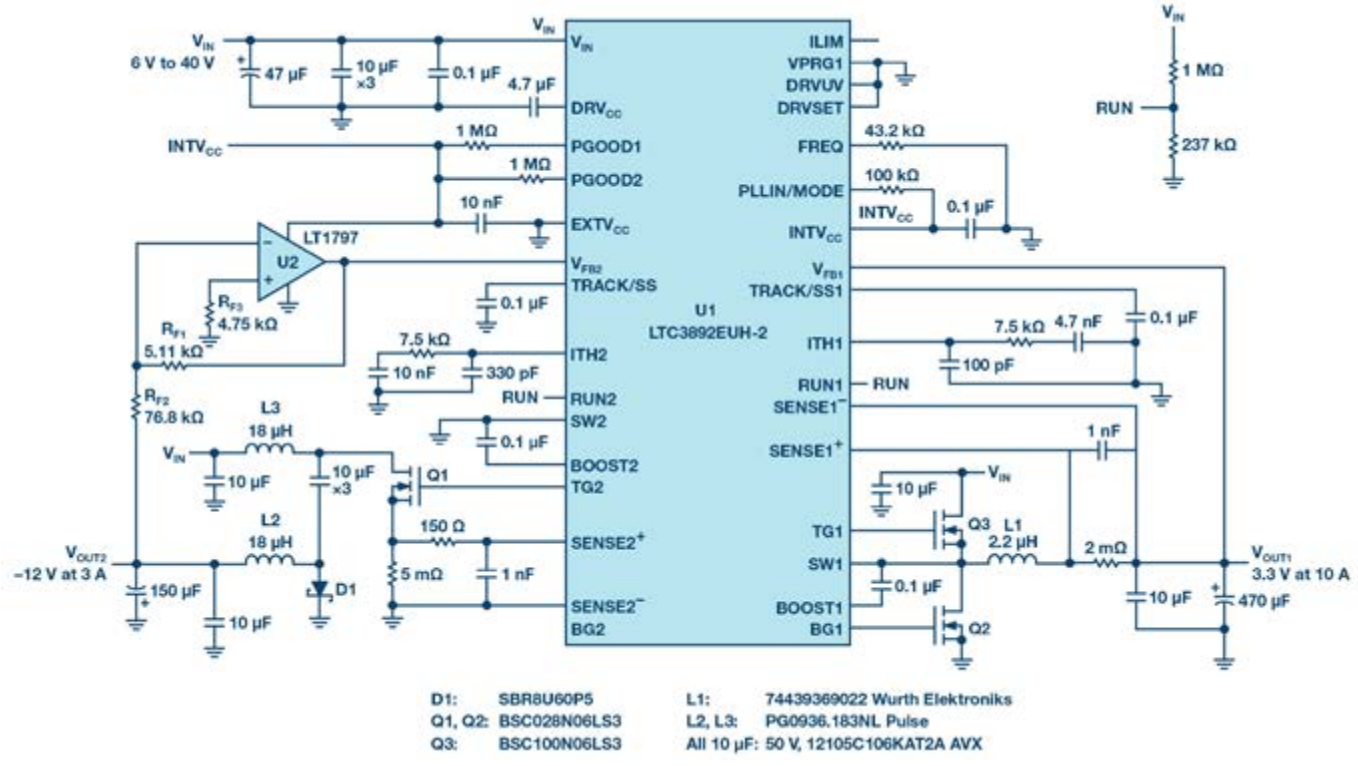

Figure 1: A solution for generating positive and negative voltages. VOUT1 is 3.3 V at 10 A and VOUT2 is –12 V at 3 A.

The VOUT2 employs a nonsynchronous Ćuk topology and includes power train components of Q1, D1, L2, and output filter capacitors. The Ćuk topology is widely covered in other technical literature, so it is not covered at length here. The stress on the power train components can be summed up by:

$$D = \frac{|V_O|}{|V_O| + V_{IN}}$$

$$V_C = \frac{V_{IN}}{1 - D}$$

$$V_{DS} = V_D = V_C$$

$$I_{L2} = \frac{I_O \times V_O}{V_{IN}} + \Delta I_{L2}$$

$$I_{L3} = I_O + \Delta I_{L3}$$

A DC2727A demonstration board was used to evaluate this solution, with the VOUT2 efficiency shown in Figure 2. This approach is also available in our LTspice® simulation model of the LTC3892-2.

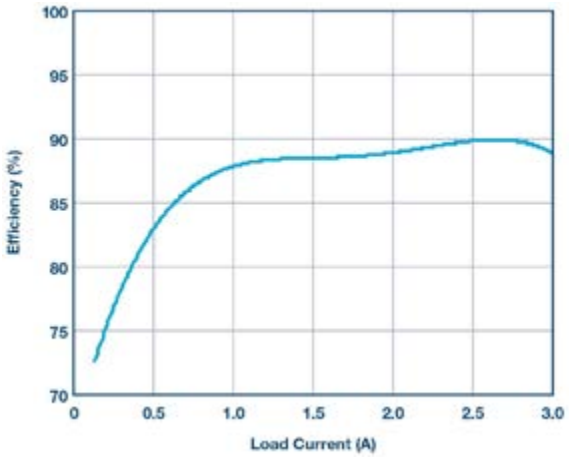

Figure 2: Efficiency for the negative output (VOUT2) at 14 V input.

Conclusion

The LTC3892 is a versatile and flexible controller ostensibly designed for synchronous step-down conversion, but it can be used in a Ćuk topology to generate positive and negative voltages for automotive, industrial, and other applications.

About the Author

Victor Khasiev is a senior applications engineer at Analog Devices. Victor has extensive experience in power electronics both in ac-to-dc and dc-to-dc conversion. He holds two patents and wrote multiple articles. These article relate to use ADI semiconductors in automotive and industrial applications. They cover step-up, step-down, SEPIC, positive-to-negative, negative-to-negative, flyback, and forward converters, as well as bidirectional backup supplies. His patents are about efficient power factor correction solutions and advanced gate drivers. Victor enjoys supporting ADI customers: answering questions about ADI products, design and verification power supplies schematics, layout of the print circuit boards, troubleshooting, and participating in testing final systems

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How Thermal Environment Impacts Power Supply Success

Operational temperature range can make or break a design – choose wisely

Selecting the right AC/DC power supply for a given application starts with environment. A power supply that is intended to spend its operational life in an office cubicle will clearly be subject to a different set of design challenges than one that will be potted into an enclosure and mounted to the side of an industrial irrigator.

By Dylan Howes, TT Electronics

Many physical properties of circuit elements and the media that surround them are in fact functions of environmental factors such as ambient temperature, air pressure, humidity, pollution degree, etc. Changes in ambient temperature can also affect the behavior, performance, and reliability of power supplies, making understanding the power supply's operational temperature range crucial to the success of the design.

Where to begin

The implications of operating power supplies at extreme temperatures are certainly key concerns in the design phase. But first, let's define some basic, expected operating ranges for two of the most common types of power conversion products: AC/DC power adaptors and internal AC/DC power supplies. While there is no one single standard for operational temperature range (nor for thermal derating), the following offer a rule of thumb for the industrial, commercial, and medical markets. Other markets may be expected to observe different generic ranges:

- AC/DC Power Adaptors (Wall Mounts and Desktops)
  The typical AC/DC power adaptor, enclosed in a plastic case, can be expected to offer its full nameplate-rated output power in ambient temperatures between 0°C and 40°C (32°F and 104°F). This range is ideal for devices used indoors—in an office, home, or similar setting—where people work or live. Most people are not interacting with electrical office equipment or hospital equipment in environments outside this range. These types of power converters can usually operate safely and reliably in environments between 40°C and 60°C with appropriate derating considerations.

$$P_{AVAILABLE} = \begin{cases} P_{RATED} & ;\ 0°C < T \leq 40°C \\ P_{RATED}(2 - 0.025T) & ;\ 40°C < T < 60°C \\ 0 & ;\ T > 60°C \end{cases}$$

- Internal AC/DC Power Supplies (Open Frame and Enclosed):
  Open frame power supply thermal derating curves often carry one additional caveat, especially when dealing with super-100W systems. That caveat is the presence of a conduction or convection based cooling mechanism. It is not uncommon to see open frame derating curves with multiple traces, each for different cooling considerations, and/or different output voltages. Lower voltages represent higher currents and higher currents translate to greater dissipation. Most higher-power open frame power supplies are rated under the assumption that a prescribed volume (usually between 20 and 40 CFM) of forced air will be provided to push hot air away from the surface of dissipative elements. Without this airflow, the available output power can be expected to suffer by as much as 40 or 50%. Further discussion on convection cooling will be provided later in this article.

It warrants reiteration that these functions are generic and are presented to further this article's discussion on environmental factors, but that manufacturer datasheets should always be consulted before making formal design decisions.

The typical internal AC/DC power supply can be expected to offer its full nameplate-rated power output in ambient temperatures between 0°C and 50°C (32°F and 122°F). It is also rather common to see open frame converters with lower temperature reaches well below 0°C. This range spawns from the assumption that the devices are being operated in some enclosed end device that may house other dissipative elements and may offer limited means for generated heat to escape. Further, the possibility exists that the internal supply may be used in an end device designed for use outdoors or in more extreme environments than a home or office. These types of power converters can usually operate safely and reliably in environments between 50°C and 70°C with appropriate derating considerations.

$$P_{AVAILABLE} = \begin{cases} P_{RATED} & ;\ 0°C < T \leq 50°C \\ P_{RATED}(2.25 - 0.025T) & ;\ 50°C < T < 70°C \\ 0 & ;\ T > 70°C \end{cases}$$

Low temperature operation concerns

Power supply performance is degraded at sub-specified temperatures via two primary mechanisms: "self-removing" **inrush current limiting devices** and **electrolytic capacitors**.

- **Inrush Current Limiting Devices**
  When the rectified high voltage (HV) rail rises rapidly from 0VDC to √2•Line upon application of AC, the bulk capacitor on the primary of the switch mode power converter (SMPS) acts like a short circuit, drawing large amounts of current, known as inrush current, as the capacitor begins to charge. Excessive inrush current is undesirable, and so efforts are made to mitigate it.

One common strategy is to place an NTC thermistor in series with the bulk capacitor. Care is taken by the design engineer to ensure that the chosen thermistor maintains an appropriately high impedance at the upper limits of the PSUs rated temperature range to mitigate inrush currents, while still maintaining an appropriately low impedance during steady state, light load operation at the lower limits of the PSUs rated temperature range. For a given design, there exists an ambient temperature below which the input impedance will be too large for the converter's start-up circuit to pull the needed amount of current off the HV rail to initiate a successful start-up.

- **Electrolytic Capacitors**
  At typical SMPS switching frequencies, the inductive nature of the mains lines effectively limits the available current that can be supplied to the converter. Accordingly, a local energy store (bulk capacitor) with low HF impedance is needed to receive and store the incoming 50 or 60Hz energy, while simultaneously providing energy to the downstream conversion network at a much higher frequency. One of the earliest PSU design determinations is just how much energy needs to be stored in this bulk capacitor to support stable operation. As the temperature of the electrolyte within an electrolytic capacitor decreases, its viscosity increases, resulting in a degradation in electrical conductivity. This drop in electrolyte conductivity ultimately manifests itself as a decrease in capacitance of the structure. Accordingly, there exists a temperature below which the available HF energy is insufficient for stable operation of the converter. E-caps are also used widely in the output filter to reduce voltage ripple. As the capacitance in the filter decreases with temperature, the ripple increases and may become unsuitable for some applications.

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Turning up the heat

Heat is a power converter's worst enemy. At high operational temperatures, thermal runaway can cause semiconductors to overheat and burn out. Component temperatures may exceed those permitted by applicable safety standards, and a device's operational lifetime can be cut short as chemical processes are accelerated.

Further complicating this is the fact that power supplies generate heat as a biproduct of normal operation. This occurs when functional or non-functional currents pass through any element with a real impedance, such as diodes and transistors, PCB traces, transformer windings, even transformer cores (eddy currents). The heat generated by a power supply is related to its operational efficiency.

$$Q_d = P_{OUT_o}\left(\frac{1}{\eta_o} - 1\right)$$

Where Q_d is the heat dissipated in Watts, P_{OUT} is the output power in Watts, and η is the efficiency. P_{OUT} and η have been assigned like subscripts to make clear the fact that the operational efficiency varies with output power and is not just some fixed value.

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Heat is transferred out of a power supply through a combination of all three heat transfer mechanisms: radiation, conduction, and convection, but primarily via the latter two. If there is disparity between the heat generated and the heat transferred, the device's temperature will rise according to the equivalent thermal impedance between it and the cooler environment. To prevent component temperatures from rising to levels that adversely affect their reliabilities or safe operation, the power supply must be designed to allow generated heat to escape (by reducing the thermal impedance between heat sources and the ambient environment), and also perhaps in a manner that minimizes the amount of heat generated in the first place.

The Origin of Thermal Derating

Given that the heat transferred from a PSU to the ambient environment is directly proportional to the difference in temperature between the two media by some constant *k* determined by the material properties, and that the average rise in temperature of the PSU is proportional to the heat generated (function of efficiency and throughput) less the heat transferred, one can assert:

$$\Delta T_C \propto P_{OUT_0}\left(\frac{1}{\eta_0}-1\right)-k(T_1-T_2)$$

Where T_2 is the ambient temperature, T_1 is the temperature of the PSU, and ΔT_C is the PSU temperature rise. The above equation tells us exactly why we must derate the output power of a power supply as the ambient temperature surrounding it increases. As T_2 approaches the value of T_1, ΔT_C rises. That is, as the ambient temperature of a power supply approaches its internal temperature, the ability of the components to transfer their self-generated heat out to the ambient environment diminishes.

Convection Heat Transfer and the Origin of Convection vs. Forced Air Ratings

Convection is the transfer of heat via the movement of fluids, including air, across the surface of an object with a temperature different than that of the fluid. Convection heat transfer can get a good deal more complex than conduction in the context of power supply cooling. The key takeaway is to understand that conduction does not work alone to remove heat from inside a power supply; conduction simply brings the internally generated heat out to the surface of the power supply. From there, we depend on convection to "carry" the heat away from the supply into the ambient environment.

Consider for a moment a situation whereby the air directly abutting the surface of a power supply is somehow disallowed from moving. As the air stays in proximity with the hot power supply surface, its temperature will rise. Eventually, the temperature will become equal to the temperature of the power supply surface. There is once again a dependence on a temperature differential between the two media. If the fluid (air) and the power supply (the hot object) are the exact same temperature, no heat will be transferred. Without allowing heat to move away from the outside of the power supply, its temperature will begin to rise as well, further impeding the effects of conduction. Fortunately, air is not inclined to stay in one static location, particularly in the presence of temperature gradients throughout the fluid. As they say, "warm air rises." Indeed, as the temperature of the air nearest the warm power supply increases, the density of the air decreases, causing cooler, denser air to "sink in" and take its place.

Tackling density

For some power supplies, the natural process of convection is sufficient for maintaining an adequate temperature differential between the power supply's outer surfaces and the air for appropriate heat transfer. However, the rate of heat transfer via convection, not unlike conduction, has a dependence on interface area, or how much surface in squared meters is actually in contact with the fluid.

The power supply industry, alongside many of the industries it supports, strives to achieve greater functional densities. One of the strongest ongoing industry trends is to develop technologies that allow us to put more and more power into smaller and smaller packages. Recall that, in general, as output power increases, the amount of heat generated increases as well. Combining this with the fact that the ability of convection to remove heat from the surface of a power supply is dependent on the size of the power supply and its effective contact area reveals the need for forced air cooling in many of today's modern, high density power converters. The natural process simply isn't fast enough to maintain adequate heat transfer rates and prevent internal components from overheating.

Choosing wisely

Ambient temperature impacts the behavior, performance, and reliability of power supplies, making environment a critical factor in their selection. By understanding industry conventions and popular cooling methods, factors that underscore a power supply's operational temperature range, thermal derating curves, and what to expect if thermal limits are exceeded, designers are well equipped to make the right choice.

About the Author

Dylan Howes, Applications Engineer, TT Electronics
Power Partners, Inc. – a TT Electronics company

Dylan Howes manages all technical aspects of power converter design-in efforts, and authors technical content featuring power conversion trends and technologies.

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pels IEEE POWER ELECTRONICS SOCIETY Powering a Sustainable Future

PSMA Power Sources Manufacturers Association The Professional Power Electronics Association

Surface-Mount Fully Integrated Current Sensors

Allegro MicroSystems announced significant ease-of-use enhancements to its popular high current fully integrated ACS772/3 current sensor “CB” package family. These automotive grade high voltage isolation current sensors already provide economical and precise solutions for both AC and DC current sensing up to 400A. Building on that leadership and deep customer-understanding, Allegro’s surface-mount leadform option for the CB package is the answer to many customer challenges by providing a flexible solution for space constrained applications. “This is a classic, ‘You asked – we listened.’ innovation with purpose moment for us,” explains Shaun Milano, Business Unit Director for Current Sensors. “Our customers want flexibility, and we’re excited to provide these innovative, robust solutions in this new surface-mount option to complement our highly popular through-hole version. High current PCB designs improve power density and efficiency and this surface-mount option allows customers to realize these advantages with a simpler manufacturing process.”

The ACS772/3 family of current sensor ICs has an enhanced feature set that helps engineers simplify their bill of materials and improve efficiency in the toughest of applications.

www.allegromicro.com

SiC Schottky Diode for DC Electric Vehicle Charging

CALY Technologies is very pleased to announce the release of a 25A, 1700V SiC Schottky Diode (KE17DJ25) ideally suited for high-efficiency power conversion applications, such as Electrical Vehicle (EV) charging applications, Industrial Power and Renewable Energy converters. The KE17DJ25 is commercially available in wafer, bare die and 2-lead TO-247 package, allowing designers to use the device in a broad range of configurations. The TO-247-2L package option make possible the use of 1700V devices in high-pollution environments, such as charging stations and solar inverters.

CALY Technologies SiC Schottky diodes offer nearly zero reverse recovery and state-of-the-art forward voltage drop, leading to extremely low switching and conduction losses. This contributes to achieve higher efficiency systems, being faster, cooler, smaller and less costly than attainable with silicon (Si) devices. CALY Technologies offer wafers and bare die products with metallization compatible with top brazed connections (clips, power skins) as well as with standard wire bonding.

Thanks to the very short lead time offered by CALY Technologies, KE17DJ25 devices can be used in new designs as well as drop in replacements of other commercially available 25A, 1700V SiC Schottky diodes.

www.caly-technologies.com

DC-DC Converter in Conduction Cooled Format

Power System Technology announces the introduction of PST14X family, very high power density 320W DC-DC converter in conduction cooled format. In a very small package 160*50*25mm,with input voltage ranges of 9-50Vdc, 18-36Vdc, 16-50Vdc, PST14X incorporates EMI filtering, input active reverse polarity and transient protection, output protections, very robust mechanical package and connection, required in most of the severe environment for industrial, railways, defense type of applications. The converter provides high power density thanks to the integration of Vicor Corp. DCM modules, high efficiency (>90%), input-to-output isolation, soft start, overtemperature protection, input over/undervoltage lockout. The outputs are short-circuit proof. The 100°C baseplate operation allows operation in high temperature environment. The output can be configured in many different output voltages from 3,3V to 48Vdc, others possibilities are even possible as semi- standard versions. With the -MV option, the converter is protected against surges and transients MIL-STD-704 and MIL-STD-1275, EMI filtered built to meet MIL-STD 461 and ruggedizzed according MIL-STD-810.

www.powersystemtechnology.com

Ultra-Low IR Schottky Barrier Diodes

ROHM recently announced the availability of 200V ultra-low IR Schottky Barrier Diodes (SBD) optimized for automotive applications including powertrains and xEVs. The RBxx8BM/NS200 expands on the RBxx8 lineup of SBDs enabling high temperature operation that have already been proven in the automotive market in Japan. This series offers ultra-low leakage current (IR) characteristics to achieve high withstand voltage of 200V. Replacing Fast Recovery Diodes (FRD) and rectifier diodes typically used in vehicle systems with ROHM's new SBDs make it possible to improve forward voltage (VF) characteristics significantly (11% lower than conventional FRDs). This reduces application power losses and allows smaller package designs by reducing heat generation, contributing to greater space savings. In recent years, the technological trend in Drive Systems for 48V mild hybrids is mechanical integration, in which the motor and peripheral circuits are combined into a single module. This demands high efficiency and high voltage SBDs capable of stable operation at high temperatures. At the same time, higher voltage SBDs are required in systems utilizing conventional 150V components to increase functionality and reliability. ROHM has been offering the RBxx8 lineup of ultra-low IR SBDs that withstand up to 150V compatible with high temperature automotive environments. This latest series adds 200V models to meet the new automotive requirements.

www.rohm.com

High Isolated Current Sensors

LEM has expanded its range of miniature, integrated circuit sensors range for AC and DC isolated-current measurement with the introduction of the HMSR series. Despite their small size, the components can handle overload current bursts of up to 20 kA (8-20 us surge test profile), such as those that occur in photovoltaics applications while still providing a reinforced isolation. Products in the series are designed to measure currents of up to 2.5 times their nominal ratings of 6 A, 8 A, 10 A, 15 A, 20 A or 30 A. Packaged as SO16 surface-mount devices with a height of just 6 mm, the sensors can be mounted directly onto a printed circuit board in the same process as other board-level components. This helps to reduce manufacturing costs and decrease the overall footprint, vital for space-constrained applications. As a result, HMSR sensors can be readily built into small form-factor intelligent power modules (IPMs). The HMSR series uses a proprietary Open Loop Hall effect ASIC associated with a unique low-resistance primary conductor to minimise power losses allowing direct current measurement and high transient overload currents to pass without damage.

www.lem.com

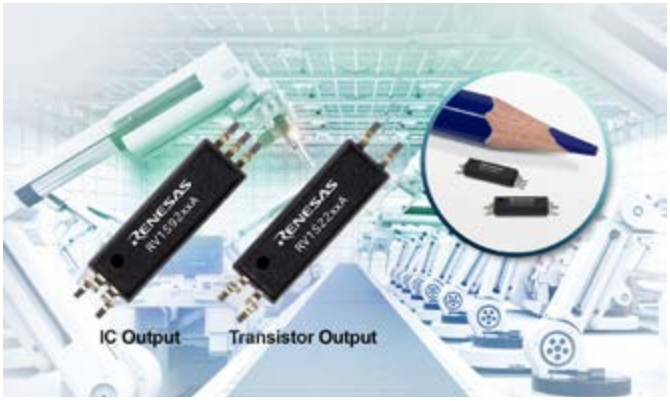
Buck-Boost High-Efficiency DC/DC Converter

The recently introduced RECOM RBBA3000 buck-boost, non-isolated, DC/DC converter features a maximum of 3kW of output power rating in a industry-standard half brick baseplate-cooled package. Input range is 9-60VDC and the output voltage and maximum current can be user-programmed from 0-60VDC and 0-50A respectively. Programming can be via a single resistor or by an externally applied voltage. A particular feature is that the buck-boost topology utilised allows the output voltage to be set lower or higher than the input voltage. With its excellent 98% conversion efficiency, the RBBA3000 provides a full power over an operating temperature of -40 up to +85°C when appropriately cooled. The load current can be monitored from a current share pin which can also be used to parallel two modules to provide up to 100A output with active load balancing. The converter complies with EMC standard EN55024 and also EN 55032 class A and B with an external filter. Typical applications for the product are 48V to 24V or 12V to 24V battery power conversion, electric vehicle voltage regulators, battery voltage stabilisers or high power laboratory DC power supplies. “The RECOM RBBA3000 has a great combination of high efficiency, power density and functionality” commented Steve Roberts, CTO of RECOM, “It’s also backed by our two-year warranty for peace of mind”.

www.recom-power.com

Photocouplers for Industrial Automation and Solar Inverter Applications

Renesas Electronics announced five 8.2mm creepage photocouplers that are the world's smallest isolation devices for industrial automation equipment and solar inverters. With a package width of 2.5mm, the RV1S92xxA and RV1S22xxA photocouplers reduce PCB mounting area by 35 percent compared to competitive couplers. They help designers shrink equipment size, increase robot axes, and improve factory floor productivity. They also meet the needs of the zero-energy house that requires smaller solar equipment for more installations in limited space. The RV1S92xxA and RV1S22xxA photocouplers are ideal for DC to AC power inverters, AC servo motors, programmable logic controllers (PLCs), robotic arms, solar inverters, and battery storage and charging systems.



The RV1S9260A 15 Mbps communications coupler and RV1S9213A intelligent power module (IPM) driver are the first photocouplers to use tiny LSSO5 packages with a 0.65mm pin pitch, half the pitch of conventional packages. With a package height of 2.1mm, the photocouplers can be directly mounted on the backside of a PCB, freeing up valuable space for topside mounted components. Three times infrared reflow soldering provides maximum flexibility. The RV1S92xxA photocouplers' electric isolation and high CMR noise rejection (50 kV/µs) protects low voltage microcontrollers and I/O devices from high voltage circuits when transferring high-speed signals.

www.renesas.com

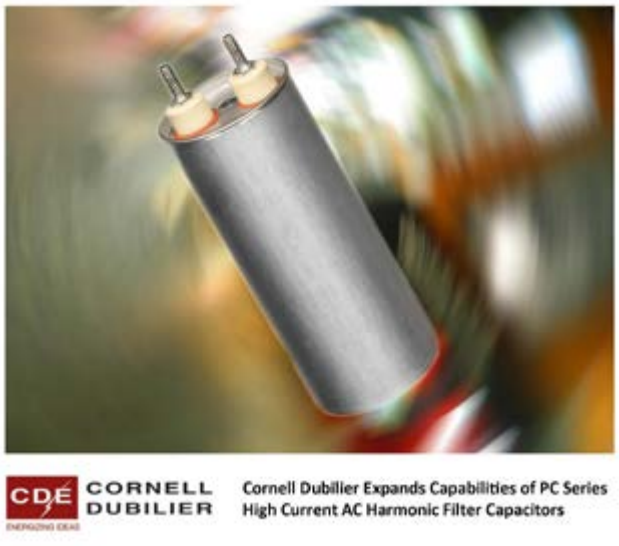
Powder Alloy Material

For designers targeting superior efficiency and who need inductors with the lowest losses at high frequency, Magnetics has developed a powder alloy material: Kool Mµ® Hf. Kool Mµ Hf is a sendust powder alloy similar to Kool Mµ®, Magnetics' economical power inductor material, and Kool Mµ® MAX, which offers superior DC bias under current loading. With the availability of Kool Mµ Hf, engineers have a third option when considering a Kool Mµ core inductor, an option which optimizes for best AC core loss at any frequency. Kool Mµ Hf was derived from the growing need for efficient power inductors in GaN and SiC power supplies. Although customer demand influenced a target operating range of 200-500 kHz, Kool Mµ Hf losses are dramatically improved at all frequencies.

Kool Mµ Hf displays improved losses as high as 2-3 MHz for high efficiency inductors while matching MPP (molypermalloy powder) losses at traditional lower frequencies (20-200 kHz). Therefore, Kool Mµ Hf can be attractive for any high efficiency power supply design, not only those using GaN and SiC switching at high frequency. Kool Mµ Hf is currently available in permeabilities of 26 and 60 and in standard toroid sizes up to 40 mm diameter. Additional permeabilities and larger cores are in development for release later this year.

www.mag-inc.com

High Current AC Harmonic Filter Capacitors



Cornell Dubilier announced that it now offers 85 Ampere RMS ratings and numerous other enhancements to its PC series of AC harmonic filter capacitors. The series improvements include UL recognized construction and an internal pressure interrupter system that has passed the rigors of UL testing to ensure fail-open performance under high current fault conditions. The higher current ratings improve the capacitor's ability to handle the high levels of harmonic content encountered in inverter AC input and output filtering applications. The series is typically networked with inductors to filter out undesirable harmonics in both single-phase and three-phase AC power systems. As a two-terminal capacitor device, multiple PC series capacitors can be connected in delta or wye configurations to achieve the reactive power and harmonic tuning needed to filter out the unwanted frequencies. The presence of multiple harmonics puts additional stress on capacitors in the form of self-heating. The PC series is designed with robust terminations and low equivalent series resistance (ESR), to minimize heating. The service life objective of the PC series is 60,000 hours when operated at full rated voltage and a case hot spot of 70 °C.

www.cde.com/PC

Synchronous DC/DC Buck Regulator

Alpha and Omega Semiconductor introduced AOZ6682CI and AOZ-6683CI. These devices are high efficiency, simple-to-use synchronous buck regulators. The AOZ6682CI and AOZ6683CI are both available in an ultra-thin, thermally enhanced TSOT23-6 package and deliver

2A and 3A output current, respectively. The new devices offer high efficiency over the full load range, allowing greener power conversion for a variety of consumer electronics applications such as LCD TVs, set-top boxes, high definition Blu-rayTM Disc Players and Networking terminals.

The new devices incorporate a low resistance synchronous buck power stage that enables up to 95% efficiency. Combined with a thermally enhanced package, the AOZ6682CI and AOZ6683CI achieve 10°C cooler operation at full load compared to similar competing devices. Under heavy load conditions, the devices operate in a fixed frequency continuous-conduction mode (CCM). At light loads or in standby mode, the devices employ a proprietary pulse energy mode (PEM) control scheme. This control scheme and low quiescent current of 200uA, allows the buck converter design to achieve industry-leading efficiencies of 89% at light loads.

“Modern consumer equipment must achieve less than 0.5W in standby power consumption and this is a tough problem for system designers to solve,” said Kenny Hu, Power IC Marketing Manager at AOS. “The newest 2A and 3A additions to the EZBuck family simplify this task, offering up to 6% improved efficiency compared to competing devices thanks to low quiescent current and a proprietary power-saving light load control scheme.”

www.aosmd.com

Automotive DC/DC Converter

MORNSUN launched a SMD DC/DC converter module CFB0505XT-1WR3 which is specifically designed for automotive applications. This module meets automotive EMC standards and AEC-Q100 requirements. Besides, CFB0505XT-1WR3 features compact size, 3000VAC/4200VDC high isolation voltage, operating temperature range of -40°

~+105°, which make it ideal for automotive applications with efficiency up to 82% and output continuous short-circuit protection.

www.mornsun-power.com

Dr.-Ing. Artur Seibt - Consultant - Electronics Design Lab

Former R & D manager and managing director in D, USA, NL, A, author of 156 publications and patent applications, offers consultant's services and a fully equipped design lab. 30 European and US customers (firms) to date. Assistance in all stages of development, design of complete (or parts) of products, tests of designs, failure analysis, evaluation of products for cost reduction or/and performance improvement. Specializing in power electronics (SMPS, lamp ballasts, motor drives, D amplifiers including EMI, 5 years experience with SiC and GaN), measuring instruments, critical analog circuitry.

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50 and 60 mm Modules for Drives and UPS Applications

Infineon Technologies Bipolar has expanded its product portfolio of thyristor/diode modules. The new Prime Block 50 mm modules feature solder bond technology and the 60 mm modules pressure contact technology. They are designed for highest performance when the desired current exceeds 600 A for a 60 mm footprint or 330 A for a 50 mm footprint. This avoids the paralleling of modules when this is not an option. Prime Block modules are a perfect fit for industrial AC and DC drives as well as for rectifiers and bypasses in UPS. The modules have been optimized for better thermal resistance and higher operational temperatures to push their performance beyond the existing limits. As a result, the Prime Block achieves the highest power density in its respective footprint while maintaining the well-known reliability, which leads to an outstanding lifetime. The pressure contact modules in general provide best-in-class blocking stability, the solder bond modules fully undergo an X-ray monitoring after the soldering process.

The variant in the 60 mm standard housing comes in the topologies thyristor/thyristor and thyristor/diode with a blocking voltage of either 1600 V or 2200 V and in current ratings from 700 A to 820 A. The 50 mm standard housing variant is offered in the topologies thyristor/thyristor, thyristor/diode and diode/diode.

www.infineon.com

eBook on Electric Vehicles Charging Infrastructure

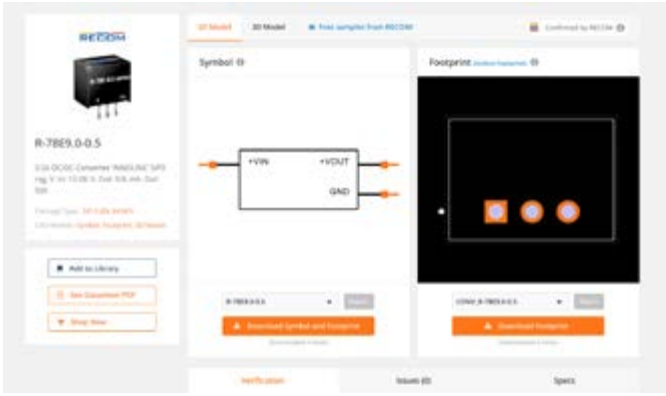
Mouser Electronics announces an eBook in collaboration with Bourns, exploring new components, technologies, and strategies for the design and development of electric vehicles. In Electrification of the Vehicle, subject matter experts from Mouser and Bourns provide detailed explanations of concepts and products, including shunt resistors, inductor designs for on-board chargers, and the use of inductors and current sense resistors to reduce automotive emissions.

Citing industry surveys and industry projections, Electrification of the Vehicle predicts growing adoption of electric vehicles throughout the United States. To keep pace with increasing numbers of electric vehicles, significant strides must be made in the development of charging infrastructure. The eBook highlights some of the most pressing challenges relating to electric vehicles and charging stations, providing in-depth guides to potential technical solutions and useful products. The new eBook from Mouser and Bourns incorporates detailed information on products such as the Bourns Model CSM2F Series of shunt resistors. Available in three footprint sizes, the CSM2F series delivers accurate current sense measurements in high-energy storage applications. Bourns' useful guide highlights the key elements of each transistor in the series.

https://eu.mouser.com

Design Faster with Digital Models

Symbols & footprints for RECOM's entire catalog are now available for free download via the RECOM and SnapEDA websites, helping engineers design electronics faster. RECOM Power is launching digital models for its entire product catalog in collaboration with SnapEDA. As part of the collaboration, engineers can now access over 20,000 symbols & footprints for RECOM's power supplies - the digital models needed for circuit board design - saving them weeks of development time versus making them from scratch. When designing electronics, engineers need digital models for each component on their circuit boards. Designing them is a time-consuming, repetitive, and error-prone process, which takes engineers away from what matters most - designing and innovating the most impactful products possible. With this new collaboration, engineers can now simply drag-and-drop models into their schematics and PCB layouts, so they can start designing and innovating instantly.



"We're excited to work with RECOM Power because our visions for simplifying and accelerating the development process for engineers are perfectly aligned. RECOM is doing this by simplifying the integration of power supplies, which are an essential part of most electronics products," said Natasha Baker, CEO & Founder of SnapEDA.

www.snapeda.com

High-Efficiency GaN FET

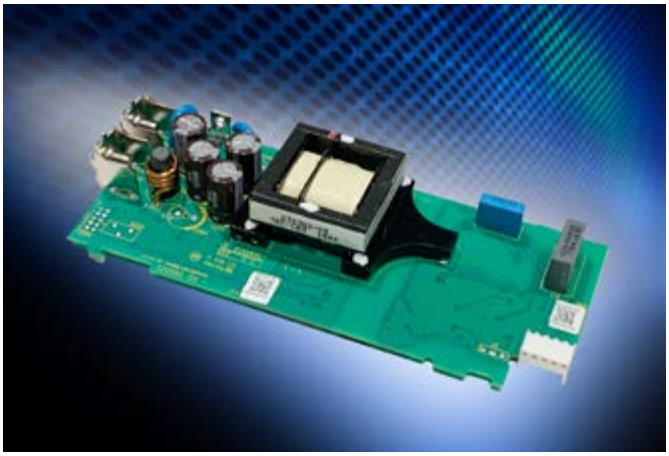
Nexperia announced its entry into the gallium nitride (GaN) FET market with the introduction of the 650 volt GAN063-650WSA, a very robust device with a gate-source voltage (VGS) of +/- 20 V and a temperature range of -55 to +175 °C. The GAN063-650WSA features

a low RDS(on) - down to 60 mΩ - and fast switching to offer very high efficiency. Nexperia is targeting high performance application segments including xEV, datacentres, telecom infrastructure, industrial automation and high-end power supplies. Nexperia's GaN-on-silicon process is very robust and mature with proven quality and reliability, plus it is highly scalable as wafers can be processed in existing silicon fabrication facilities. More, this device is available in the industry-standard TO-247, allowing customers to benefit from exceptional GaN performance in a familiar package. Toni Versluijs, General Manager of Nexperia MOS Business Group said: "This is a strategic move for Nexperia into the high voltage area, and we can now deliver technology suitable for xEV power semiconductor applications. Our GaN is a technology that is ready for volume production, and with scalability to meet high volume applications. The automotive sector is a key focus for Nexperia and one which is forecast to grow significantly for two decades as electric vehicles replace those powered by traditional internal combustion engines as the preferred means of personal and public transport."

www.nexperia.com

Modular Power Supply Series

TDK Corporation announces the addition of the SA modules to the 550 to 2000W TDK-Lambda branded QM series of AC-DC modular power supplies. The SA modules are available with 5V /15A, 12V /12.5A, 15V /10A and 24V /6.25A outputs and offer a cost-effective



solution for low power output requirements. The SA module's patented loop control design uses a digital controller and TDK-Lambda developed algorithms. Phase mode control provides higher stability across a wider range of operating conditions. This enhances the output response to sudden load changes, with a faster and improved recovery. The use of a digital controller enables a reduction in component count of 40%.

Using TDK-Lambda's online Quick Product Finder will automatically optimise the most suitable modules to generate the most cost-effective solution for a customer requirement, and provides a choice of signals, leakage current and standby voltages. Upon entering the desired output voltages and currents, the configurator will automatically produce a short 7-digit code for easy order placement.

All models in the QM series feature low acoustic noise and full MOPPs isolation. With medical and industrial safety certifications, the QM series addresses a wide range of applications, including BF rated medical equipment, test and measurement, broadcast, communications and renewable energy applications.

www.emea.lambda.tdk.com

Low-Temperature Alloy Technology

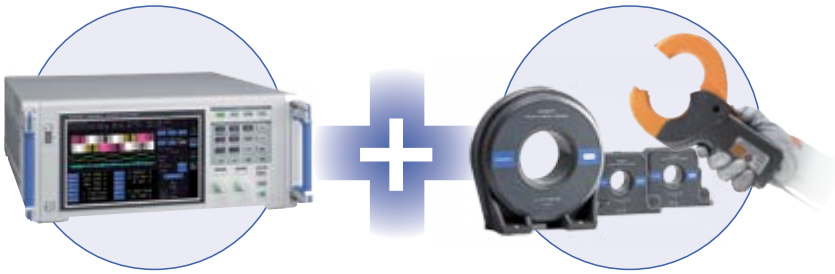
Indium Corporation continues to innovate alloy technologies with a high-performance, high-reliability low-temperature alloy. Durafuse™ LT is a novel, low-temperature alloy system designed to provide high-reliability in low-temperature applications that require a reflow temperature below 210°C.

Where traditional low-temperature solders often produce brittle solder joints that are susceptible to drop shock failures, Durafuse LT offers improved drop shock resilience, outclassing BiSn or BiSnAg alloys, and performing better than SAC305 with optimum process setup. Durafuse LT provides a solution for heat-sensitive components and flex polymers, prevents thermal warpage of processor components and multilayer boards and meets low-temperature requirements for step soldering, particularly in RF shield attachment and rework applications.

www.indium.com

HIOKI Expertise in Power Analysis & Leading Sensor Technology

How do you handle **Phase Shift Error** in your **Power Analysis?**



HIOKI Power Analyzer PW6001
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- ±0.02% accuracy, 6 channels

HIOKI High-Accuracy Sensors
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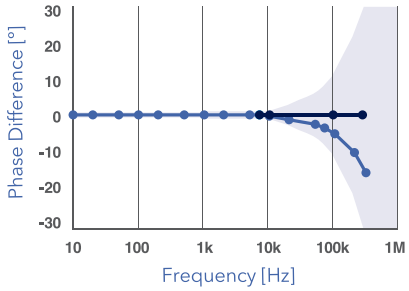
- DC to 1 MHZ, Up to 1000 A



HIOKI Power Analysis Solution
Compensate Phase Shift to Flat

hioki@hioki.eu www.hioki.com/europe

Automotive Fuse for Particularly High Voltages

High voltages and high currents occur in electric vehicles in numerous places. Their battery packs with several thousand rechargeable cells store enormous amounts of energy. First and foremost in order to meet customer requirements in terms of driving performance and range with the shortest possible charging times. To safeguard such outputs, correspondingly resilient and highly reliable fuses are required. They are used, for example, in the BMS (Battery Management System), on-board and off-board chargers. DC-DC converters and other systems exposed to high voltages. A weak point of every fuse is the connection between the melting wire and the contact cap. This is usually designed as a solder joint. In the fuse production process, however, this technology is not always 100 % error-free. Contact by means of welding is way more reliable. SCHURTER uses a new, patented process which guarantees highest reliability. The fuses of the AEO series offer a multitude of possible mounting options. In addition to the mere fuse, which requires a fuse holder (recommended model: SCHURTER CSO) and the classic mounting directly on a printed circuit board, screwable lugs for surface mounting or even flush mounting (axial mount) are also available.

www.schurter.com

Advertising Index

SOLVE YOUR SiC MOSFET GATE DRIVE CHALLENGES

Introducing the New IX4351NE SiC Gate Driver

IXYS
A Littelfuse Technology

Designed specifically to drive Silicon Carbide (SiC) MOSFETs and high-power IGBTs, the IX4351NE features:

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- Operating voltage range: -10 V to +25 V
- Internal negative charge pump regulator for selectable negative gate drive bias
- Desaturation detection with soft shutdown sink driver
- TTL and CMOS compatible input
- Undervoltage-lockout (UVLO)
- Thermal shutdown
- Open drain FAULT output

Target applications include EV on-board and off-board chargers; PFC, AC/DC and DC/DC converters; UPS; and industrial inverters.

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