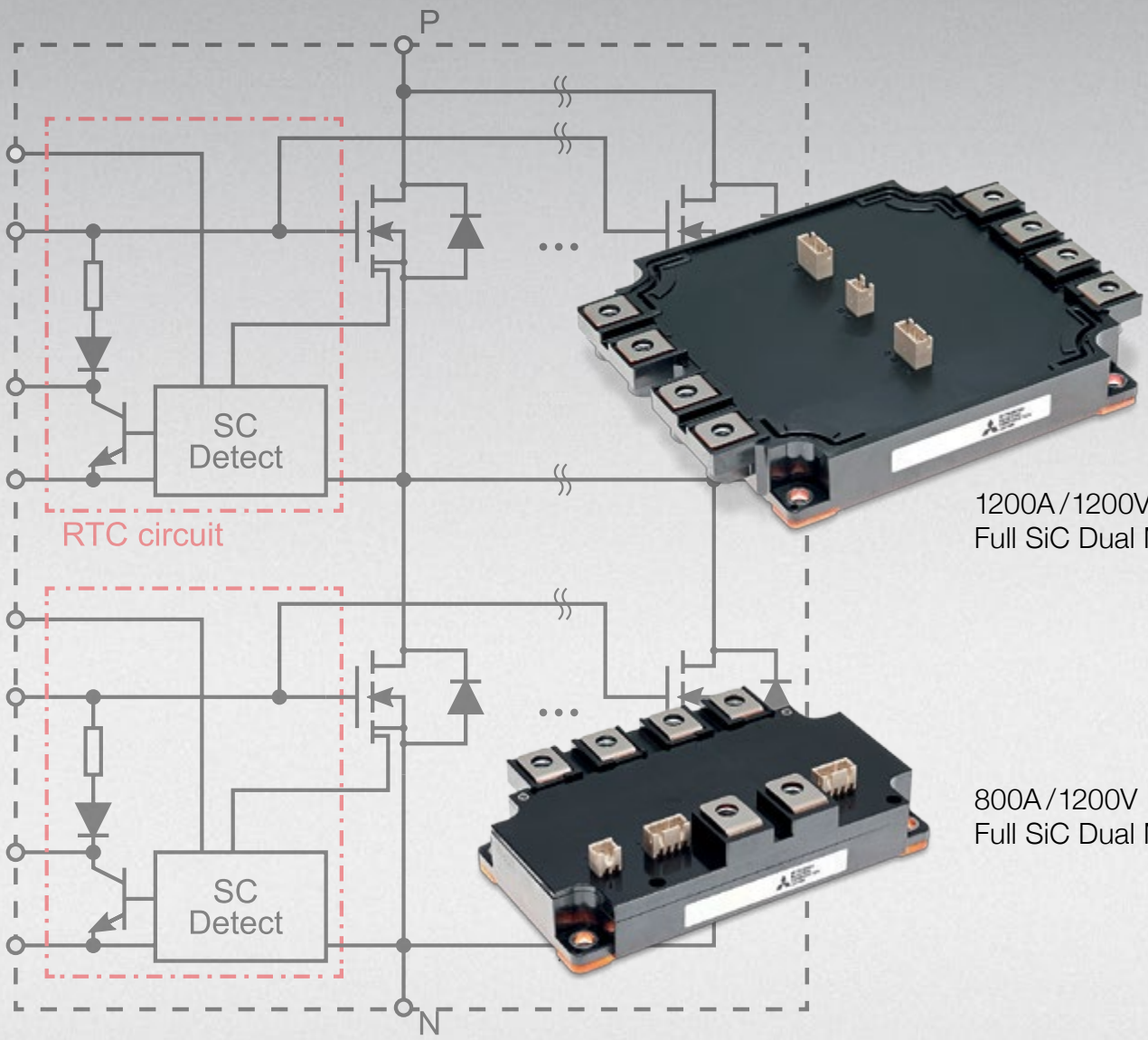
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September 2019



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Picking Strawberries

August always brings back memories from the past from when I was working for RCA / GE and later HARRIS, in Mountain Top, PA. During a visit to the factory, a friend took me to the Pocono Mountains and a strawberry field. We picked berries and his wife baked a nice cake. In those days, I worked on a power module program, hoping to catch up with established manufactures. That was in the mid 90s - management hesitated to spend enough money to be successful, and shortly later Harris got out of power semiconductors. And that was the starting point of my editorial career, and then starting my own publication. So all's well that ends well.



Summer will soon be over and we look forward to the fall and exciting events ahead of us. Starting with EPE ECCE in Genoa Italy in September, followed by productronica together with SEMICON Europe in November in Munich, and then sps in Nuremberg. Finally, we have the Wide Band Gap power conference early December.

It is a shame to see politicians targeting minorities just for their own voter appeal. Working for more than 40 years in international business and having lots of friends around the world, it worries me that protectionism, borders and walls are making life more difficult for so many. History has shown that such actions end mostly in disasters – walls never resolve underlying problems. Examples are the Great Wall in China, the wall that divided Germany, and the wall between the two Korean nations today. We must understand that our world is one big community, our only home. We need to keep on with political democratization world-over.
It is essential to save our resources for the survival of future generations. More air conditioners cannot be the answer for global warming. Power electronics can help to stabilize energy usage by using modern power semiconductors to reduce losses and boost efficiency. Wide band gap (WBG) semiconductors help to achieve these goals. We Engineers must drive this progress.
Experts will once again gather together in Munich for a WBG power conference at the Hilton Hotel at Munich airport on December 3rd, 9 am to 5 pm. We are in the final planning phase of the event - more details will be published soon. Look out for it – it's a hot (or is that cool) topic.

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. 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:
If you're not in a hurry to dry your clothes, try air drying them instead of putting them in the dryer. It may take longer, but that will save lots of energy.

Best Regards



Events

IEEE DAPE 2019
Genova, Italy September 6
https://e3da.csce.uark.edu/dape

EU PVSEC 2019
Marseille, France September 9-13
www.photovoltaic-conference.com

EV Tech Expo 2019
Novi, MI, USA September 10-12
www.evtechexpo.com

PCNS 2019
Bucharest, Romania September 10-13
www.passive-components.eu/pcns

CWIEME Americas 2019
Chicago, IL, USA September 17-18
www.coilwindingexpo.com/americas

Solar & Storage Live 2019
Birmingham, UK September 17-19
www.terrapinn.com/exhibition/solar-storage-live

ESREF 2019
Toulouse, France September 23-26
https://esref2019.sciencesconf.org

LPS 2019
Bregenz, Austria September 24-26
www.led-professional-symposium.com

ECCE 2019
Baltimore, MD, USA September 29-October 3
www.ieee-ecce.org

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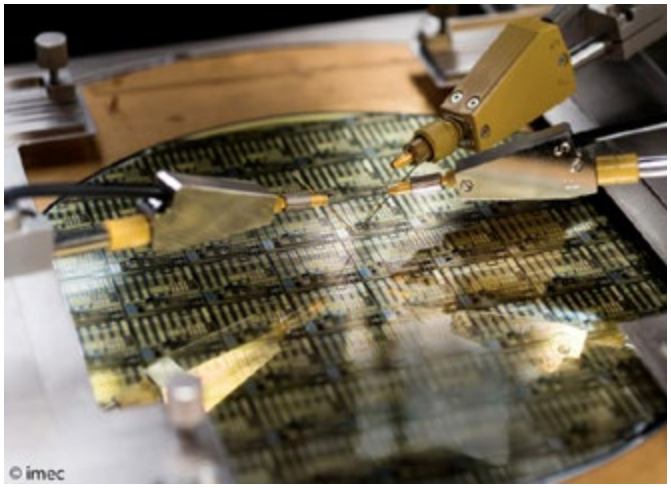


Nexperia announced that it has received a Bosch Global Supplier Award in the category 'Purchasing of direct materials – Mobility Solutions'. Nexperia was one of only 47 companies from Bosch's 43,000-strong supplier base to be honoured with such an award for its outstanding performance and teamwork in 2017-2018. Bosch has presented these awards every two years since 1987, to reward outstanding performance in the manufacture and supply of products or services – notably as concerns quality, costs, innovation, and logistics. This year's award ceremony carried the theme: 'Transforming Together. Staying Ahead", and was held in Blaichach, Germany. For Bosch, suppliers do more than just deliver components, they are also partners in development and innovation that help the company stay competitive. Bosch relies on partners who share the company's long-term competitive objectives and who are willing to collaborate closely with the company. Frans Scheper, CEO, Nexperia: "The Bosch awards are highly-valued in our industry, so to receive one is a great honour for Nexperia and we thank Bosch very much. Like Bosch, we also value partnership, teamwork and innovation in all business activities very highly and we look forward to continuing our successful relationship."

www.nexperia.com

Semiconductors — at the Core of Electronics Production

Semiconductors have been an indispensable part of our lives for a long time. The tiny chips are the most important technology of the modern world—they are the key components of all electrical systems.



From November 12 to 15, 2019, productronica, together with SEMICON Europa, which takes place at the same time, will organize the largest microelectronic exhibition in Europe at the Messe München fair grounds with innovative solutions and products from the complete supply chain.
Semiconductors are everywhere. Since 1978, their numbers have been growing worldwide at an average rate of 8.9 percent. In 2018, industry experts from IC Insights counted more than a trillion ICs, sensors and optical and discrete components (O-S-D) for the first time. According to Gartner, they generated USD 476.7 billion in sales revenue—an increase of 13.4 percent compared to 2017. Almost 35 percent of this was earned in the "microchips" area. According to WSTS (World Semiconductor Trade Statistics), this year's figure is expected to collapse by more than thirty percent, thus pulling the semiconductor market into the red by twelve percent. Europe, in contrast to America (-23.6 percent), Japan (-9.7 percent) and the Asia-Pacific region (-9.6 percent), was comparatively less affected with a decline of 3.1 percent.

www.productronica.com

Power Electronics for the Energy Transformation

Fraunhofer Institute for Solar Energy Systems ISE in Freiburg officially inaugurated its new Center for Power Electronics and Sustainable Grids. With a propriety connection to the 110 kV high-voltage grid and 40 MVA transformer, the center offers a worldwide unique research infrastructure which enables it to meet the growing demands on power electronics, a key technology for the energy system transformation. "In the future energy system, electricity will be provided not by a small number of conventional power plants but by many wind and solar power plants with fluctuating electricity generation. Thus, power electronics will assume a dominant role at all grid levels. Moreover, we require new components and functions, which enable inverters to provide stability and control for the power grid of the future," explains Prof. Hans-Martin Henning, director of Fraunhofer ISE. The development of new power electronic components and systems with more advanced properties is one of the main challenges. To achieve this, silicon carbide and gallium nitride power semiconductors will be increasingly implemented. These devices operate with high frequencies therefore making power converters with higher power densities possible. Also, new grid services shall be investigated, especially with respect to the stability of future, inverter-based grids – focusing, not least, on procedures for testing the grid assistance capabilities of inverters, e.g. voltage and frequency stability.



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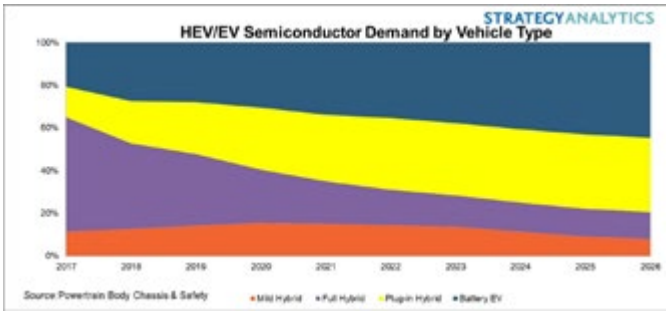
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SiC and GaN-Based Power Electronics to Boost Automotive

Strategy Analytics predicts that as HEV/EV (hybrid electric vehicle/ electric vehicle) platforms become a greater proportion of the global vehicle manufacturing mix, the demand for power electronic components will account for over 55% of the total semiconductor demand from HEV/EV powertrain by 2026. The Strategy Analytics Powertrain Body Chassis & Safety (PBCS) service report, “HEV-EV Semiconductor Technology Outlook: What Role will SiC and GaN Play?),” finds the emphasis on improving system efficiencies will dictate a move towards the use of higher value SiC and GaN-based components, creating a window of opportunity for the automotive semiconductor industry for higher margins and greater profitability. While the power electronics market for wideband semiconductors is at an early stage, it offers significant upside potential for companies that are able to leverage the growing opportunity from the HEV/EV sector. Silicon-based IGBTs, MOSFETs and SBDs will continue to dominate the



power electronics landscape, but SiC and GaN are starting to make in-roads and will collectively account for almost 20% of the HEV/EV automotive power semiconductor market in 2026.

www.strategyanalytics.com

Opening Branch in China

SMT Thermal Discoveries further expands its presence in Asia and opens the branch Suzhou SMT Machine Co., Ltd. in Suzhou. The industrial park, which was built in 1994, and the city´s good transport links, quickly transformed Suzhou into one of the country´s emerging cities. The ideal starting point for expanding the involvement in China. SMT set up an office with conference facilities and a showroom. Here, customers and interested parties can convince themselves on site of the innovative systems in the area of thermal processes, such as vacuum soldering systems and reflow soldering systems. Lucky Xia, Process and Sales Engineer, leads the team of seven employees covering the areas of service, sales, administration and process management. “This is another milestone for SMT. With our branch in Suzhou, we can respond quickly and directly to the needs of our Asian customers and the trends in the Asian market”, says Florian Graf, Head of Sales and Marketing at SMT.
The official opening of the branch took place during an event with long-standing customers and employees.

www.smt-wertheim.de/en



Collaboration Helps PCB Designers and Electronic Engineers

SnapEDA recently announced its collaboration with Osram Opto Semiconductors which allows engineers worldwide to quickly and effortlessly integrate Osram’s components in their designs. Osram Opto Semiconductors is releasing its entire collection of photodiodes, phototransistors, laser diodes and infrared emitters on SnapEDA’s website. Traditionally, engineers have spent days creating digital models for each component in their designs. With this collaboration, engineers can now simply drag-and-drop Osram components into their designs, saving days of time and allowing them to focus on what matters most - building high-quality products on schedule. SnapEDA is used by over one million professional engineers. Osram’s products are recognized in the market for their dependability, compact size, robustness, easy integration and excellent price-performance ratio. Osram components include LEDs, Infrared LEDs (IREDs), laser diodes, photodiodes and phototransistors, which are an integral part of everything from automotive lighting, industrial electronics, mobile electronics, general lighting and more. The models can be downloaded for free from SnapEDA’s electronics design library, as well as from websites of Osram’s franchised distributors that support SnapEDA models.



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Dr. Wolfgang Eder Takes Over as Chair of Supervisory Board

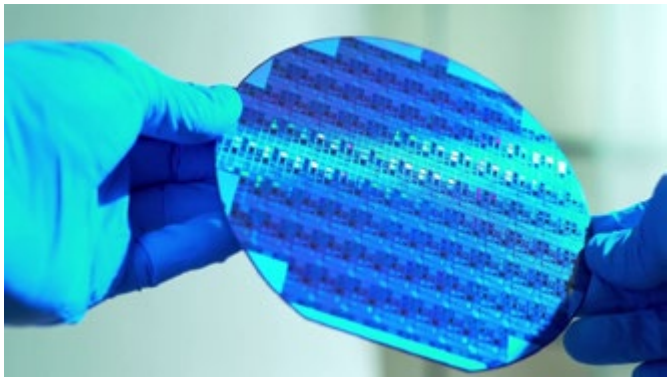


The Supervisory Board of Infineon Technologies elected Dr. Wolfgang Eder (67) as its new Chair. He succeeds Dr. Eckart Sünner (75), who became Chair of the Supervisory Board in February 2018.
Dr. Wolfgang Eder, Chairman of the Infineon Supervisory Board: "Infineon is developing in a highly dynamic manner, systematically expanding its leading position in central future-oriented fields of semiconductor technology. I am extremely pleased to take over as Chair of the Supervisory Board in an environment characterized by such enormous future potentials. At the same time, I would like to thank Reinhard Ploss in the name of the entire Supervisory Board for continuing to lead the company as Chief Executive Officer for the next three years. As CEO, Dr. Ploss has decisively influenced the successful path of Infineon over the past seven years. Both the planned acquisition of the US company Cypress Semiconductor and a wide range of new technological developments will present Infineon with crucial strategic decisions in the future. Dr. Ploss will have a determining impact on these decisions with his strategic vision, his experience and his skilled leadership. I am equally grateful to my predecessor as Chair of the Supervisory Board, Dr. Sünner, who has led the Board through eventful times with a steady and extremely competent hand."

www.infineon.com

Domestic Source of Gallium Nitride Epiwafers

Transphorm announced that the U.S. Department of Defense (DoD) Office of Naval Research (ONR) has exercised a three-year $15.9 million option on an existing $2.6 million base contract with the company. This contract, N68335-19-C-0107, administered by Naval Air Warfare Center Aircraft Division, Lakehurst establishes Transphorm as a U.S.-based dedicated production source and supplier of GaN epiwafers for DoD and Commercial radio frequency (RF)/millimeter wave (mm-wave) and power electronics applications. The award comprises a Base Program for key technology development/transfer and an Option Program to establish production scale capability. The program's core objective is to commercialize nitrogen polar (N-polar) GaN, a breakthrough technology beyond the incumbent Ga-polar GaN. N-polar GaN holds significant promise for the continued advancement of GaN-based electronics, in today's RF electronics and future power conversion systems. The technology, exclusively licensed to Transphorm, was invented under ONR and DARPA sponsorship at the University of California, Santa Barbara (UCSB) by the team of Professor Umesh Mishra, Distinguished Professor at UCSB and Transphorm's Co-founder, CTO and Chairman. "The N-polar orientation of the material is reversed from the traditional Ga-polar GaN

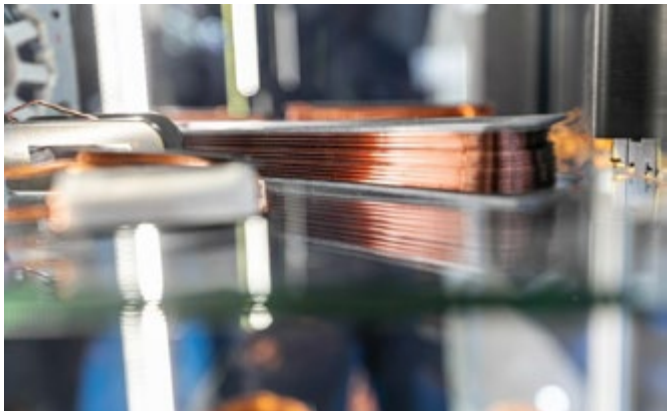


currently being widely used in base station and DoD applications. The flip produces radical benefits in output power along with groundbreaking efficiencies to frequencies as high as 94 GHz," said Dr. Mishra. "Applications span the frequency range of interest for 5G, 6G and beyond and also fill a critical technological void for DoD systems."

www.transphormusa.com

Products, Technologies and Trends in Coil Winding

CWIEME Americas, North America's only dedicated event for the supply chain of coil winding, electric motors, transformers, and generators will take place at DESCC Chicago from September 17-18, 2019. With more than 100 exhibitors from the electrical manufacturing sector, including global leaders such as Broomfield, ELANTAS, Huntsman, Marsilli, Megger, Odawara Automation, Orchid International, and Superior Essex, CWIEME Americas is uniquely positioned to bring together specialized engineers, as well as procurement & business professionals from all over the world to Chicago – in the heart of American manufacturing. With new partners and features in 2019, CWIEME is tailored specifically to meet the needs of industry professionals from the electrical manufacturing industries. The two-day program is designed to deliver pure business value by accelerating business networking and focused conversations; saving time and money and creating new opportunities. To ensure that all attendees obtain the maximum value for their attendance, admission to the CWIEME trade show is free of charge.
Offering unparalleled networking opportunities for industry experts, CWIEME Americas kicks off with an Opening Party at the Hofbräu-

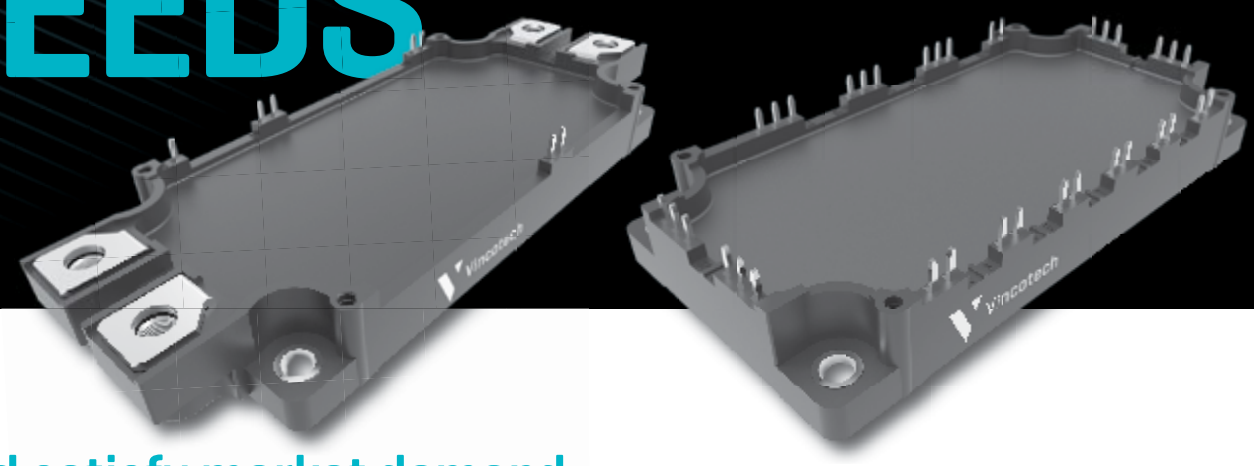


haus Chicago on Monday evening, September 16. The trade show opens to visitors on Tuesday, September 17 and Wednesday, September 18.

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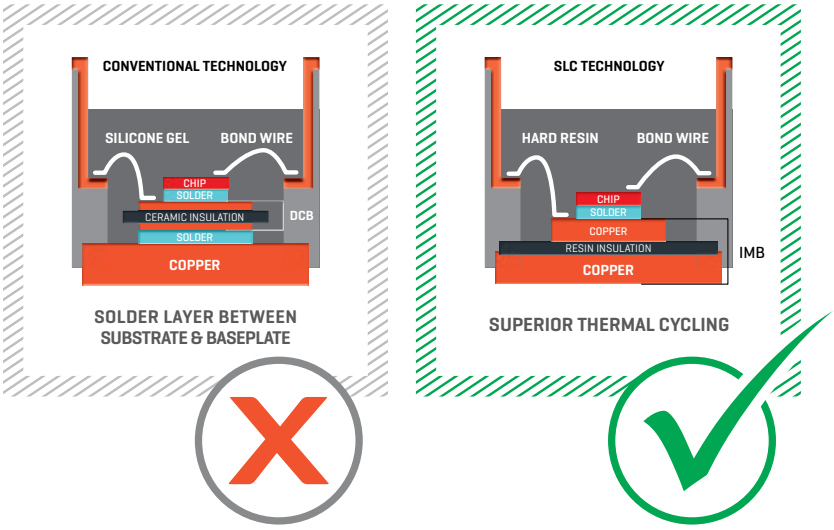
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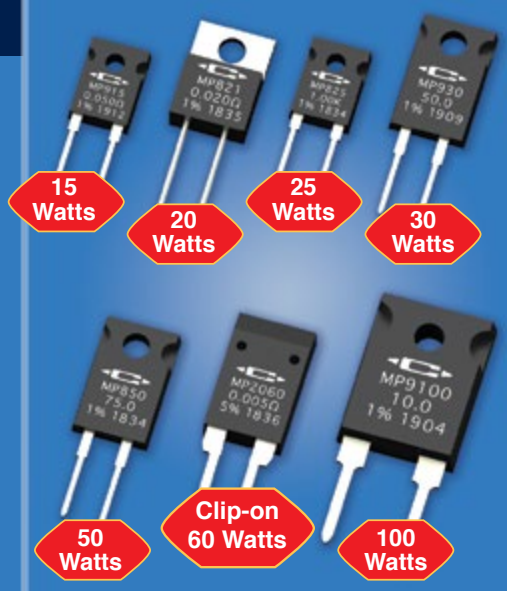


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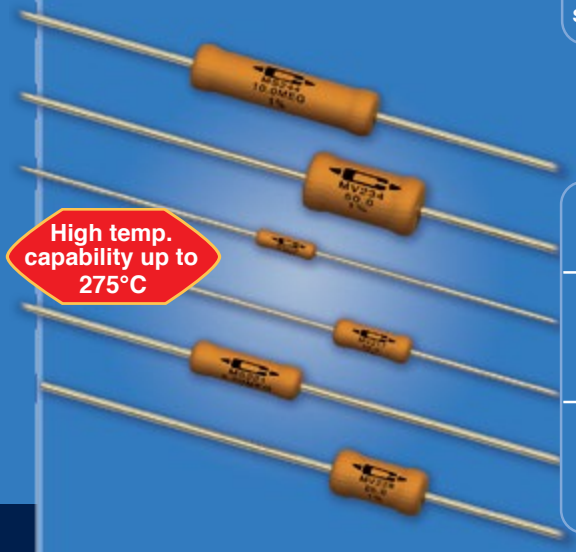
Caddock's Power Film Resistor Technology brings unique power resistor packaging options to the power system designer. The non-inductive designs of these power resistor products provide outstanding low reactance for power switching systems, high frequency circuits and other reactance sensitive applications. s.



Heat Sink Mountable *with Non-Inductive Design*

Power rating is based on a +25°C case temperature. The thermal mounting issues are the same as with power semiconductors.

Resistor Style	Model No.	Power Rating at +25°C Case Temp.	Resistance Range	Comments
TO-126 Style Package	MP915	15 Watts	0.02 Ω to 1K	Low Cost Design Standard Resistance Values
	MP825	25 Watts	0.02 Ω to 10K	Copper Heat Sink Integral in the Molded Package
TO-220 with Metal Mounting Tab	MP820	20 Watts	10 Ω to 10K	Metal Mounting Tab
	MP821	20 Watts	0.02 Ω to 9.99 Ω	Metal Mounting Tab
TO-220 Style Package	MP916	16 Watts	0.01 Ω to 0.019 Ω	Low Cost Design Low Resistance Range
	MP925	25 Watts 500V max.	5K to 100K	Low Cost Design Standard Resistance Range
	MP930	30 Watts	0.02 Ω to 4.99K	Low Cost Design Extended Resistance Range
	MP850	50 Watts	0.2 Ω to 10K	Copper Heat Sink Integral in the Molded Package
TO-220 Style Package	MP2060	60 Watts*	0.005 Ω to 1K	Clip Mount, Values to 0.005Ω *60 amps max. for 0.015Ω and below
TO-247 Style Package	MP9100	100 Watts	0.05 Ω to 100 Ω	Highest Power Rating



Axial Lead - High Power *with Non-Inductive Design*

Power rating is based on +25°C ambient, derated to zero at +275°C.

Resistor Style	Caddock Type	Power Rating	Resistance Range	Comments
Axial Lead	Type MS 18 Models to choose from	0.5 Watt up to 22 Watts	20 Ω up to 30 Meg	These non-inductive resistors are about as inductive as a straight piece of wire the length of the resistor body.
Axial Lead Low Resistance	Type MV 5 Models to choose from	1.5 Watts up to 10 Watts	0.1 Ω up to 20 Ω	Low Resistance with EXTREMELY low inductance. Best price at 5% and 10% tolerance (1% available).

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The Caddock website includes downloadable pdf data sheets for over 250 Models of High Performance Film Resistor Products, Applications Notes, and Environmental Information.

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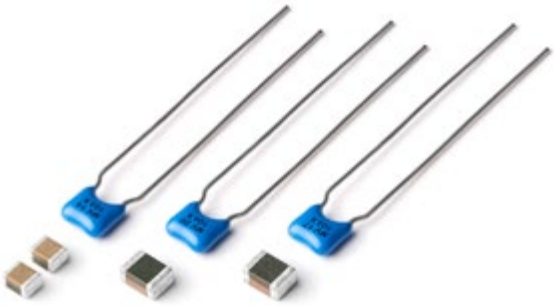
Elements of Indium: Malleability

In celebration of Indium Corporation's 85th anniversary, the company will release monthly installments of the Elements of Indium Series—an educational program to raise awareness of the unique applications, abundance, and interesting properties of the 49th element.

Because of its unique properties with virtually limitless applications, indium metal is literally all around us. Indium is a soft and malleable metal that stretches with the metal it's soldered to. This makes it the perfect solder for joining two metals in order to avoid coefficient of thermal expansion (CTE) mismatch.
CTE mismatch occurs when solder joints containing two different metals expand at different rates. This stress on the solder joint can cause it to crack upon cooling, resulting in the failure of the device.

www.indium.com

Acquiring Circuit Protection Component Company



Bourns, Inc. announced that a member of the Bourns group of companies has acquired all shares of KEKO-Varicon d.o.o. Žužambrek (KEKO-Varicon) from its three shareholders, consisting of two members of the MSIN Group and one minority shareholder. KEKO-Varicon is a leading manufacturer of overvoltage protection products that include varistor and EMI suppression products. Financial terms of the transaction were not disclosed. Along with adding breadth and depth to Bourns' industry-leading overvoltage and overcurrent protection portfolio, KEKO-Varicon brings a strong employee base, superior overvoltage protection technologies, expanded R&D, and production facility assets as part of the acquisition. "The acquisition allows Bourns to gain a significant strategic advantage in the range of protection solutions we can offer our customers, particularly in addressing the strict requirements of the automotive industry," said Erik Meijer, President and COO of Bourns, Inc. "Acquiring KEKO-Varicon further reinforces Bourns' ability to meet both complex technology and on-time delivery needs with an even stronger global organization to deliver the highest quality circuit protection devices."

www.bourns.com

PCIM Europe Conference 2020: Call for Papers Launched

The PCIM Europe Conference 2020 will once again be opening up the stage to experts to present their latest research findings and developments. The qualified audience attending the Conference can annually benefit from a lecture or poster presentation. Experts are invited to submit their abstracts by 15 October 2019. The conference topics include recent developments on power semiconductors, passive components and energy storage. In addition, the topic "Packaging and Interconnection Materials" will be addressed at PCIM Europe Conference. The event will take place in Nuremberg from 5 – 7 May 2020.



https://mesago.de/PCIM2020

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We invented the MANGANIN® resistance alloy 125 years ago. To this day, we produce the MANGANIN® used in our resistors by ourselves.

More than 20 years ago, we patented the use of electron-beam welding for the production of resistors, laying the foundation for the ISA-WELD® manufacturing technology (composite material of Cu-MANGANIN®-Cu). We were the first to use this method to manufacture resistors. And for a long time, we were the only ones, too.

Today, we have a wealth of expertise based on countless projects on behalf of our customers. The automotive industry's high standards were the driving force behind the continuous advancement of our BVx resistors.
For years, we have also been leveraging this experience to develop successful industrial applications.

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sales.components@isabellenhuette.de · www.isabellenhuette.de

Sponsored Formula E Team Caps Exhilarating Season

Mouser Electronics celebrates the GEOX DRAGON Formula E racing team on their tenacity and grit over a formidable racing season. Driving the Mouser-sponsored car this year were three-time FIA WTCC drivers' champion José María López and former test and reserve driver Maximilian Günther.

Just over halfway through the season, Günther nabbed a fifth-place finish on a rain-slicked track at the Paris E-Prix. In the next race, at Monaco, López earned a hard-fought top-10 finish plus one of the race's coveted FANBOOST slots — where fans vote for their favorite driver to award them a significant, five-second burst of power. Two races later, Günther put up an impressive Super Pole run after qualifications in Bern and expertly powered the No. 6 electric racecar to another fifth place finish after scraping through trouble early in the race. This was the fifth season of the ABB FIA Formula E Championship and the fifth season Mouser Electronics was a team sponsor along with valued supplier Molex. Mouser and Molex sponsored the team throughout the season in collaboration with AVX and TTI, Inc.

"López, Günther, and the entire team showed great determination in a very demanding season," said Todd McAtee, Vice President, Americas' Business Development for Mouser Electronics. "Everyone here at



Mouser is proud of the team and their awesome top-10 finishes, and we're excited to be a part of the electric car racing revolution and the GEOX DRAGON racing team."

https://eu.mouser.com

Acquisition of Graphite Production Capacity

Mersen has announced the acquisition of assets in the graphite business of the former Graftech site in Columbia (Tennessee). Luc Themelin, Mersen's Chief Executive Officer, said: "Given today's particularly buoyant market, our goal at Mersen was to find a solution that would give us the additional graphite production capacity we need to satisfy market demand from 2020 and beyond. This acquisition is an excellent opportunity to fulfil several objectives: limited initial investment despite the quality of the assets, a gradual ramp-up in line with market dynamics, and additional capacity to give us a new competitive advantage on certain materials that the Group currently purchases from outside suppliers."

The operation concerns the acquisition of land, buildings and equipment for a total of USD 7 million and coupled with additional, modular investment, will enable the Group to meet several strategic goals over time. The Group could invest between €25 million and €35 million over the next three to five years to ensure the optimal commissioning of the facilities that will give it an additional production capacity of between 2,000 and 4,000 tons per year for each isostatic and extruded graphite specialties segments. These investments will start in 2019, for an estimated amount of €5 million.

www.mersen.us

Joint Venture for Lithium-Ion Batteries

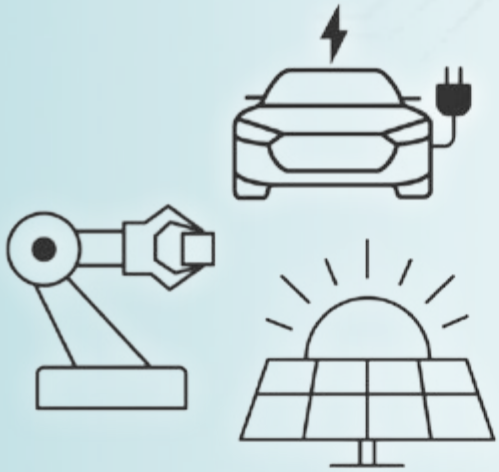
BMZ Holding will join forces with KION GROUP to form a joint venture under the name of KION Battery Systems GmbH. This joint venture will manufacture lithium-ion batteries for industrial trucks in the EMEA region. The two companies now signed an agreement to this effect. BMZ Holding GmbH and KION GROUP AG will each hold a 50 percent stake in the joint venture (JV). The objective of the JV is to broaden the lithium-ion product offering and to increase production capacity to best serve the rapidly growing demand for lithium-ion battery systems in the intralogistics market. The production facility for the joint venture is built by BMZ Holding GmbH in Karlstein am Main, the headquarters of the BMZ Group. By 2023, the workforce of the JV is expected to grow to around 80 employees working in mainly research, development and production functions. Both BMZ and KION have world-leading know-how in the field of lithium-ion technology. Initially, the JV will focus on the production of 48-volt and 80-volt batteries for counterbalance trucks. Soon, the offering will be expanded to 24-volt batteries for smaller warehouse trucks. The transaction still needs to be approved by the competent antitrust regulator.



https://bmz-group.com

Advanced protection and greater efficiency for high-voltage systems

Texas Instruments





First isolated gate drivers with integrated sensing for IGBTs and SiC MOSFETs save energy and protect high-voltage systems.

http://www.ti.com/product/UCC21750

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Saving Costs with Solution for Power Modules

Sempro Technologies has Created a Powerful Solution for Semiconductor Manufacturing which has the Lowest Costs of Ownership.



The Power X1 was created for customers who want to automate the trim & form processes for their power modules (IGBT modules) and who would like to speed up the process. The Power X1 is a system which produces more than 700 single products per hour.

Our customers have 100% quality check of the product, by machine vision and 3D-scanning. The advantage of a 3D-scanner is that it can accurately measure a wide range of products, thanks to its big depth of focus. This saves not only costs but also time and guarantees quality of the product.

The Power X1 has a unique modular design with high simplicity. The system can be configured to customer preferences, e.g.: the number of press modules, the option for laser marking, the way of loading and unloading of products. Default is loading of lead frames in slotted magazines and unloading of the finished products in trays. A SCARA robot in the output module makes the Power X1 suitable for different products and trays. The magazine handler can be adjusted to a wide range of magazine sizes.

The press unit is very user friendly – only 15 minutes are needed to change a tool. All of the tools can be automatically wide-opened to get good access for maintenance and inspection.This feature reduces downtime of the machine. The machine can be operated by one person and has a standalone time of one hour.

Specifications of the machine:
- Machine Speed: 720 UPH
- MTBA: 1 hour
- Trim accuracy: ±0,1 mm
- Form accuracy: ±0,5°
- Measurement accuracy: 0,05 mm
- SECS/GEM (OPTIONAL)
- Shape inspection by 3D-scanner (OPTIONAL)
- Discoloration by 2D-camera (OPTIONAL)

The Power X1 was designed for the lowest costs of ownership for our customers. Costs of machine, tools and spares are also relatively low thanks to our production facilities in Sempro Malaysia.

Sempro Technologies is the lean organization which is bringing innovation, flexibility in design, reliability and low cost of ownership. Thanks to our team we are the leading partner on the power and sensor market.

Sempro Technologies: We make ideas a reality.

Get in touch with us: info@sempro.nl

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ABB Semiconductors has a long history in providing the market with the most rugged and highest reliable products. Our new medium power products build on this heritage. The LoPak design features excellent internal current sharing for optimal chip usage and 175 °C operation temperature, giving a healthy margin to cope with overload situations. Additionally the module features copper bond-wire interconnects that reduce resistive losses compared to the classical approach with aluminium wires. The LoPak1 phase leg IGBT module is available in 1700 V with current ratings of 2 x 225 A, 2 x 300 A and 2 x 450 A, respectively.
abb.com/semiconductors

Gallium Nitride-Based AC-DC Converter ICs

Advanced GaN Technology Yields Significant Increase in Power and Efficiency



Power Integrations announced new members of its InnoSwitch™3 families of offline CV/CC flyback switcher ICs. The ICs feature up to 95% efficiency across the full load range and up to 100 W in enclosed adapter implementations without requiring a heatsink. This groundbreaking increase in performance is achieved using an internally developed high-voltage GaN switch technology.

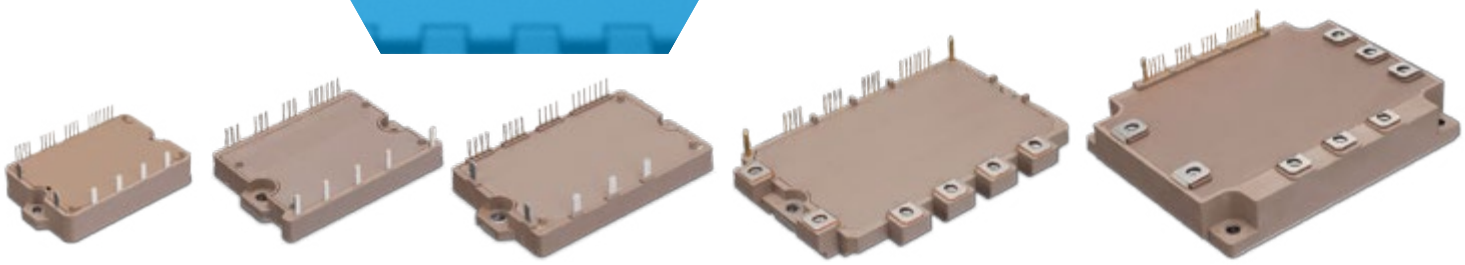
Quasi-resonant InnoSwitch3-CP, InnoSwitch3-EP and InnoSwitch3-Pro ICs combine primary, secondary and feedback circuits in a single surface-mounted package. In the newly released family members, GaN switches replace the traditional silicon high-voltage transistors on the primary side of the IC, reducing conduction losses when current is flowing, and considerably reducing switching losses during operation. This results in substantially less wasted energy and therefore increased efficiency and power delivery from the space-saving InSOP-24D package.

Targeting high-efficiency flyback designs, such as USB-PD and high-current chargers/adapters for mobile devices, set-top boxes, displays, appliances, networking and gaming products, the ICs provide accurate CV/CC/CP independent of external components, and easily interface to fast-charging protocol ICs. The InnoSwitch3-CP and EP variants are hardware-configurable, while the InnoSwitch3-Pro incorporates a sophisticated digital interface for software control of CV and CC setpoints, exception handing and safety-mode options.

Comments Balu Balakrishnan, president and CEO of Power Integrations: “GaN is a pivotal technology offering significant efficiency and size benefits over silicon. We anticipate a rapid conversion from silicon transistors to GaN in many power applications. InnoSwitch3 has been the clear technology leader in the offline switcher IC market since we launched the silicon variants 18 months ago, and the new GaN-based ICs further extend our lead by advancing both the efficiency and power capability of our flyback products.” Five new reference designs describing USB-PD chargers from 60 W to 100 W are available on the Power Integrations website, along with an automated design tool, PI Expert™, and other technical support documentation.

www.power.com





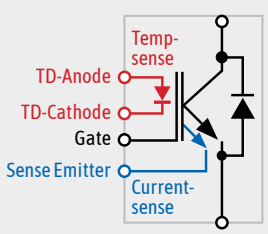
Intelligent Power Modules (IPM)

with Fuji Electric's VR "on chip sensing" IGBT

FEATURES

- VR IGBT-Chip with on chip T_j and current sensing
- 600 V and 1200 V / 10 A to 400 A
- Embedded driver, control and protection functions
- 1 wire provides 3 alarms: over-current, over-heating and under-voltage
- Temperature sensor analog output
- Dead time down to 1 µs (low distorsion)
- 6 in 1 and 7 in 1 topology (full inverter + brake)
- Suited for industrial application

Sensing



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

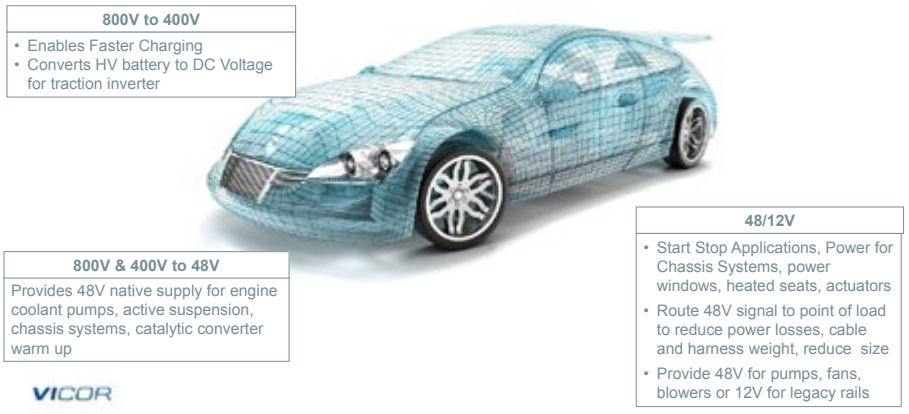
Fuji Electric
Innovating Energy Technology

Disrupting Conventional Electrical Power within Automotive

During a press conference in Munich, Patrick Wadden, Global VP of Automotive Business Development, and Robert Gendron, P.E., Corporate VP, Product Marketing & Technical Resources, presented the company and especially its activities and achievements in the automotive sector, predominantly addressing the car of the future.

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

Vicor operates two world class manufacturing facilities in Massachusetts, is exclusively focused on power conversion and vertically integrated: from silicon to system. It sells its products to the power systems market, including enterprise and high-performance computing (HPC), industrial equipment and automation, telecommunications and network infrastructure, vehicles and transportation, aerospace and defence.



Rail, military, satellites, drones, industrial are all pushing for more power, Vicor is supporting the power needs of today, covering

- HPC and Cloud AI deployment,
- Migration to the IoT enabler => 5G communication,
- More and more information being conveyed through LED Lighting
- Increasing electrification of autos (EV, hybrid, autonomous, combustion).

Within this scope, Vicor is going the extra mile, reducing weight and size. Eight out of the largest 13 automotive OEMs (making up 98% of the cars produced each year) are expected to face enormous fines in 2021 for exceeding CO2 Emission Standards, some will see fines as high as 10-20% of annual revenues (or in VW's case as high as 1.6 B€). As CO2 goals drive major architecture changes for reduced weight and size, Vicor products help OEMs reduce CO2 emissions or extend drive distance with EV vehicles, making vehicles better.

In manufacturing Vicor offers military grade processing and quality, PPAP, highly automated, computer-integrated, and scalable, supporting high volume datacenter and computing. Moreover ISO 9001:2015 qualification and certification, IATF 16949 quality management systems, certification in process, as well as complete environmental reliability testing (AECQ100) for integrated circuits available, IPC-A-610 Class 2 & 3 certification, GMW3172GM environmental/durability testing specification for electrical/electronic components and power Modules. Functional safety ISO26262 is in review.

Each device is serialized for product traceability

Its "Automotive Center of Excellence" qualifies Vicor as a world class military supplier with world class quality and reliability, narrow gap to close on ISO/TS16949 certification in Q42019. Credentials include ISO9001:2015, where product traceability for automotive – each device is serialized. The Automotive Quality Supplier Manager started March 4, 2019. Further accomplishments and goals:

- Automotive qualified modules to GM3172 environmental and durability testing, targeting Q22019 (PowerStrip and NBM)
- Currently engaged with (4) L5 autonomous vehicle customers with 3.6KW PowerStrip development system, 8-10 pending
- Currently performing PPAP, FMEA/DFMEA with associated control plans
- Manufacturing process flow and continuous quality improvements, CPK limit and test limit enhancements through six sigma training for 35 employees
- Automotive programs with OEM's/tier-ones, SOP expectations estimated in 2023.

In addition, the company is on its way to a wide transformation to a zero defects (ZD) mindset.

The Rise of Electrical Complexity on Wheels

To meet the challenges through rising complexity, especially in the EVs of tomorrow, Vicor offers a broad range of corresponding converters, which are essential for the following reasons:

800V to 400V

- Enables faster charging
- Converts HV battery to DC voltage for traction inverter

800V & 400V to 48V

Provides 48V native supply for engine coolant pumps, active suspension, chassis systems, catalytic converter warm up

48/12V

- Start Stop applications, power for chassis systems, power windows, heated seats, actuators
- Route 48V signal to point of load to reduce power losses, cable and harness weight, reduce size
- Provide 48V for pumps, fans, blowers or 12V for legacy rails.

New bus converter module

The 800V BCM4414 is a 1.6kW, isolated, 1/16 fixed-ratio, bus converter module (BCM), that can operate from a 500V to 800V input voltage, to deliver SELV output voltages with 97.7% peak efficiency. The new 800V module complements the existing Vicor 700V BCM4414, to create a family of products with reinforced isolation (4,242VDC) and bidirectional voltage conversion capability.

The BCM can easily be paralleled into higher power arrays and the SELV outputs can be stacked (connected in series) for higher output voltages. Both BCMs are available in a 111 x 36 x 9.3mm VIA (Vicor Integrated Adapter) package which has integrated PMBus communication, EMI filtering, and voltage-transient protection. The VIA's planar form factor package simplifies heat management and ease of interface to a wide variety of cooling technologies.

The BCMs are available in either M grade (-55 to 100°C) or T grade (-40 to 100˚C).

High-Voltage BCM family

This high-voltage BCM family addresses the need for increased density and performance in Industrial and Military 3-phase AC power supplies and in high-voltage DC transmission systems for tethered unmanned vehicles.

Advanced cooling technique

At Embedded World Exhibition and Conference in Nuremberg earlier this year, Vicor in partnership with Future Electronics demonstrated the benefits of an advanced data center cooling technique, liquid immersion cooling with 48V components. High-performance computing applications create excessive heat and while conventional air cooling is an option, greater system efficiency is delivered using advanced cooling techniques like liquid immersion cooling. Some of the most advanced processors to date operate in immersion cooling, mitigating the thermal limitations of traditional air-cooled systems.

Summary

Vicor addresses the power challenges of the future car, of ADAS and EV, including autonomous cars on every level. Vicor´s modular approach to power provides self-produced converters with a high level of integration, advanced switching topologies and thermally adept packaging. Modular power replaces larger, heavier discrete solutions that are present in so many vehicles today. They enable a HEV, EV, and ADAS to be lighter, faster, and/or travel farther.

www.vicorpower.com



The Next Generation of SiC Power Modules

Since years, Mitsubishi Electric is well-known for its high-current SiC Power Modules, available in different voltage classes. For 1200 V and 1700 V, the second generation SiC Power Modules is released now. Compared to the first generation, the performance has been improved and a wider line-up will be available. As one promising technology for 3300 V and 6500 V SiC Power Modules, Mitsubishi Electric is embedding the Schottky diode into the MOSFET chip. For this cutting-edge technology, latest research results are presented.

By Nils Soltau and Eckhard Thal, Mitsubishi Electric Europe B.V., Ratingen, Germany and Toru Matsuoka, Mitsubishi Electric Corporation, Fukuoka, Japan

Introduction

The use of silicon carbide (SiC) is the one big evolutionary step in modern power electronics. Due to the physical properties, power electronics made of SiC are more powerful and more efficient compared to classical silicon materials. Mitsubishi Electric has started the development of SiC power semiconductors already in the early 1990s. Over the past decade, Mitsubishi commercialized many SiC devices for various voltage and current ratings putting special focus on large SiC-chips and high current SiC-modules. In several applications, such as elevators, uninterruptable power supplies, photovoltaics or railway, the use of Mitsubishi high power SiC-modules allows outstanding system performances and power densities.

This article presents the latest information of Mitsubishi's research and development in the field of SiC Power Modules. For the 1200 V and 1700 V class, the 2nd generation is introduced. The technical innovations as well as the performance increase compared to the previous generation is discussed.

For higher voltage ratings, one of today's challenges of SiC-MOSFETs is the degradation of the body diode. An answer to this problem is the use of a Schottky Barrier Diode (SBD) anti-parallel to the SiC MOSFET. The Mitsubishi specific approach is integrating the SBD into the MOSFET chip. This approach allows significant increase in power density of high-voltage SiC devices. The details are explained for a 3300 V and 6500 V device in the final chapter.

Second Generation 6-inch SiC Modules

In the following, Mitsubishi's 2nd generation of 4H-SiC MOSFETs rated for 1200 V and 1700 V are introduced (see [1] for information on 600 V SiC MOSFETs). The 2nd generation 1200 V SiC MOSFETs, as shown in Figure 1, manufactured on the newly developed 6-inch SiC wafer line, feature an optimized p-well, a cell-pitch shrinkage and an optimized channel-doping profile as illustrated in Figure 2 [2]. This results in an improved gate-oxide reliability and a reduction of the conduction loss. Figure 4 shows the specific resistance $R_{on,sp}$ at room temperature of 1st and 2nd generation 1200 V MOSFET chips rated for 100 A/cm². Consequently, the resistance decreases by 33% from 4.5 mΩ·cm² to 3.0 mΩ·cm² by the optimized cell structure.

When the cell pitch is decreased, the JFET region becomes narrower as well. If the JFET width becomes too narrow, it will become a bottle neck and the on-state resistance will increase. By special doping of the JFET region, however, Mitsubishi solved this problem. Figure 3 shows how the on-state resistance is reduced by an optimized JFET doping. With the optimized JFET doping, these cutting-edge planar MOSFETs are able to compete against today's trench structures as illustrated in Figure 6. At the same time, the planar structure has lower complexity compared to a trench gate structure.

The switching performance of the 2nd generation has been improved as well. The reverse transfer capacitance (or Miller capacitance) has become smaller. This allows faster switching speeds. As shown in Figure 5, turn-on and turn-off losses reduce by 23% and 37% respectively compared to the previous generation.



Figure 1: 2nd generation 1,200V Full-SiC module with RTC short-circuit protection

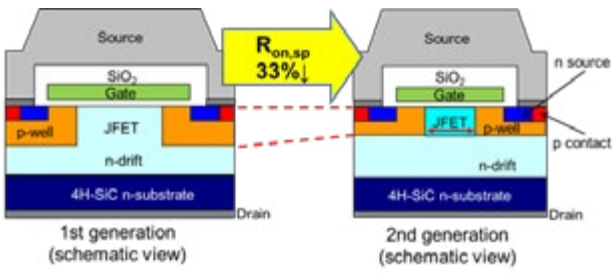


Figure 2: Cross section of a 1st and 2nd generation SiC MOSFET chip

Also for the 1700 V SiC MOSFETs, cell-pitch shrinkage and the optimized doping profile is applied. Reference [3] demonstrates the performance of these large-current chips packaged in a 300 A half-bridge module. Correspondingly, a $V_{DS(on)}$ of 2.75 V at 300A drain current and 150 °C junction temperature is achieved. The turn-on and turn-off energies at 300 A and 150 °C are 12.0 mJ and 3.0 mJ respectively (at R_g = 1.6 mΩ). These conduction and switching performances are among the best ever reported.

short-circuit current magnitude. Therefore, the energy dissipated in the SiC-MOSFET during SC-mode is reduced. This means the user can design his gate driver and his gate conditions without requiring too fast SC-precautions. The RTC gives effective protection against short circuit and has been well accepted already for 1st gen SiC modules. Consequently, Mitsubishi Electric will provide the RTC feature for the complete lineup of the 2nd generation from 300 A to 1200 A as summarized in Table 1.

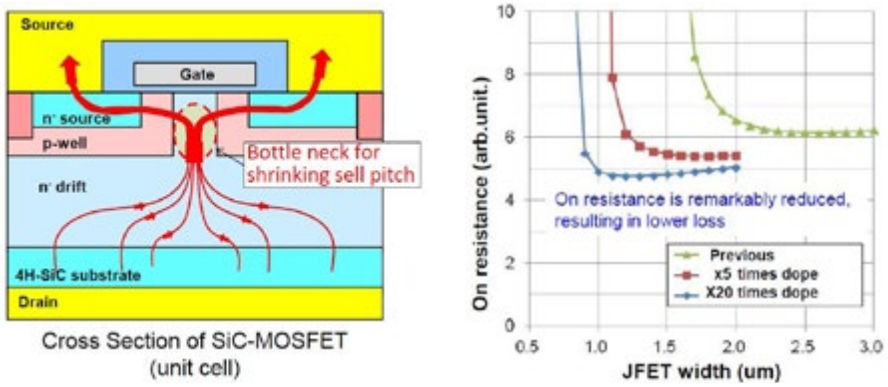


Figure 3: Impact of JFET doping on the on-state resistance

Usually, we have to trade the lower $R_{DS(on)}$ off against short-circuit capability. Moreover, short-circuit protection is challenging for SiC in general. Therefore, Mitsubishi Electric has developed, already for the 1st SiC generation, the Real-Time Control (RTC) [4]. It allows inherent and fast short-protection of SiC modules. Figure 7 and Figure 8 show the principle schematic of the RTC and the waveforms during a short circuit respectively. If the RTC detects a short circuit, it will automatically reduce the gate voltage to limit the

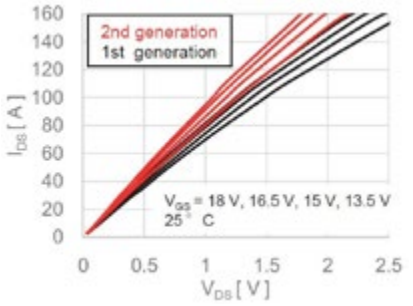


Figure 4: Typical output characteristic of 1st and 2nd generation 1200 V SiC MOSFETs [2]

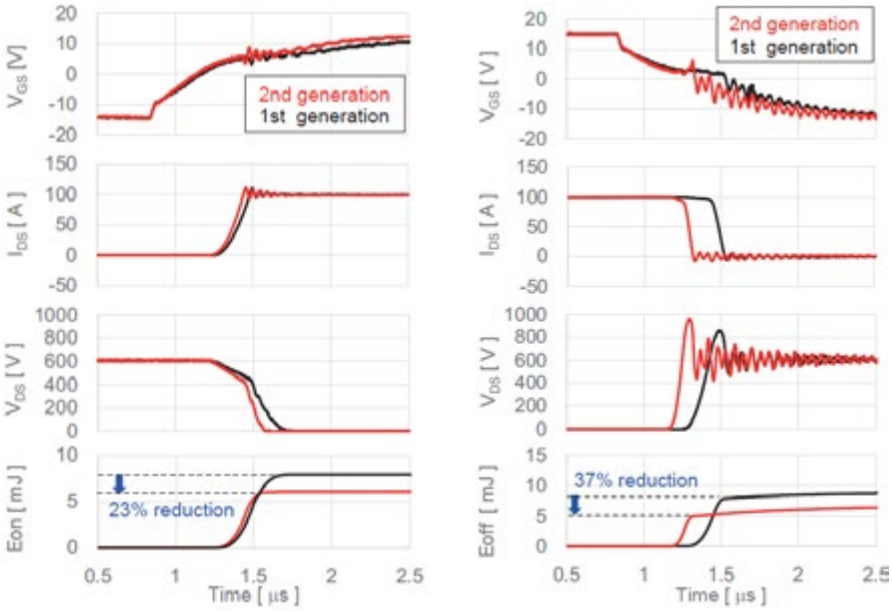


Figure 5: Switching waveforms of 1st and 2nd generation 1200 V SiC MOSFETs (left: turn-on, right: turn-off) [2]

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• Delta Connected
• UL Material
• Dry Type


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• AC/-Pulse-Application
• Oil Impregnated

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SiC Modules for High-Voltage Applications

A well-known and widely discussed degradation mechanism in SiC semiconductor material is the so-called bipolar degradation (BPD) (cf. Figure 10). Today we know that a bipolar current through the internal body diode of the SiC-MOSFET may cause a dislocation of the SiC lattice. This dislocation can be the reason for an irreversible degradation mechanism [5] [6].

Mitsubishi's strategy to prevent BPD is the connection of a SiC Schottky barrier diode (SBD) in parallel to the MOSFET's body diode.

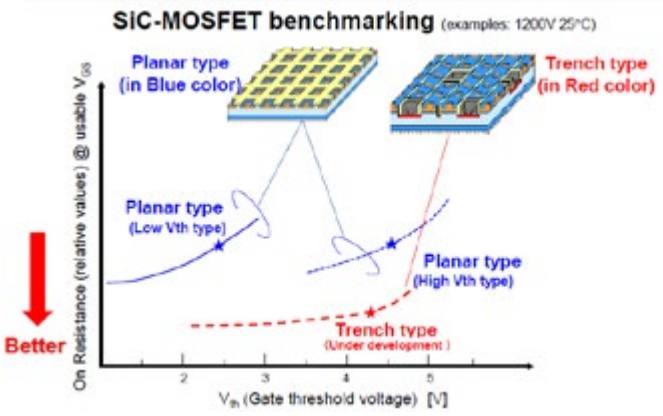


Figure 6: Resistance comparison of different planar and trench type 1200V SiC MOSFETs

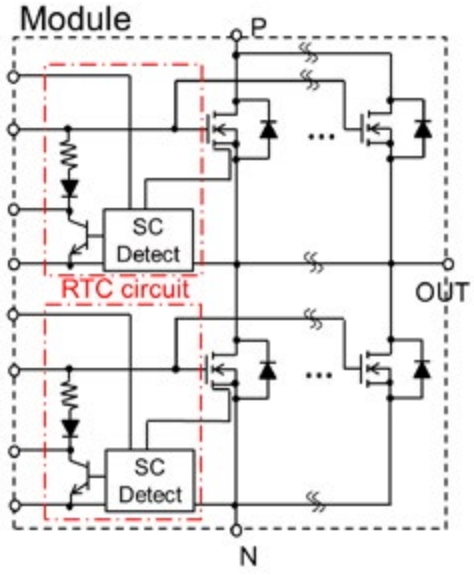


Figure 7: Schematic of Real Time Control (RTC) for inherent short-circuit protection

	1200 V		1700V	
	without RTC	with RTC	without RTC	with RTC
300 A	-	4-in-1	-	2-in-1
400 A	4-in-1	4-in-1	-	-
600 A	-	2-in-1	-	-
800 A	2-in-1	2-in-1	-	-
1200 A	-	2-in-1	-	-

* 2-in-1: half-bridge module
4-in-1: full-bridge module

Table 1: Planned line up 2nd generation SiC

When the voltage drop of the SBD is small enough, the SBD will take over the current and will prevent bipolar current flow through the body diode. In 4 years of field-experience with a 3300 V Full-SiC device, the ruggedness against BPD has been proven using this method.

The SBD chip area to prevent bipolar current dependents on the device voltage. For a 3300 V device, the SBD chip area in relation to the MOSFET are is 1.3-times. For a 6500 V device, however, it is already 3-times. Since this would lead to a poor utilization of chip mounting area in the power modules, Mitsubishi investigates more advanced strategies for high-voltage devices.

Embedding the SBD into the MOSFET chip is a promising approach, which has been demonstrated for a 6500 V SiC-MOSFET already [7] [8]. As illustrated in Figure 11, the new SBD-embedded MOSFET structure results in smaller total chip area, thus allowing enhanced density of the power module.

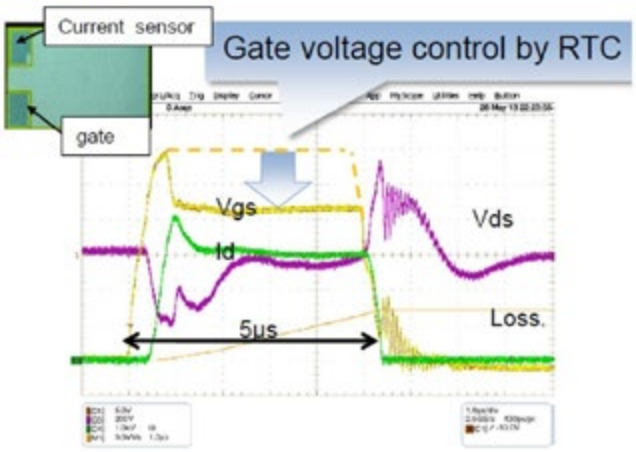


Figure 8: RTC operation during short circuit

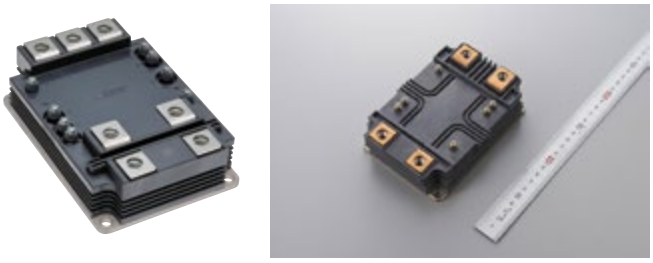


Figure 9: 3.3 kV and 6.5 kV Full-SiC modules for high-voltage applications in the LV100 (left) and HV100 (right) package

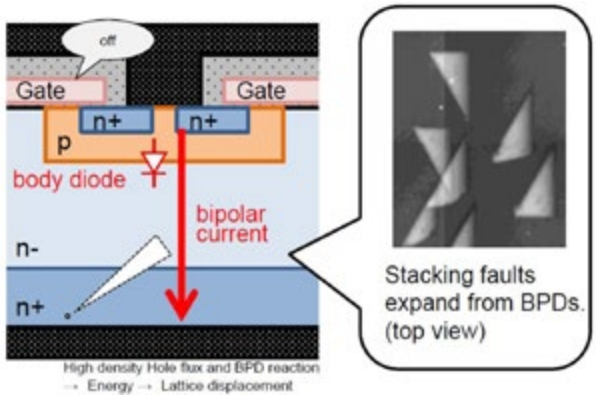


Figure 10: Illustration and picture of bipolar degradation (BPD) due to stacking faults

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Furthermore, embedding the SBD, leads to superior switching characteristics as demonstrated in [9] for a 3300 V device. Figure 12 shows the switching waveforms for the SBD-embedded MOSFET (A – blue), MOSFET with external SBD diodes (B_4 – green) and, for comparison, solely the MOSFET without diode (C – red). Consequently, the SBD-embedded MOSFET has the lowest switching losses, because the total charge Q_{tot} is the smallest of all devices. As a result, the losses during MOSFET turn-on are reduced by 20% compared to the external SBD diode. Moreover, compared to the MOSFET without SBD, the SBD-embedded device is free from bipolar degradation and has superior power density.

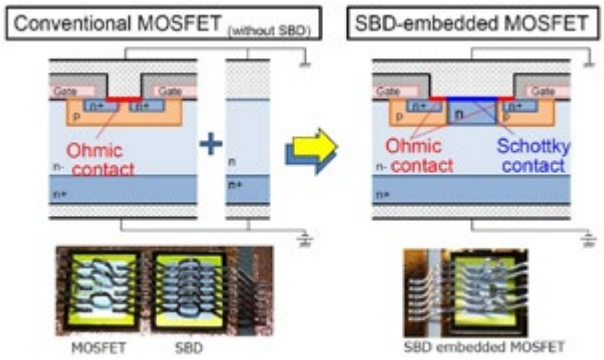


Figure 11: Comparison between conventional MOSFET and SBD-embedded MOSFET

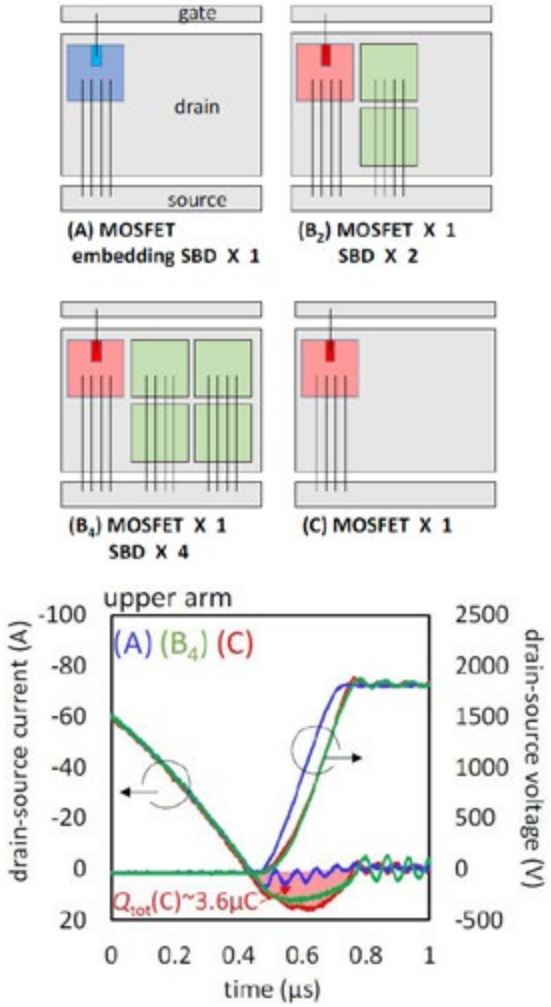


Figure 12: Chip layout and diode turn-off waveform of the SBD-embedded (A), external SBD diode (B_4) and without SBD diode (C) [9]

Conclusion

Converters utilizing SiC power modules are the next big step in modern power electronics. They enable best-in-class power densities and highest efficiencies. In all voltage classes, Mitsubishi Electric offers SiC Power Modules with high current ratings, which are required for high-power converters. Now, Mitsubishi launches the second generation of 1200 V and 1700 V SiC Modules. The performance of these devices has been increased further and, utilizing the RTC technology, they are protected against short-circuits. For 3300 V and 6500 V, the development of MOSFET chips with integrated SBD diode enables Power Modules with high power densities.

After starting the development of SiC devices in the 1990s, Mitsubishi Electric today offers a large SiC line-up from 1200V to 3300V. Module with even higher voltages are under development.

Acknowledgement

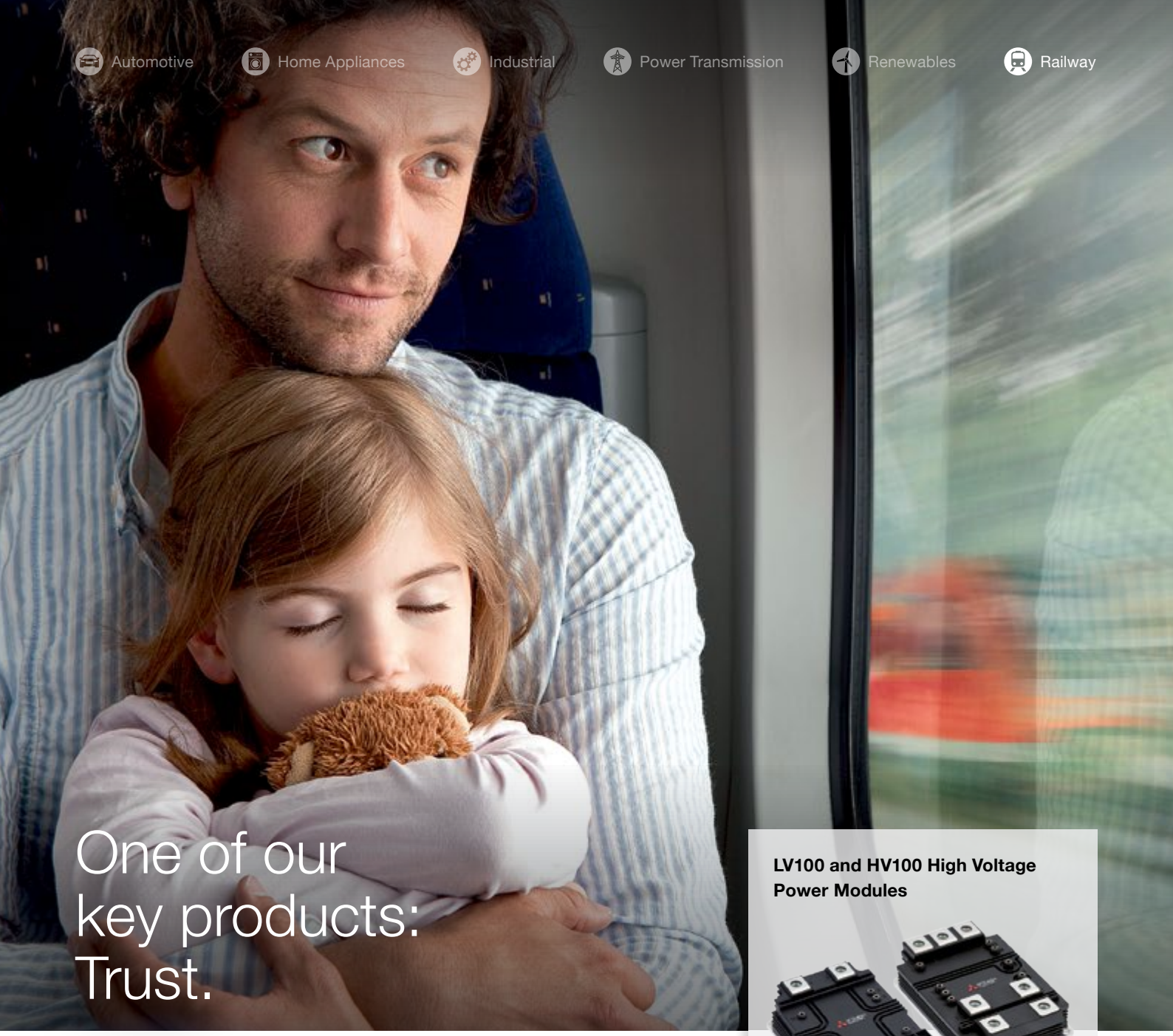
This work is partially supported by New Energy Industrial Technology Development Organization (NEDO).

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The Simplicity of Driving CoolSiC™ MOSFETs: A Gate Driving Design Guide

Parasitic turn-on caused by the Miller capacitance is often considered a weak spot of today's silicon carbide MOSFETs. In order to avoid that effect, gate-drive designs for hard-switching converters are typically implemented with negative turn-off gate voltages. However, is that really needed with CoolSiC™ MOSFETs?

By Klaus Sobe, Infineon Technologies

Introduction

A key element of all gate-drive designs is the selection of the gate-voltage levels. With the CoolSiC MOSFET technology, Infineon allows designers to choose a turn-on gate voltage between 18 V and 15 V, and thus configure the switch for highest current-carrying capability or short-circuit ruggedness, respectively. The turn-off gate voltage level, on the other hand, only needs to ensure that the device remains safely turned off. Infineon encourages designers to operate its discrete MOSFETs at 0 V and benefit from a simplification of the gate-drive circuit.

In order to underline that encouragement, this article introduces an easily reproducible approach to characterize the susceptibility of silicon carbide MOSFETs, and presents tests results obtained with discrete CoolSiC™ MOSFETs.

Parasitic turn-on effect

An unwanted turn-on of a semiconductor switch can be caused by inductive as well as capacitive feedback to the gate. In conjunction with silicon carbide MOSFETs, however, it is typically the capacitive feedback via the Miller capacitance that is considered. A scenario explaining this effect is shown in figure 1. The body diode of the low-side switch S_2 conducts the load current IL until the high-side switch S_1 turns on. After the load current has commutated to S_1, the drain-source voltage of S_2 starts to increase. During this phase, the rising drain potential pulls up the gate voltage of S_2 via the Miller capacitance C_{GD}. The turn-off gate resistor tries to counteract and pull the voltage down. If this resistor value is not low enough to pull the voltage down, the voltage might exceed the threshold level, leading to a shoot-through and an increase of switching losses.

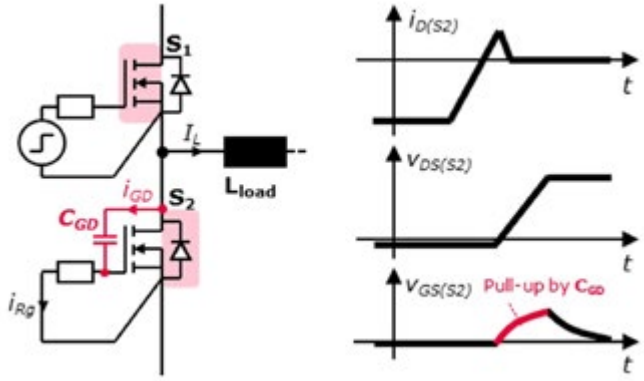


Figure 1: Impact of the Miller capacitance C_{GD} during the turn-off of the body diode.

Naturally, the risk and severity of shoot-through events depend on the particular operation conditions and the measurement hardware. The most critical operating points are at high bus voltages, steep voltage rises and high junction temperatures. These conditions not only lead to a stronger pull-up of the gate voltage, but also lower the threshold level. On the hardware side, the major factors of influence are the undesirable parasitic board capacitance parallel to C_{GD}, an external capacitor parallel to C_{GS}, the turn-off gate voltage as well as the turn-off gate resistor.

Characterization setup and approach

Designers often study the gate-charge curve of a specific semiconductor switch in order to get an impression of its susceptibility to parasitic turn-on. While this approach is rather straightforward – a brief look into the data sheet is sufficient – it does not really enable conclusions to be drawn for the application. The main shortcoming is that the gate-charge characteristic is rather static in nature, while the parasitic turn-on is clearly a dynamic effect. Hence, dedicated characterization tests are performed to assess the parasitic turn-on behavior of 1200 V/45 mΩ CoolSiC MOSFETs in TO-247 3-pin and 4-pin packages under application conditions. All tests are conducted with a turn-off gate voltage of 0 V.

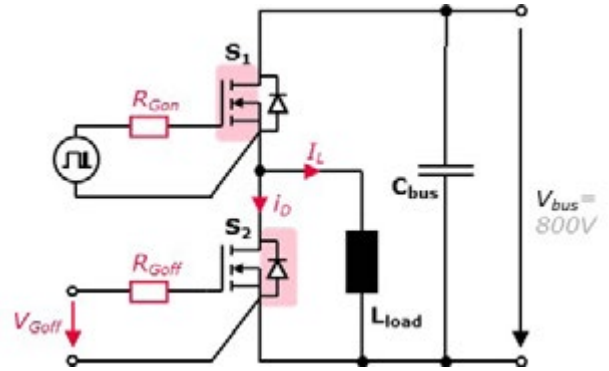


Figure 2: Hardware setup for the characterization: the high-side switch S_1 acts as "dv/dt generator", the low-side switch S_2 is the device under test. The aim of the test is to find the maximum turn-off gate resistance for S_2 that still avoids parasitic turn-on.

A half-bridge evaluation board is configured as depicted in the schematic drawing of figure 2. It is essentially a commutation cell where the low-side switch is the device under test and the high-side switch acts as dv/dt generator. When the high-side device turns on, the rising drain-source voltage on the low-side device leads to a gate voltage

the dv_{DS}/dt, and the lower the turn-off gate resistance, the lower is the chance of a parasitic turn-on. The goal of the experiment is to identify the critical turn-off gate resistance values for a given test case. This so-called critical gate resistance is the value that causes a Q^*_{rr} increase of 10 percent compared to the reference waveform obtained with 0 Ω. A threshold level of 10 percent is large enough to get reliable measurement data, but small enough to be considered negligible in most applications, cf. figure 3.

Tests are carried out at different temperatures, different load currents and different voltage slopes. The latter are adjusted using the R_{Gon} of the high-side switch S_1.

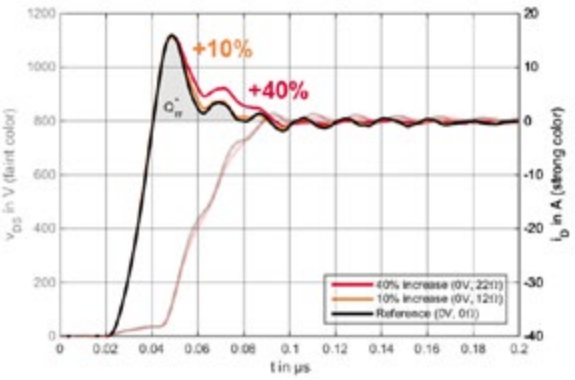


Figure 3: Example waveforms obtained with a 1200 V/45 mΩ CoolSiC MOSFET operated at 100°C and with different values for R_{Goff}. Compared to the reference waveform (black; 0 Ω), Q^*_{rr} of the other waveforms are increased by 10 (orange; 12 Ω) and 40 percent (red; 22 Ω). The symbol Q^*_{rr} denotes a sum of three charges: (1) the reverse recovery charge of the body diode, (2) the capacitive charge of the semiconductors, the layout and the passives, and (3) the contribution coming from parasitic turn-on.

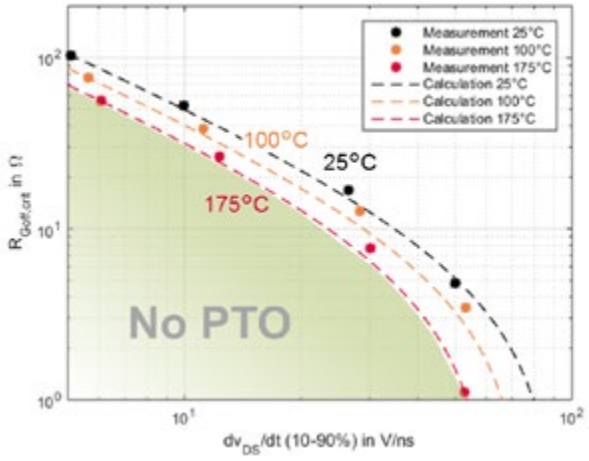


Figure 4: Critical gate resistor values as a function of dv_{DS}/dt for the 1200 V/45 mΩ CoolSiC MOSFET under test. The measurement points were obtained at 800 V and 0 A using a turn-off gate voltage of 0 V. The dashed lines indicate calculated trend lines.

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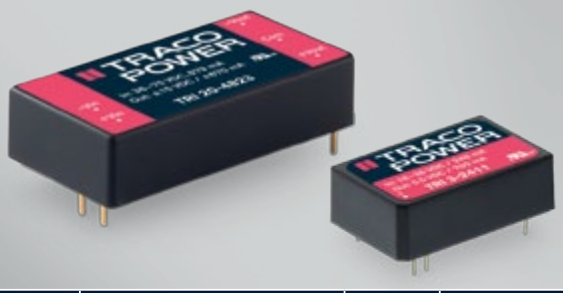
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Series	Power	Package	Temperature	Isolation	Working voltage
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TRI 6	6 W	DIP-24	–40 °C to +85 °C w/o derating	5000 VAC	1000 VACrms
TRI 10	10 W	DIP-24	–40 °C to +65 °C w/o derating	5000 VAC	1000 VACrms
TRI 15	15 W	2"×1"	–40 °C to +65 °C w/o derating	4200 VAC	1000 VACrms
TRI 20	20 W	2"×1"	–40 °C to +55 °C w/o derating	4200 VAC	1000 VACrms

Characterization results

Testing at zero load current means that the body diode of the device under tests is not forward biased prior to the switching transient. No diode recovery occurs; the transient is merely a charging and discharging of capacitances. In this condition, voltages induced in parasitic inductances do not play a significant role. Consequently, also the performance of the TO-247 and the TO-247-4-pin package is the same.

The measurement results obtained at 800 V and 0 A are summarized in figure 4. It is clearly visible that in order to prevent parasitic turn-on, the R_{Goff} needs to be lower, the higher the dv_{DS}/dt and the higher the temperature. It is worth mentioning that a turn-off gate voltage of 0 V is sufficient to prevent parasitic turn-on even at 50 V/ns and 175°C. In case the R_{Goff} cannot be selected at a level that is low enough, drivers with an active Miller-clamp functionality such as the 1EDC30I12MH provide a way out.

At higher load current levels, a hard commutation from the body diode of S_2 to the MOS channel of S_1 occurs. Due to the presence of diode reverse recovery and induced voltages, the situation becomes slightly more complicated. Simply speaking, three effects come into play:

1. The body diode recovery slows down the average dv_{DS}/dt and relaxes the situation with parasitic turn-on.
2. Oscillations between the commutation loop inductance and the device output capacitance increase the dv_{DS}/dt locally and make the situation more critical.
3. Assuming a standard TO-247 package, the negative feedback via the common source terminal of S_2 leads to a reduction of the gate voltage, and thus to an increased ruggedness against parasitic turn-on.

Apparently, the weighting of the effects described above depends on the actual hardware setup. With the evaluation board that was used for all tests presented in this article, the most critical condition is 175°C and 0 A. Thus, the area that is free of parasitic turn-on highlighted in figure 4 holds for 40 A measurements, too – regardless of whether the TO-247 or TO-247-4-pin is considered.

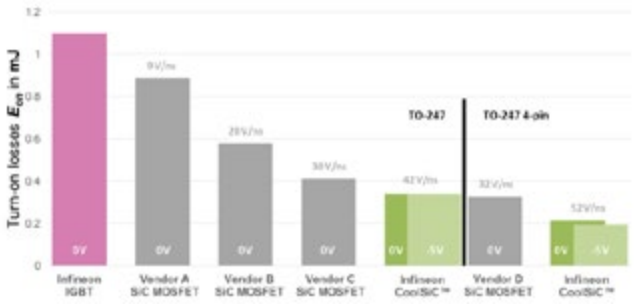


Figure 5: Minimum achievable turn-on switching losses of various 1200 V silicon carbide MOSFET technologies at 800 V, 15 A and 150°C. The devices under test have a nominal on-state resistance of 60-80 mΩ and are operated with 18/0 V and 4.7 Ω on the gate. For comparison purposes, the switching losses of the CoolSiC MOSFETs are also shown with a driving voltage of 18/-5 V.

Implications on high-speed switching applications

As indicated in figure 3, the shoot-through current caused by the capacitive turn-on and the reverse-recovery current of the body diode are difficult to differentiate. Both effects slow down or smooth the voltage transient, and cause an increase of the switching energies, not only on the diode but also on the switch. In applications that require highest switching speeds, parasitic turn-on limits the performance similar to an improper freewheeling diode.

Figure 5 shows the minimum achievable turn-on switching losses of various silicon carbide MOSFET technologies operated with 18/0 V on the gate. While not all devices are able to maintain their high-speed switching nature at such a driving condition, the results confirm the high immunity of CoolSiC MOSFETs against parasitic turn-on.

Summary and conclusion

This article describes a simple approach for characterizing the susceptibility of a power semiconductor switch to parasitic turn-on via the Miller capacitance. Test results obtained with discrete CoolSiC MOSFETs operated at a bus voltage of 800 V and a switching speed of 50 V/ns demonstrate that even in high-speed, two-level converters, a turn-off gate voltage of 0 V is feasible. When looking at three-level circuits where the switched voltage is just half the bus voltage, the situation eases entirely. In such cases, CoolSiC MOSFETs are virtually free of capacitive turn-on, regardless of the gate resistance value.

Assuming a carefully designed PCB layout with minimized gate-drain capacitance, Infineon encourages power electronic engineers to operate discrete CoolSiC MOSFETs with a turn-off gate voltage of 0 V. This leads to a simplification of the gate-drive design without penalizing the performance.

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Designing a SiC-MOSFET Based 6.6kW Bi-Directional EV On-Board Charger

At PCIM Europe 2019, Wolfspeed, A Cree Company, presented the design of a SiC MOSFET-based 6.6 kW bi-directional Electric Vehicle (EV) on-board charger (OBC), with high efficiency and high power density. A digitally controlled prototype with a switching frequency of 67kHz for CCM totem pole PFC, and 150 to 300kHz for a CLLC resonant converter were demonstrated with 54W/in3 power density exceeding 96.5% in peak efficiency.

By Chen Wei, Dongfeng Zhu, Haitao Xie, all Wolfspeed China and Jianwen Shao Wolfspeed US

Cree's Wolfspeed product families include SiC materials, power-switching devices and RF devices targeted for applications such as electric vehicles, fast charging, inverters, power supplies, telecom and military and aerospace.

Introduction

In accordance with the world moving towards cleaner fuel alternatives, the EV transportation segment is experiencing rapid growth. Further, EVs equipped with a sufficient battery capacity can potentially be used to support standalone loads (V2L), and to supplement grid power (V2G). Thus, the design trend of the EV's OBC is a transition to bidirectional operation capacity.

In order to optimize EV space and weight, an OBC design requires high power density and maximized efficiency. The bi-directional OBC consists of a bidirectional AC-DC converter followed by an isolated bi-directional DC-DC converter. The conventional LLC resonant converter was originally proposed as a solution to improve the efficiency of the DC-DC converter[1]. However, given its unidirectional design, in reverse operation mode voltage gain of the converter was limited, thus the intended advantages of the converter could not be realized[2] - [3]. Subsequently, a bidirectional CLLC resonant converter [3] - [4] was selected for the DC-DC stage, as it was found to provide high efficiency and a wide output voltage range in both charging and discharging modes.

The most popular single-phase PFC topology is a conventional PFC boost converter. Unfortunately, conduction losses of the diode bridge rectifier are not efficient, nor does it support bi-directional operation [5]. Next, the totem pole bridgeless PFC boost converter was considered in order to reduce diode numbers and increase efficiency [6], [7]. However, reverse recovery of the body diode of silicon MOSFETs resulted in high power losses in continuous conduction mode (CCM) making them impractical for high power applications. Following, IGBTs paralleled with SiC Schottky diodes were considered to replace silicon MOSFETs in CCM totem pole PFC and CLLC converters [8]. Sadly, the practical switching frequency is limited due to the high switching loss of IGBT. Further, the objective of a lighter OBC with higher power-density is negatively affected by the weight and size of the magnetics and resonant tank, as well from the additional anti-parallel SiC diodes.

Owing to the favourable reverse recovery performance of the body diode of SiC MOSFETs, interleaved CCM totem pole PFC is enabled as the front-end stage of a 3.3 kW OBC [9]. For high-power density and simple control, a single-phase single choke CCM totem pole PFC solution was selected for this design.

For thermal management, MOSFETs in a TO-247 package are normally reverse-assembled on the PCB in OBC applications. They are then mounted on a flat cooling baseplate. However, when the MOSFETs are bent down PCB area is increased, thus negatively impacting the overall power density of the system.

The proposed method is utilization of a tooled heat sink which accommodates both semiconductors and magnetics. Power semiconductors are mounted on the outer side of the heat sink, allowing for vertical MOSFET assembly, thus reducing PCB footprint. Magnetics are then potted using a thermal compound inside the slots of the heat sink. Thermal resistance from the tooled aluminum heat sink to the system cooling baseplate is low. As an example, a SiC MOSFETbased 6.6 kW bi-directional OBC was designed. The experimental results for the converter operating in the charging mode and discharging mode manifest both high efficiency and high power density.

Specifications and Architecture of a Bi-Directional OBC

Bidirectional OBC Specifications

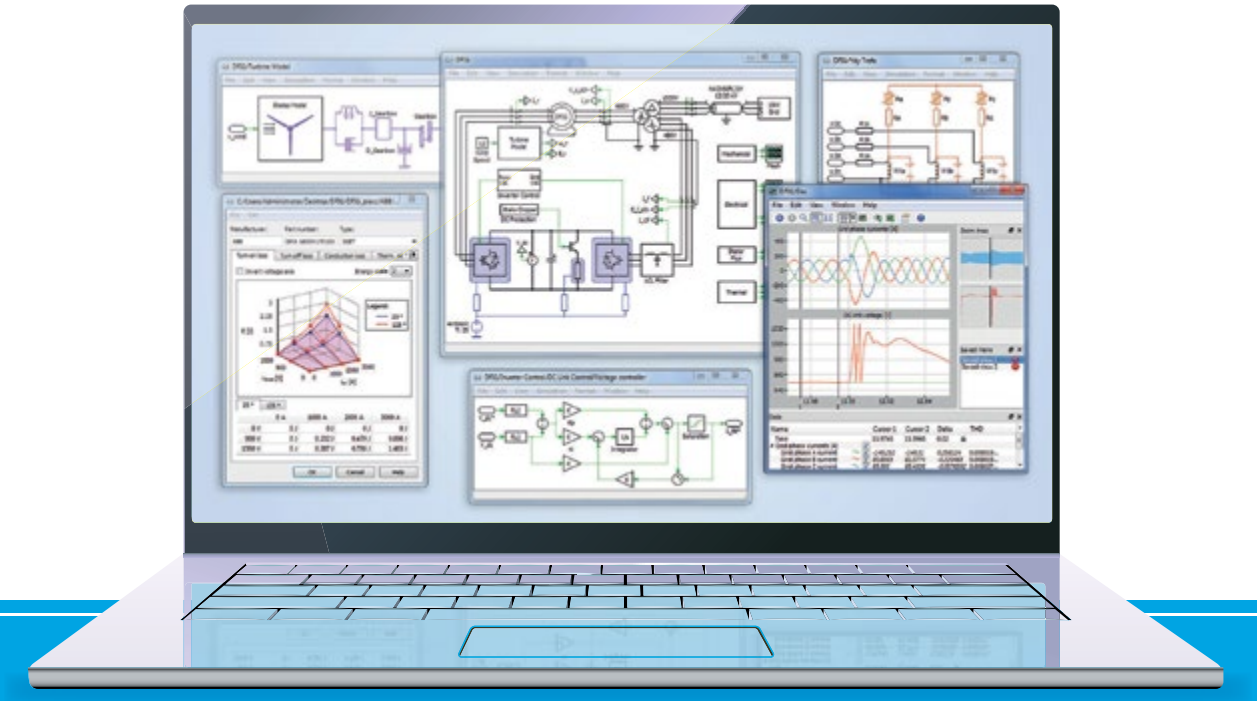
Major design specifications of the 6.6kW bi-directional on-board charger:

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- DC input/output Voltage 250 – 450VDC
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Block Diagram, DC-link Voltage and Switching Frequency Selection

Figure 1 shows the system block diagram of the bidirectional OBC.

An OBC design with a 500-840V variable DC-link for 250-450V battery voltage based on 1200V SiC MOSFET was demonstrated [10]. Overall efficiency of the OBC is optimized, however, 1200V SiC MOSFET cost is high. Power loss of PFC MOSFET and PFC choke is also elevated with high DC-link voltage. Two 500V or 450V rated E-caps in serials are required for the 840V DC link design. The size of the DC link capacitors and PFC choke are larger.

Totem Pole PFC DC Link 385-425V Bi-Directional DC/DC Battery 250-450

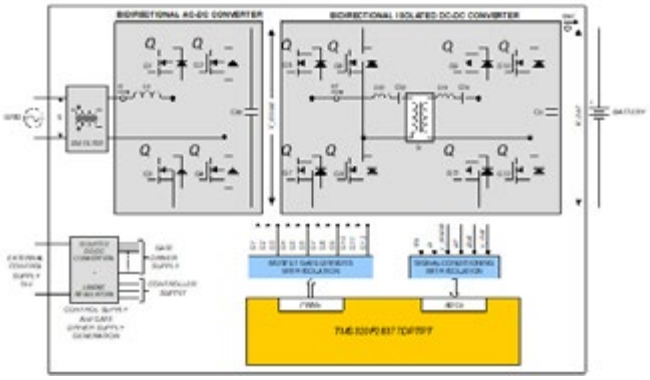


Figure 1: System block diagram of a bi-directional OBC

450 V Ecap, which is commonly used in the industry, is optimized with smaller size and low cost. When using 450V Ecaps not in serials, the DC-link voltage is maxed at 425V. A 385V DC link is the minimum voltage to maintain adequate power for an AC input, up to 265VAC. In this design, as shown in Fig. 2, the DC-link voltage of the OBC is variable from 385 to 425V, to allow the CLLC converter a smaller required gain range and better efficiency over the 250V-450V battery voltage range compared to a fixed 400V DC-link in charging mode.

DC-Link 380-425V

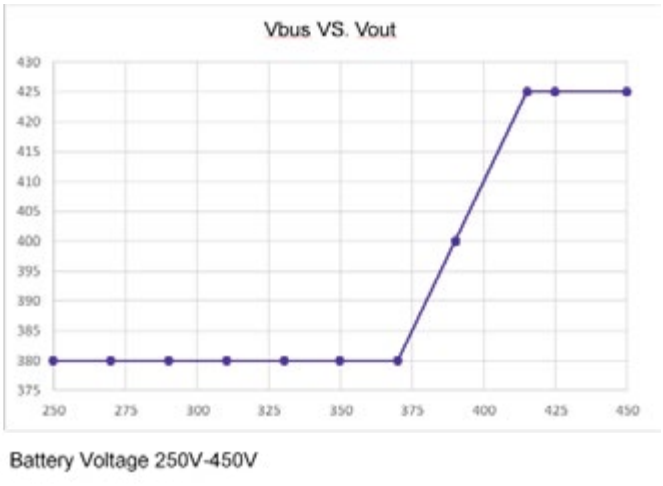


Figure 2: DC-link voltage vs. battery voltage: Digital controller adjusts the DC bus voltage (380-425V) based on the actual battery voltage. It is to help the DC/DC converter to operate with a smaller gain range.

To attain a balance between power density, efficiency, thermal performance, and conducted EMI, 67kHz is selected for the switching frequency of the high frequency half bridge Q1 and Q3 of the totem pole PFC.

To achieve high power density and efficiency, 200kHz is selected for the CLLC converter resonant frequency, and 150 to 300kHz for the frequency range. It is a trade-off between power density, efficiency and thermal performance. For a light load at low output voltage, combined PFM and phase shift control are applied in this design.

Power MOSFET Selection

A fast reverse recovery body diode is required for efficiency and reliability for both the CCM totem pole PFC and bidirectional CLLC resonant converter. A smaller Coss is preferred for high frequency hard-switching operations for the totem pole PFC, and it is also critical for achieving zero voltage switching (ZVS) with a lower magnetizing current and a shorter blanking time for the CLLC resonant converter. With reduced magnetizing current, the conduction loss and turn-off switching loss of the MOSFET can be minimized. That is important for optimizing the efficiency of the CLLC converter, particularly at high frequencies. The maximum DC-link voltage is 425V and the battery is 450V. In consideration of voltage de-rating reliability requirements, a 650V SiC MOSFET is preferred in the OBC application.

In order to deliver 6.6kW output power, C3M0060065D 650V 60mohm SiC MOSFET in TO-247 package, two parts in parallel are selected for the high frequency half bridge of CCM totem pole PFC. A single C3M0060065D is selected for the low frequency half bridge of PFC and both the DC-link side and the battery side of the CLLC resonant converter.

Digital Controller Selection

Digital controller TMS320F28377D was chosen to implement the flexible control of both the totem pole PFC and CLLC converter of the OBC in charging and discharging modes. As shown in Figure 1, TMS320F28377D provides 12 independent PWMs G1-G12 to MOSFETs Q1-Q12 for the totem pole PFC and CLLC converter. The digital controller also handles the real-time CAN communication, start-up sequence, OCP, OTP, UVP and OVP.

Magnetics and Key Parameters

The PFC choke is designed to keep the totem pole PFC current ripple under 40%. The maximum current ripple occurs at low line, high battery voltage and full load. The minimum required inductance is 75μH, which is calculated in the following equation

$$L > Vin^{2\frac{(Vo-\sqrt{2}Vin)}{k\,Po\,fs\,Vo}}$$

Considering the permeability degrade with DC bias, 230μH is selected for the PFC choke without DC bias. To get a balance between core loss and DC bias capability, the choke is fabricated with 2 stacks of KAM185-060A cores[11]. The winding consists of 36 turns of 2-strand AWG-13 magnet wires.

The main transformer of the CLLC converter is designed to meet the requirements of both 450V/14.67A and 366V/18A output. The maximum flux density and core loss are designed for and verified at 425V DC-link and 450V/14.67A output. The winding wire size is designed for maximum current conditions with a 366V/18A output. With a bobbinless design, the window area of the core can be fully utilized. Next, a PQ5040 core using 3C97 material is selected for the 6.6kW CLLC

converter. To meet the gain range requirements for 250V450V battery in both charging and discharging mode, a 15:14 turn ratio is selected. A 60µH magnetizing inductance is selected to ensure the ZVS of CLLC MOSFETs.

Conclusion

In this articel, a 6.6kW bi-directional OBC on SiC MOSFET is designed and evaluated. The DC-link voltage range is optimized to 385 to 425V per a common battery voltage range of 250 to 450V for an OBC. A prototype based on engineering samples of 650V 60mohm SiC MOSFET C3M0060065D is built to verify the performance and thermal integrity of the design. 54 W/in3 power density and above 96.5% peak efficiency in both charging and discharging mode are demonstrated by the prototype with 67 kHz for the CCM totem pole PFC converter and 150-300 kHz for the CLLC resonant converter.

By integrating the power semiconductors and power magnetics on the same tooled heat sink, high power density and high efficiency can be achieved in bi-directional high power conversion applications such as OBC for EV, owing to the low power loss of the 650V SiC MOSFET.

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Choosing the Right Current Sensor to Observe the Current Waveform of Switching Devices

Research and performance evaluation of high-speed power devices that use materials such as SiC and GaN are progressing at a feverish pace. Researchers and manufacturers work to achieve further efficiency gains in switching power supplies.
In recent years, the need to reduce power device switching losses and control switching noise has driven particularly active programs of research in which current sensors designed for wavelength observation with high-frequency response are specifically used to observe switching device response waveforms.

By Atsushi Nomura, Shougo Toya, Hidekazu Masuda, Hioki E.E. Corporation

Introduction

Generally speaking, tools for sensing high-frequency currents include current probes, Rogowski coils, and shunt resistors[1]. Since the various types of current sensors have their respective strengths and weaknesses, users are called upon to choose the right current sensor based on the characteristics they wish to measure. Although some manufacturers disclose the general characteristics of such current sensors[2], in some cases high-frequency characteristics are not clearly defined in such documentation or are not available at all.

This article provides an overview of general characteristics of current sensors and also defines their respective strengths and weaknesses based on measurement results for high-frequency characteristics. Additionally, it offers precautionary information concerning use of current sensors based on the high-frequency current measurement knowledge and expertise that Hioki has accumulated over many years of designing and providing current probes to industry.

General Characteristics of Current Sensors

Table 1 summarizes the specifications of the three types of current sensors used to observe and evaluate high-speed switching waveforms. Hioki's CT6711 was used as the current probe (Fig. 1). Table 2 lists general characteristics of the current sensors. Since these characteristics derive from detection methods and associated hardware designs, they generally apply across manufacturers and product lines. To highlight differences in the characteristics of these current sensors in the high-frequency domain, the authors conducted measurements using evaluation equipment that would typically be available in a development setting. Table 2 summarizes the specifications of the current sensors used.

	High-frequency bandwidth	Rated current or E_{max} joules
Current probe	120 MHz	30 A_{rms}
Rogowski coil	30 MHz	120 A_{peak}
Coaxial shunt	2 GHz	1 J (0.1 Ω)

Table 1: Specifications of the evaluated current sensors

Type (detection method)	Features
Current probe (Hall element, zero flux)	1. Can measure DC and AC current 2. Features a clamp-type design 3. Exhibits high noise resistance thanks to electromagnetic shielding 4. Offers exceptional minuscule-current measurement capability thanks to high detection sensitivity
Rogowski coil (induced electromotive force)	1. Can measure AC current only 2. Can be easily applied in tight spaces thanks to a flexible design 3. Is susceptible to the effects of external noise 4. Offers exceptional large-current measurement capability
Coaxial shunt resistor (I-V conversion using a resistor)	1. Can measure DC current; broad frequency band 2. Requires insertion into the circuit under measurement. 3. Is less susceptible to the effects of external noise 4. Is unable to measure large currents continuously

Table 2: General features of high-speed current sensors

Rectangular Wave Response and Delay Time

Figure 2 illustrates the results of measuring rectangular wave response with each current sensor. The measured signal was created by converting a voltage signal with a rise time of 1 ns and an amplitude of 100 mA generated by a pulse generator into a current signal. The input voltage waveforms shown in the figure were synchronized with the measurement current generated by the pulse generator.

Although each current sensor's waveform differs, it is their respective signal delays that are noteworthy. Both the current probe and Rogowski coil exhibit a delay of at least 10 ns. This delay is caused by the design of the current transformer (CT), and it is unavoidable for reasons related to the devices' phase characteristics. When using an oscilloscope, current sensor delay can generally be corrected by deskewing. Since the delay exhibited by a current sensor depends on its specific design, manufacturers publish representative values for each current sensor model to allow users to correct for the delay. Given the importance of voltage and current response timing when measuring switching loss, it is necessary to deskew not only the current sensor, but also the voltage probe to enable accurate measurement. With a delay of less than 1 ns, coaxial shunt resistors would seem to require no correction, but caution is necessary because the values shown here describe the response of the coaxial shunt resistor itself. Coaxial shunts and oscilloscopes are generally connected via a coaxial cable, and measurement exhibits a delay that varies with the length of the cable. As a general rule, 1 m of cable introduces a delay of about 5 ns. In actual testing, delay-free measurement is achieved by using two coaxial cables of identical length, one to connect the pulse generator that generates the reference signal to the oscilloscope, and the other to connect the shunt resistor to the oscilloscope.



Figure 1: Hioki CT6711 Current Probe

Figure 3 illustrates waveforms obtained by measuring a current waveform with a rise time of 5 ns. In this figure, each sensor's output has been deskewed. The current probe exhibits the response that most closely approaches the reference signal. By contrast, the narrow frequency band of the Rogowski coil prevents that device from tracking the reference signal's rising edge. Additionally, the high-frequency component superposed on the waveform, which consists of noise generated by the sensor's Rogowski coil arithmetic circuit, is caused by the low S/N ratio of the sensor for this type of measurement, in which a current of about 100 mA is being measured.

Effect of Coaxial Shunt Resistor ESL

A coaxial shunt resistor is a shunt resistor with a high frequency band that reduces parasitic inductance (or Equivalent Series Inductance a.k.a. ESL) by canceling the internal magnetic field with a coaxial design. However, it is difficult to completely eliminate parasitic inductance, and in some cases ESL cannot be ignored when observing high-frequency response, even when using a coaxial shunt resistor. This section makes use of actual measurement data for frequency characteristics to gauge the effect of a coaxial shunt resistor's ESL on the high-frequency domain characteristics of the coaxial shunt resistor. Figure 4 illustrates the frequency characteristics of each current sensor. The graph shown in the figure illustrates relative variation using gain at 100 kHz as the reference. The coaxial shunt resistor's frequency characteristics show an increase in gain at about the point when 30 MHz is exceeded. This change is due to an increase in the detected voltage, the result of an ESL impedance value that has grown too high relative to the coaxial shunt resistor's resistance value of 0.1 Ω to be ignored in the high-frequency domain. Although the coaxial shunt resistor can respond to signals with short rise times since it exhibits less gain attenuation at high frequencies than the other sensors, the device's response is accompanied by ringing and overshoot.

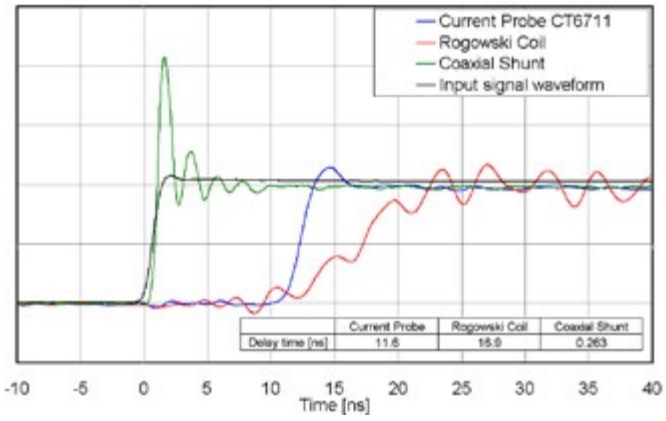


Figure 2: Response delay times for each sensor when measuring an input signal with a rise time of 1 ns

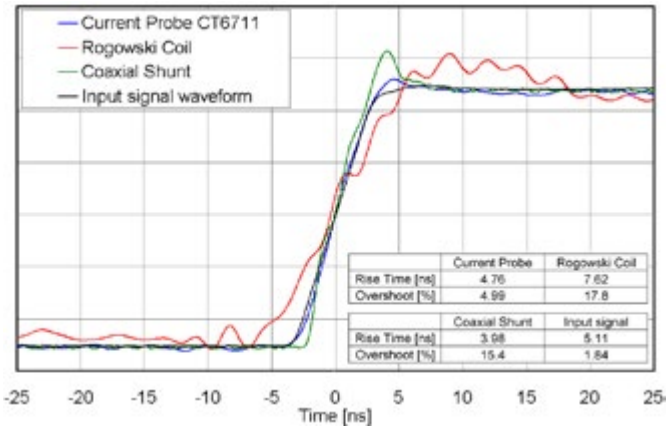


Figure 3: Sensor startup response when measuring an input signal with a rise time of 5 ns

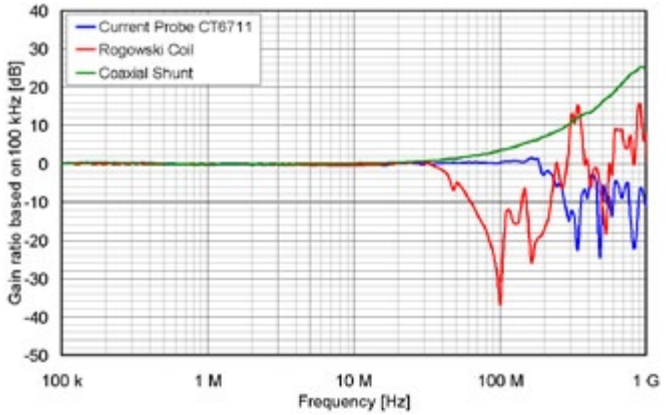


Figure 4: Gain-frequency characteristics for each sensor

The Rogowski coil's frequency characteristics remain flat up to its specifications value of 30 MHz. Increased gain above 0 dB in part of the high-frequency domain consists of noise components.

The current probe exhibits sufficiently flat frequency characteristics up to around 200 MHz, and high-frequency components that fall outside its band are clearly being cut. As a result, the waveform contains no ringing or noise arising from the sensor, which is therefore capable of accurately observing measurement current waveforms. Flat characteristics beyond 120 MHz, which is the specifications value for the current probe's frequency characteristics, reflect use of an FET probe to convert the current probe's output impedance to 50 Ω.

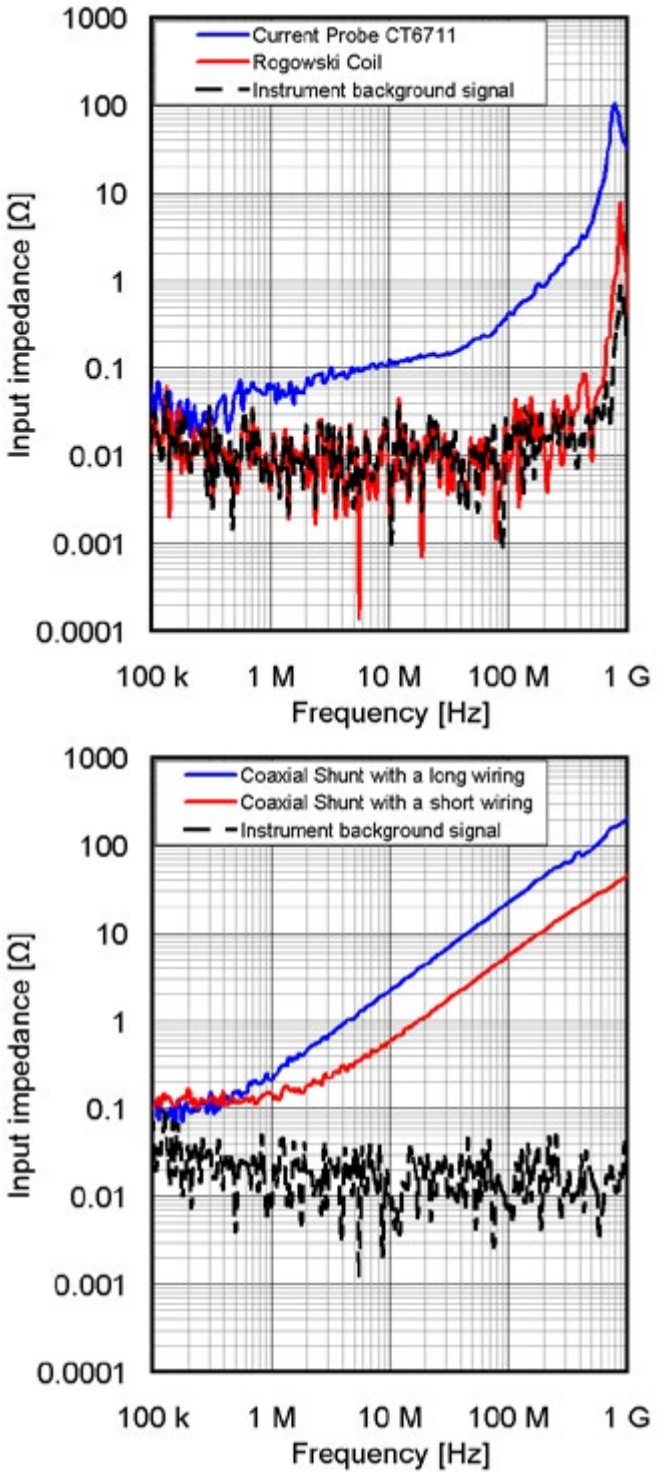


Figure 5: Insertion impedance values for each sensor

Measurement of Insertion Impedance

Figure 5 illustrates the results of measuring each sensor's insertion impedance. Generally speaking, lower insertion impedance is desirable in light of the resulting effects on measurement circuit operation.

Although insertion impedance tends to increase with frequency due to the current probe's use of a core made of a magnetic material and shielding for the sensor, this effect is limited to less than 0.1 Ω up to 10 MHz for the Hioki CT6711. This level of performance is the result of the product's use of Hioki's zero-flux method, which reduces the operating magnetic flux level of the magnetic core.

The Rogowski coil has an insertion impedance of approximately zero since no magnetic materials are used in its construction.

Coaxial shunt resistors always impose an insertion loss since the shunt resistor must be inserted into the circuit. Additionally, the coaxial shunt resistor's internal ESL and the inductance of the wiring used to connect it to the circuit will affect measurement as insertion impedance. Results of measuring insertion impedance values caused by differences in wiring lengths indicate that more caution must be paid to the effects of wiring than when using a clamp-on current probe.

Other Precautions

Apart from differences in characteristics, each sensor has associated precautions that should be borne in mind to ensure safety.

Coaxial Shunt Resistors

When connecting output from a coaxial shunt resistor directly to an oscilloscope, the coaxial shunt must be connected to the low side due to the danger that the measurement circuit's potential could be shorted via the oscilloscope's BNC-GND. Alternatively, the coaxial shunt resistor's signal must be detected using an isolated voltage probe.

If the shunt resistor's rating (in joules) is exceeded, it may burn up and leave the circuit open, damaging the measurement circuit in the process. Consequently, caution is necessary, for example when varying the switching duty ratio.

Current Probes

Sustained measurement of a large, high-frequency current could cause the sensor head to heat up due to the phenomenon of induction heating, damaging the sensor. Always refer to the manufacturer's frequency derating characteristics when using such devices.

Strengths and Weaknesses of Current Sensors with High-Frequency Currents

This section offers a brief summary of the strengths and weaknesses of each current sensor type.

Coaxial Shunt Resistors

Since these devices excel at high-frequency response, they are an effective choice for use in di/dt evaluation. Coaxial shunt resistors should be connected so as to minimize wire length.

Current Probes

Since these devices offer exceptionally flat frequency characteristics, they are an effective choice when measuring ringing, overshoot, and noise components. Caution is necessary concerning insertion impedance caused when the sensor is clamped in place.

Rogowski Coils
Due to the ease with which they can be clamped onto small components and their low insertion impedance, Rogowski coils can make measurements without affecting the circuit under measurement, making them an effective choice for use in applications such as the evaluation of finished circuit boards. They are generally not suited to use in measuring minuscule and low frequencies due to their low S/N ratio.

Noise Analysis Techniques Using Current Probes
This section introduces a technique for analyzing common-mode noise using the 0.5 A range of the Hioki Current Probe CT6711 (Figure 1).

Figure 6 provides a block diagram for a noise analysis system with notations indicating measurement points, while Figure 7 illustrates the current waveforms measured using current probes and the results of an FFT analysis of those waveforms. As shown in Figure 6, the two primary-side measurement signal downstream from after AC/DC conversion and the three secondary-side 3-phase lines downstream from PWM modulation were measured together, and the system's

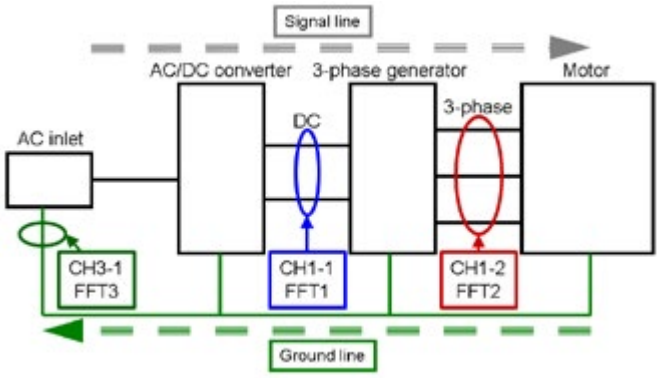


Figure 6: Block diagram for the system that underwent noise analysis and associated measurement points

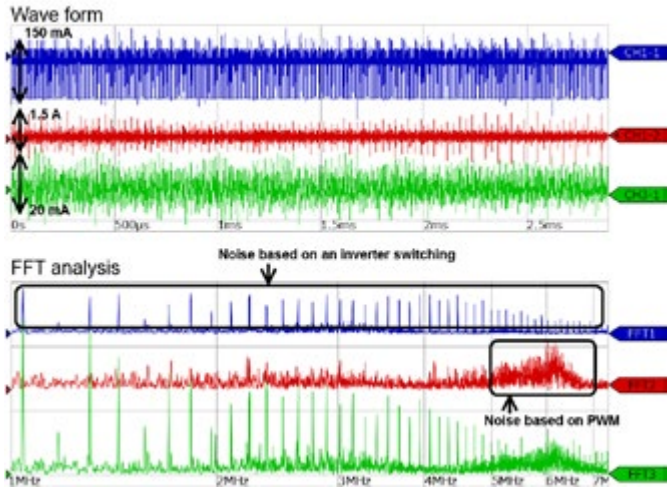


Figure 7: Current waveforms (top) and FFT analysis results (bottom)

noise components were extracted. An FFT analysis of these signals revealed switching noise occurring during AC/DC conversion across all frequencies in the primary-side signals as well as a noise distribution near 6.5 MHz in addition to the switching noise in the signal lines downstream from PWM modulation. By contrast, when the GND line current waveform near the power line inlet was measured using the CT6711 and the results subjected to FFT analysis, the authors were able to identify a frequency component composed of two noise components superposed on the signal line. By subjecting the frequency distribution of the noise components superposed on the GND line to pattern analysis in this way, it is possible to identify common-mode noise components and their sources.

Although subjecting signals to FFT analysis to extract noise components and analyzing their sources is a typical analysis technique, the CT6711's 0.5 A range can be used to identify noise components with a high level of sensitivity. The effectiveness of this approach stems from the ability to reduce the effect of the full-scale error of the instrument to which the current probe is connected. Since current probes generate the most accurate waveform output when clamped in place, they are well suited to use as current sensors for investigating and analyzing common-mode noise in systems as illustrated here.



Conclusion
In writing this paper, the authors built an evaluation system using development environment devices and made measurements using current sensors designed for observing waveforms. As a result, they were able to reaffirm differences in current sensor characteristics. Different types of current sensors have their own strengths and weaknesses, and they sometimes introduce sources of error that cannot be inferred from their product specifications alone. It is necessary to use such sensors based on an appropriate understanding of this fact.

This paper also offered an example of a method that can be used to analyze common-mode noise occurring in inverter-operated motors using the 0.5 A range of the Hioki Current Probe CT6711.

As the development of increasingly high-speed power devices continues to drive up the frequency of noise components superposed on switching signals, the CT6711, which delivers both high sensitivity and broad-band frequency characteristics, will continue to serve as an effective tool for waveform observation.

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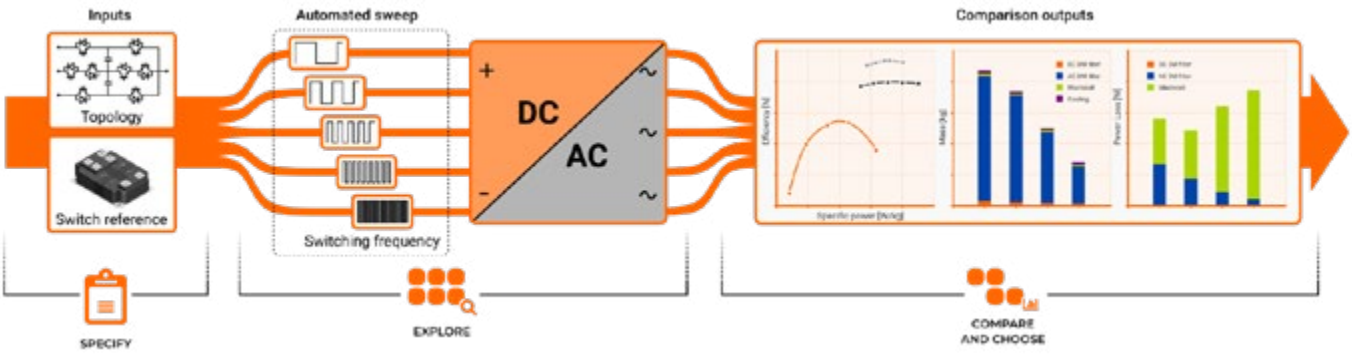
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A Step Forward for Benchmark and Design Tools for Power Electronics

Cut time & costs starting with the time spent in the early stage-phase. Discover the potential of Automated Sweep of the Switching Frequency in your Early-Stage Design Phase.

The transformation of the global energy system is speeding up. The need to reduce energy consumption and CO2 emissions is driving power electronics and power converters. The next generation of power converter designs will be even more driven by conversion efficiency, while mass, volume, cost…reduction will remain key. To achieve these goals, degrees of freedom such as multilevel topologies which increase the apparent switching frequencies, Wide Band Gap power switches which explore wider temperatures ranges and higher switching frequencies,… must be considered by designers. To help designers to meet these challenges, design or benchmark tools enabling as a first step ultra-swift sweeps of different parameters as degrees of freedom are necessary.

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



The power converter multi-objective optimization design challenge

To develop the next generation of power converters, tools should help designers overcome design and test challenges that can win in the market. Designers have to choose between a series of different components, topologies, control laws… They especially have to understand the performance specifications and reliability of power semiconductor devices since their performance strongly dictates the efficiency and reliability of the entire power converter circuit. This is critical for the success of a design that fulfills and will soon need to exceed the expected performance and the specifications.

Besides, the characteristics of the electrical equipment (lower mass, volume, cost and higher efficiency and reliability) must be significantly improved.

As these converters manage energy flows, looking for the maximum efficiency leads to design conversion systems with minimal power density: i.e. conversion systems whose size tends towards infinity. Thus, designers have to find solutions with the best compromise between efficiency and compactness (mass, volume) of the power converters. Other trends or challenges can be considered such as failure rate, cost, etc as noted in [1].

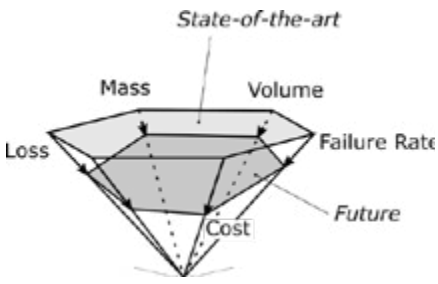


Figure 1: Performance trends & challenges [1]



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UNITEDSIC.COM APPLICATION NOTES **TECHNICAL BLOGS** **WHITE PAPERS**

Current design tools are not up to challenge
Today, generic or very specific analysis software are available for power electronic designers, but they only answer partially or locally to their needs. Few software tools in the domain of power electronics can assist them in the "operational" steps of conception such as design or optimization. The need for new tools has been clearly stated several times [1, 2]. And the first need is surely a tool which:

- allows the engineer to quickly benchmark power switches (including WBG devices [3]) and thus with a sensitive analysis of some parameters such as the switching frequency,
- provides "interfacing" features to feed into the next stage of the design process such model exports to standard circuit simulation tools.

Tools need to jump over a major hurdle
Powerswitch manufacturer's supplied datasheet information is often not homogeneous enough to easily meet these challenges: the datasheet conditions can be quite different from actual use conditions, and the supplied information often has large margins with little information on device variations. This makes it hard to evaluate the performances of different powerswitches and to compare them. This is even truer for WBG devices since manufacturers differ on what specifications need to be on the datasheet and which ones they do not include.

How do tools address the need to benchmark powerswitches & topologies?
Some semiconductor manufacturers propose different applications (essentially web applications these recent years) to evaluate the losses of their switches (ABB, Wolfspeed, Infineon, Dynex…) and more and more often for different topologies which helps a bit the engineer to evaluate powerswitch losses in an early-stage design phase.

Yet, at least two improvements are necessary to bring real help to engineer in this step:

- manage powerswitch references of different manufacturers in the same tool,
- provide an automated sweep of some parameters and especially the switching frequency.

So, is there no critical need? Or no will to address it?
Existing manufacturer-owned solutions confirm that the need has been identified. At Power Design Technologies, we believe that only a third-party can make a difference for the designers. That's why we have developed PowerForge, an innovative software which can easily allow the engineer to benchmark different powerswitch references and different topologies (including multilevel topologies) and now with an automated sweep of the switching frequency.

Why an automated sweep of the switching frequency?
Once the engineer has set voltage and current levels, chosen a topology, the switching frequency is one of the first (or the first?) parameters he would like to evaluate to see the influence on the losses, the volume and the mass of the whole converter.

The figure below plots efficiency vs specific power from a frequency of 2 kHz to a frequency of 16 kHz. It clearly shows an optimal switching frequency range in terms of mass/efficiency tradeoff.

Indeed, when the switching frequency starts to increase from 2 kHz to 8 kHz, the specific power increases because the size of the filters is reduced. But the efficiency also increases because of the decrease of filter loss (mainly because the inductor is reduced) compensates the loss increase in the switching cell. After 10 kHz, the loss reduction in the filters is not enough to compensate for the loss increase in the switching cell and that is why the whole efficiency decreases.

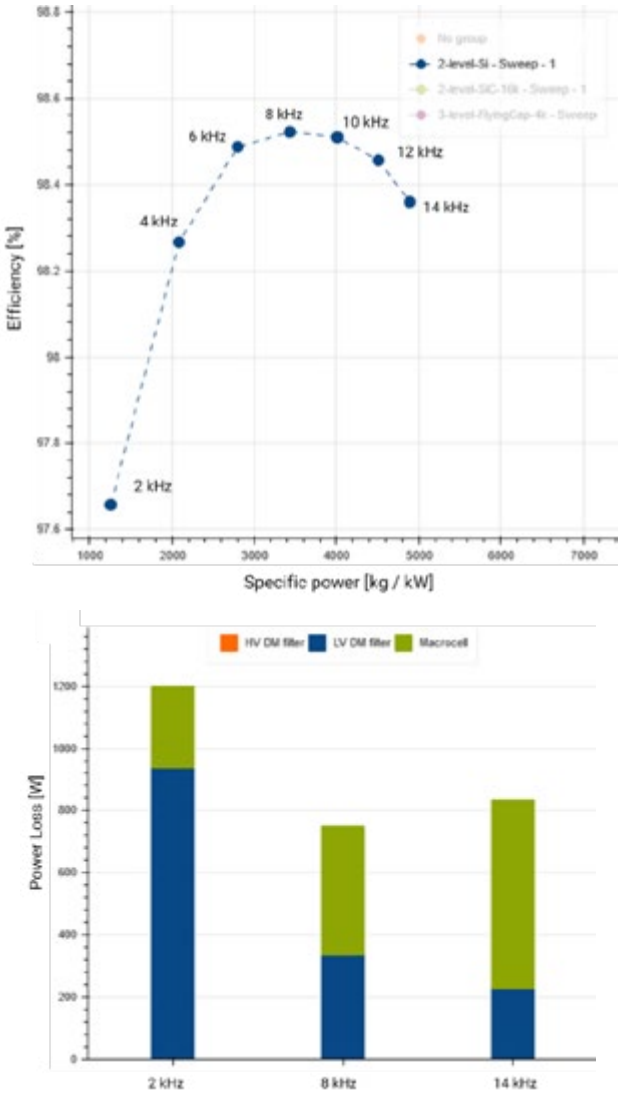


Figure 2: Result outputs of an automated sweep of the switching frequency displayed in PowerForge

Performing a manual sweep i.e. every single manual calculation for a switching frequency range is highly tedious and time-consuming. It is what we, at Power Design Technologies consider a waste of time and energy of expert teams. We thus have developed PowerForge software focusing on these key dimensions: speed, stability, and efficiency. We reduce the time-consuming steps, display critical key performance indicators in a user-friendly interface and offer the designers the possibility to explore the results they need to access. The future exploration of a new area of opportunities including those offered by wide band gap components is PowerForge.

Cut time & costs: design in a click and benchmark all your power converters' performances.
How?

- ONE ARCHITECTURE
- ONE SWITCHING FREQUENCY RANGE
- ONE CLICK
- ALL THE DESIGN OPTIONS AVAILABLE

PowerForge's newest feature the automated sweep of the switching frequency was released this summer. Engineers can now generate all the designs for a given architecture for a switching frequency range with a single click and within a few seconds.

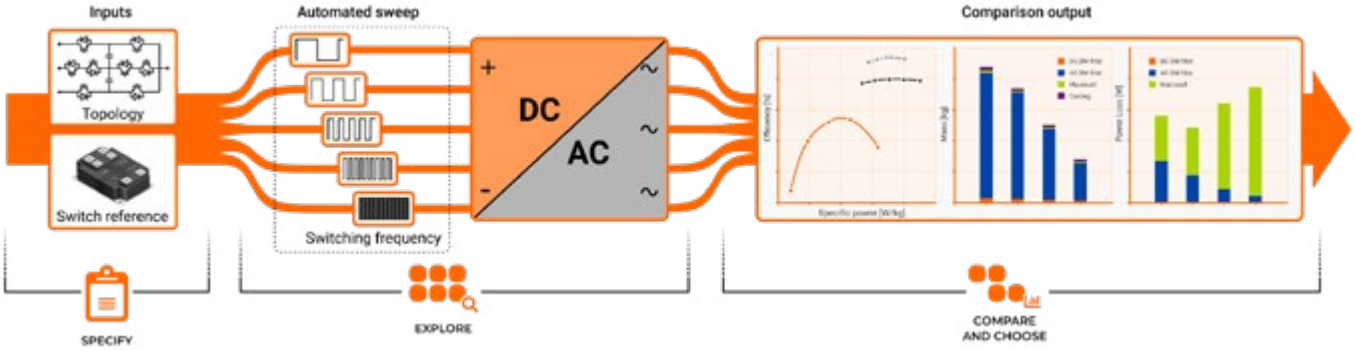


Figure 3: Workflow process in PowerForge

Designers select a topology, type the boundaries of the frequency range to be explored, enter the sweeping interval and launch the creation of the designs.
For each design created, all the key data needed to benchmark the performances of multiple options and choose the optimal power converter design solution: mass, volume, loss, cost, specific power… are calculated and displayed in a user-friendly interface.

Explore and benchmark power converters using PowerForge!
Visit our website: www.powerdesign.tech!

Power Design Technologies will be present at EPE 2019 in Genoa! Let's meet there!
Join us at **Booth #27** for an exclusive presentation of PowerForge
Find out more about PowerForge on Wednesday the 4th at 4.00PM

[1] Drofenik, U., Cottet, D., Müsing, A., & Kolar, J. W. (2007). Design tools for power electronics: trends and innovations. Ingenieurs de l'automobile, 791, 55-62.

[2] Kolar, J.W. (2014). What are the "Big CHALLENGES" in Power Electronic?. CIPS.

[3] Design and Simulation of Power Electronics with EDA Tools

Part I: https://literature.cdn.keysight.com/litweb/pdf/5992-1166EN.pdf?id=2699182

Part II: https://literature.cdn.keysight.com/litweb/pdf/5992-1167EN.pdf?id=2699184

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Voltage Dividers in Power Supplies

In the design of power supplies, the desired output voltages can be set manually. This is accomplished in most integrated power supply circuits, as well as switching and linear regulator ICs, with the help of voltage dividers. The ratio of the two resistance values must be suitable to enable the desired output voltage to be set.

By Frederik Dostal, Analog Devices, Inc.

Figure 1 shows a voltage divider. The internal reference voltage (VREF) and the desired output voltage determine the ratio of the resistance values, as seen in Equation 1:

$$\frac{V_{REF}}{V_{OUT}} = \frac{R_2}{R_1 - R_2} \quad (1)$$

The reference voltage VREF is defined by the switching regulator or linear regular IC, and is usually 1.2 V, 0.8 V, or even 0.6 V. This voltage represents the lowest voltage that the output voltage (VOUT) can be set to. With the reference voltage and output voltage known, there are still two unknowns in the equation: R1 and R2. One of the two resistance values can now be selected relatively freely, as usual values lie below 100 kΩ.

If the resistance values are too low, the power loss due to the constantly flowing current VOUT/(R1 + R2) during operation is extremely high. If R1 and R2 each had a value of 1 kΩ, then a continuous leakage current of 1.2 mA would flow at an output voltage of 2.4 V. This corresponds to a power loss of 2.88 mW generated by the voltage divider alone.

Depending on how precisely the output voltage should be set and how high the current in the power supply error amplifier at the FB pin is, Equation 1 can be specified more precisely through consideration of this current.

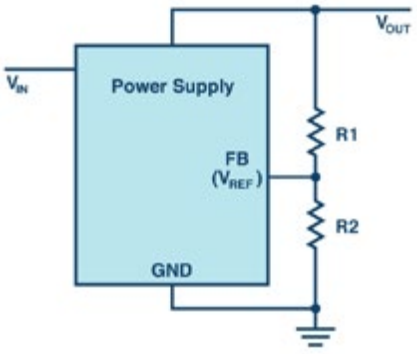


Figure 1: Voltage divider in a voltage regulator for adjustment of output voltage.

However, the resistance values should not be too high. If the resistance values were each 1 MΩ, we would only have a power loss of 2.88 µW. A major disadvantage of this resistor dimensioning with very high values is the fact that it results in a very high feedback node impedance. The current flowing into the feedback node can be very low depending on the voltage regulator. As a result, noise can couple to the feedback node and directly affect the control loop of the power supply. This can stop the regulation of the output voltage and lead to control loop instability. Especially in switching regulators, this behavior is critical, because noise arises due to the rapid switching of currents and can couple to the feedback node.

Useful resistance values for R1 + R2 lie between 50 kΩ and 500 kΩ depending on the noise expected from other circuit segments, the value of the output voltage, and the need to reduce the power loss.

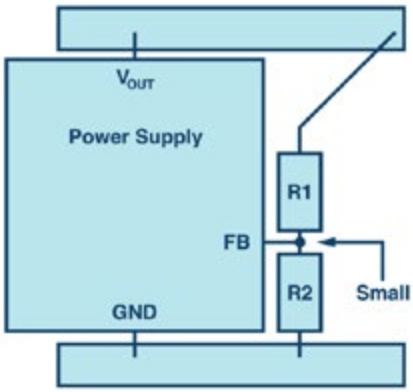


Figure 2: Example of a well-placed voltage divider in a power supply.

Another important aspect is the placement of the voltage divider on the board layout. The feedback node should be designed to be as small as possible so that very little noise can couple to this high impedance node. Resistors R1 and R2 should also lie very close to the feedback pin of the power supply IC. The connection between R1 and the load is usually not a high impedance node and can hence be designed to have a longer trace.

Figure 2 shows an example of resistors placed close to the feedback node.

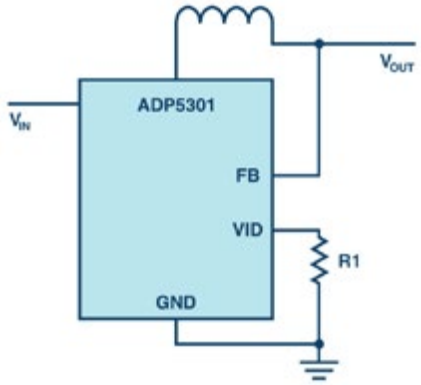


Figure 3: Adjustment of the output voltage without a continuous power loss in the voltage divider.

To reduce the power loss of a voltage divider, especially in ultra low power applications such as energy harvesting, some ICs, like the ADP5301 step-down regulator, feature an output voltage setting function in which the value of a variable resistor at the VID pin is only checked once during startup. This value is then stored for ongoing operation without current constantly flowing through a voltage divider. A very sensible solution for highly efficient applications.



Frederik Dostal studied microelectronics at the University of Erlangen- Nuremberg, Germany. Starting work in the power management business in 2001, he has been active in various applications positions including four years in Phoenix, Arizona, working on switch mode power supplies. He joined Analog Devices in 2009 and works as a power management technical expert for Europe.

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Piezo Haptic Solutions: Touch me – Feel me!

Whether for smartphones, vehicles, industrial controls, domestic appliances or gaming consoles – the future belongs to piezo-based pushbutton solutions with haptic feedback. TDK offers a unique portfolio of products that are suitable for every imaginable haptic application.

By Christoph Jehle, Manager Technology & Product Communications, TDK Electronics AG

As a result of the demand for greater convenience and safety, multi-functional human-machine interfaces (HMIs) such as touchscreens and other touch-sensitive surfaces can now be found almost everywhere. Existing solutions for haptic feedback such as eccentric rotary mass (ERM) or linear resonant actuators (LRA) have a number of drawbacks. These include their relatively large dimensions, the insertion height being particularly relevant for display controllers, and a high demand for power in battery-operated devices such as smartphones or tablets. Furthermore, neither the frequency nor the strength of the feedback are at best only variable within very narrow limits, and they do not have any sensory capabilities.

A considerably better alternative is offered by TDK's PowerHap™ and PiezoHapt™ families of piezo-based actuators. These components are a combination of pressure-sensitive sensor and actuator in one. With the two product families, TDK offers the widest range of actuators for haptic feedback.

PiezoHapt™ L – world's thinnest actuators for haptic feedback
TDK has developed the L8060 and L3015 types specially for use in vehicle and smartphone displays. They have impressively low-profile insertion heights of just 0.35 mm and 0.3 mm with areas of 80 x 60 mm (L8060) or 30 x 15 mm (L3015). The unimorph design of the PiezoHapt is based on a flat multilayer piezo element that is connected to a vibration plate on one side and can be mounted directly underneath displays.

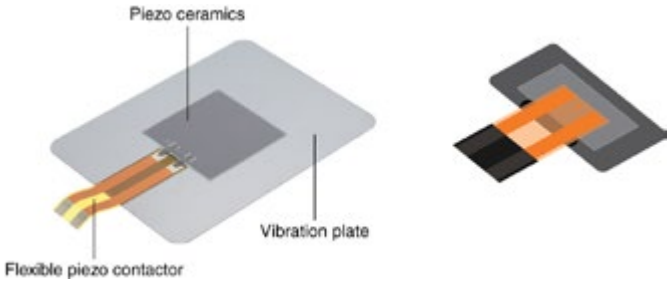


Figure 1: At no more than 35 mm, the TDK PiezoHapt types are extremely thin and are suitable for smartphones, tablets and vehicle displays.

The actuators are designed for operating voltages of ≤24 V (L8060) or ≤12 V (L3015). Depending on the amplitude and frequency of the applied voltage, a wide range of vibration patterns can be generated with PiezoHapt. These types are especially well-suited for OLED displays.

PowerHap: Unrivalled acceleration, force and response time
The actuators of the PowerHap family are based on multilayer piezo plates with copper inner electrodes. Figure 2 illustrates the basic design.

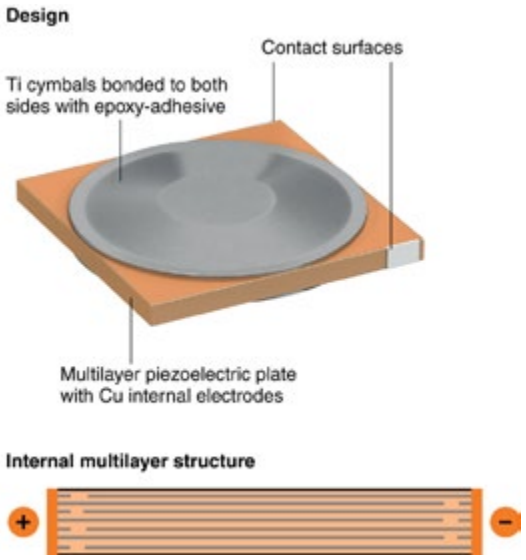


Figure 2: Design of square PowerHap actuators. This family of products includes four types with edge lengths of between 9.0 mm and 26.0 mm and insertion heights from 1.1 mm to 2.3 mm. Thanks to the multilayer technology, forces in excess of 25 N and displacements of 230 µm can be achieved.

If a voltage is applied to the piezo plate, it only expands minimally in the z axis, but due to the constant volume of the piezo effect it contracts simultaneously in both the x and y axes. Two titanium cymbals bonded to either side of the plate amplify this contraction by a factor of 15 in the z-axis, achieving a large displacement of up to 230 µm for the largest 2626H023V120 type. The high level of linearity between applied voltage and displacement is advantageous. For this type it is 1.8 µm/V, enabling precise and, at the same time, variable control of both amplitude and signal form.

Thanks to the multilayer piezo technology PowerHap offers unprecedented performance in terms of response time and acceleration. For example, with a rise time of just 1 ms the acceleration of the cymbals is already 15.0 g and attains a maximum value of 35 g when a mass of 100 grams is applied, generating a very large force of up to 25 N. Comparable values cannot be achieved using conventional solu-

tions. Figure 3 illustrates the response time and acceleration for type 2626H023V120.

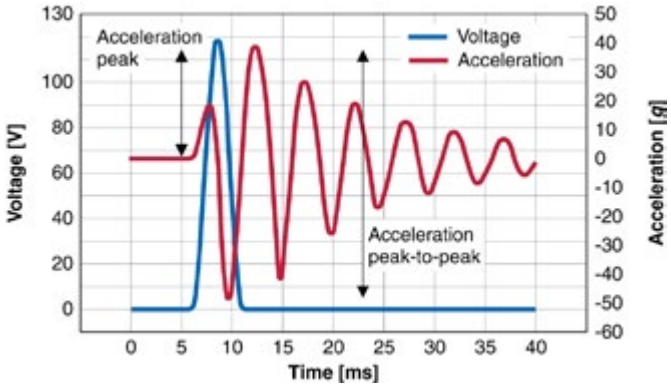


Figure 3: Typical acceleration g as a function of the voltage when a mass of 100 grams is applied. The voltage signal here is a half-sine with a peak of 120 V and a pulse length of 5 ms, corresponding to a frequency of 200 Hz.

PowerHap actuators are suitable for a wide stimulation range from 1 Hz to 500 Hz with variable amplitudes, durations and signal shapes, such as sine, triangle or rectangle. Depending on the type, the drive voltage is between -20 V and 120 V or -10 V and 60 V. These actuators are therefore able to generate a customized haptic feedback to human mechanoreceptors. Correspondingly, these actuators enable designers to create specific, high-definition haptic feedback profiles that users expect from cutting-edge HMIs in automotive and industrial applications. The combination of low-profile designs no more than 2.3 mm thick and strong feedback allows these actuators not only to be integrated in displays, but also to be placed directly below flat surfaces. This enables solutions with a high degree of leak-tightness which is just as necessary in harsh industrial environments as in applications with stringent hygiene requirements, such as in the food industry or medical technology.

Excellent sensory properties

Apart from the excellent actuator performance, the PowerHap components also feature outstanding sensor functionality thanks to the multilayered piezo technology. In contrast to conventional switches or pushbuttons that, as is well known, can only provide the On and Off switching states, PowerHap delivers an output voltage that is proportional to the pressure applied. Figure 4 illustrates this behavior.

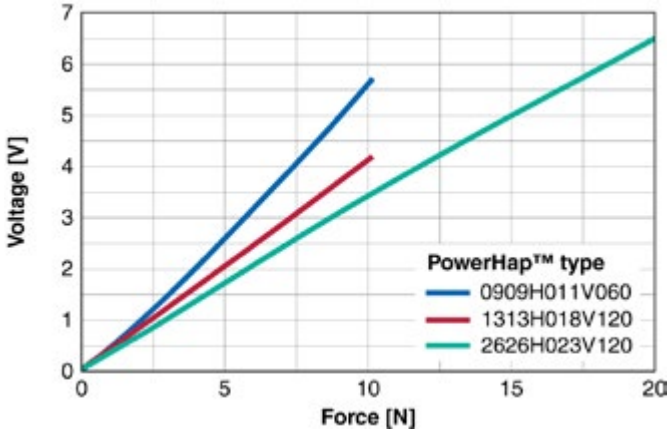


Figure 4: When functioning as a sensor, the output voltage of PowerHap is to a great extent proportional to the force applied.

As a result, and unlike conventional mechanical pushbuttons, it is even possible to create solutions based on PowerHap that trigger different actions and haptic feedback, depending on the force applied.

Table 1 lists the currently available square types of the PowerHap series.

Table 1:

Type	Dimensions [mm]	Operating voltage [V]	Acceleration [*g*] *	Displacement [µm]
0909H011V060	9 x 9 x 1.1 mm	-10 to +60	2.5	35
1313H018V120	12.7 x 12.7 x 1.8	-20 to +120	7	65
1918H021V120	19.4 x 19.4 x 2.1		25	130
2626H023V120	26 x 26 x 2.3		35	230

** Under a load of 100 grams*

Slim design for lateral installation in slim devices

In addition to the square PowerHap types that are particularly suitable for use under flat surfaces, TDK has also developed four slim, rectangular PowerHap types that are designed to provide lateral lateral haptic feedback in addition to vertical haptic feedback. The two smallest versions with lengths of just 9 mm or 12 mm are particularly suitable for smartphones and tablets, home appliances, games consoles, VR/AR equipment, smart watches, digitizers or handheld medical devices. The two larger versions with side lengths of 60 mm are currently the most powerful PowerHap types, as they enable forces of up to 50 N to be generated, enabling masses of up to 1 kg to be moved. These powerful packages can, for example, be installed at the side of displays in order to achieve a horizontal haptic feedback, as shown in Figure 5.

Table 2 lists the key technical data of the rectangular PowerHap types.

Table 2:

Type	Dimensions [mm] (l x w x h)	Operating voltage [V]	Acceleration [*g*] (pk – pk)	Displacement [µm]
0904H018V060	9 x 3.75 x 1.4	-10 to +10	4.5 *	15
1204H024V060	12 x 4 x 1.8	0 to +60	9.2 *	27
6005H070V120	60 x 5 x 7	-20 to +20 /	13 **	280
6005H090V120	60 x 5 x 9	0 to +120	19 **	150

* Under a load of 100 grams
** Under a load of 500 grams

To enable users to gain initial impression of the varied possibilities of haptic feedback with PowerHap actuators, TDK offers two evaluation kits. The BOS1901Kit development board (ordering code Z63000Z2910Z 1Z44) is designed for the 60 V actuators that are contained in the kit (0909H011V060, 0904H014V060 and

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1204H018V060). The board is based on the haptic driver architecture from Boréas Technologies. The main features are the compact dimensions, low current consumption and fast response times. In addition, the board offers extensive adjustment options with regard to the voltage amplitude, frequency, pulse repetition rate, signal shape and sensor functionality.

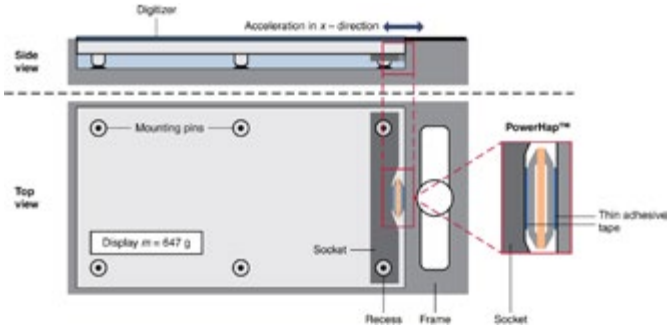


Figure 5: Rectangular PowerHap types are suitable for the lateral control of displays. Typical applications are vehicle displays.

The second evaluation kit is suitable for both 60 V and 120 V PowerHap types and is available in two versions: A driver for one actuator (Z63000Z2910Z 1Z 1) and a driver for up to 5 actuators (Z63000Z2910Z 1Z 7). These kits contain PowerHap actuators of the types 0909H011V060, 1313H018V120 and 2626H023V120.

Competent design support through cooperative ventures
Systems with haptic feedback are relatively new technologies. Accordingly, no standard solutions yet exist which can be drawn upon. In order to enable customers from every industry to complete a fast and cost-efficient design-in of haptic solutions, TDK has entered into cooperation agreements with three leading touch response companies.

Aito offers controller solutions with its HapticTouch hardware and software, which convert piezo actuators into precise touch sensors with haptic feedback. These enable tactile switches or pushbuttons to be simulated on smooth surfaces. Using the combined haptic technologies of TDK and Aito, touch response solutions can be implemented on smartphone touchscreens, or conventional switches and pushbuttons in vehicles can be replaced. Aito specializes in solutions using the small TDK actuators of the PiezoHapt S series. (www.aito-touch.com)

Boréas Technologies has developed the BOS1901 driver IC on the basis of its patented CapDrive™ technology. It is particularly energy efficient, also offering sensor functions, and is especially suitable for controlling TDK PowerHap actuators with an operating voltage of up to 60 V. In a further stage of development, Boréas will develop the first low-power piezo driver IC for the larger TDK PowerHap models with a maximum driver voltage of 120 V. (www.boreas.ca)

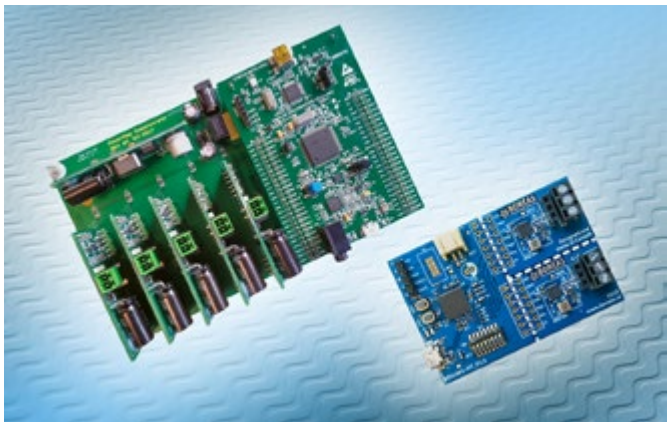


Figure 6: The evaluation kits provide an initial impression of haptic feedback with PowerHap actuators and allow users to evaluate design possibilities.

Immersion is leading developer and licenser for touch -feedback technologies. A co-marketing agreement exists with this company for the TDK PowerHap and PiezoHapt actuators. Immersion certifies these actuators for use with its software products and also includes the actuators in its reference designs. This enables customers to implement advanced haptic solutions with the world's thinnest and most powerful actuators. (www.immersion.com)

In future, growing numbers of devices and systems will be equipped with haptic feedback to improve convenience, safety and operating reliability. With its unique product range and in collaboration with its joint-venture partners, TDK can offer solutions suitable for all haptic applications.

www.tdk-electronics.tdk.com/en/powerhap



Digital Power Supply Loop Design Step-by-Step: Part 2

In the previous article we showed that the output of almost any op-amp compensator can be emulated in digital domain with a single linear difference equation. We then created a simple op-amp integrator/compensator, presented its linear difference equation (LDE) in digital domain and then plotted the output of the op-amp commentator vs its digital equivalent LDE. We saw that the output of our mathematical equation in digital domain was almost exactly the same as the op-amp circuit in analog world.

By Dr Ali Shirsavar

The vast majority of analog power supplies are compensated using only 2 different types of op-amp circuits: Type II or Type III. The design of these compensators is covered in detail both in theory and with hands-on labs in Biricha's Analog Power Supply Design Workshops [1]. We have also discussed these in previous articles [2] in Bodo Power. If the vast majority of analog PSUs are stabilised with only two different types of op-amp compensators, it follows therefore that the vast majority of digital power supplies can be stabilised with just two simple linear difference equations.

The digital equivalent LDE for a Type III compensator is called a 3-Pole, 3 Zero Compensator (3p3z) and the digital equivalent LDE for a Type II is called a 2-Pole, 2-Zero compensator (2p2z).

Biricha's "Digital Power Supply Design Workshops" covers how these are derived and how you can design your own digital compensators in detail [3]. For the purpose of this short article, all we require is the digital LDE's for these two popular compensators.

The Digital Equivalent LDE for an Analog Type III Compensator

The circuit diagram of a standard Type III compensator is shown Figure 1.

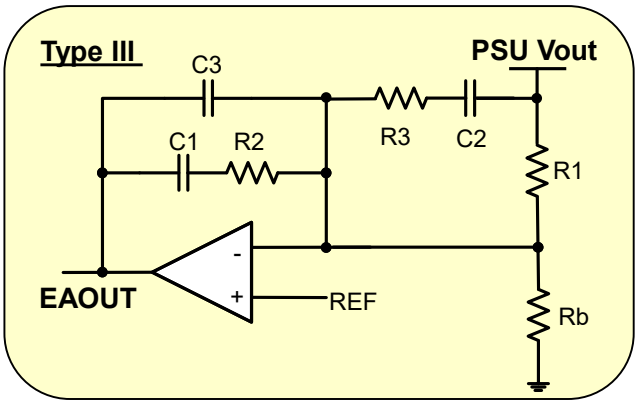


Figure 1: Analog Type III Compensator

From Biricha's design workshops [1,3] and previous articles here [2], we know that this compensator has 3 poles and 2 zeros as shown in its transfer function Hc(s) below:

We can see that we have a pole at origin , two more poles and two zeros and . Again from Biricha's workshops and previous articles in Bodo, we know exactly how to place these poles and zeros in analog

$$H_c(s) = \frac{\omega_{p0}}{s} \frac{\left(\frac{s}{\omega_{z1}}+1\right)\left(\frac{s}{\omega_{z2}}+1\right)}{\left(\frac{s}{\omega_{p2}}+1\right)\left(\frac{s}{\omega_{p3}}+1\right)}$$

world in order to get a stable loop with a desired cross-over frequency and phase margin. Please note all terms are in radians and all F terms are in Hz.

The digital equivalent LDE for this circuit is shown below:

$$y[n] = A_1\, y[n-1] + A_2\, y[n-2] + A_3\, y[n-3] + B_0\, x[n] + B_1\, x[n-1] + B_2\, x[n-2] + B_3\, x[n-3]$$

Please don't let the long equation put you off; we will explain everything shortly. This is called a 3-Pole 3-Zero digital compensator (3p3z) and every time in analog world we use a Type III in digital we must use a 3p3z to get a near exact performance. Please note that in digital we have an extra zero when compared to the analog. This is only an artefact of our transformation from analog world to digital world and therefore, the numerical output of this equation in frequency domain is an almost exact replica of the analog op-amp in Figure 1. Just like the op-map integrator of the previous article for now we are ignoring the impact of all scalings and time delays.

We know from our last article that y[n] in the equation above is our output from our digital compensator at this exact instance, i.e. the new value of demand PWM in this exact instant. We also know that x[n] is our input to the digital compensator at this exact instance, i.e. the error signal in this exact instant. In the case of a power supply this is usually the difference between our real output voltage as sampled by the ADC and our demand/reference voltage.

We also know that y[n-1] means our previous output, i.e. from the last sampling interval. If we assume a switching/sampling frequency of 200kHz, then each sampling interval would be 5us. Therefore "previous output" would be the output of the compensator 5us ago.

Similarly, y[n-2] would be our "Previous Previous output" from 10us ago and x[n-3] for example, would be our "Previous Previous Previous input" from 15us ago and so on.

Finally, you can see that the y terms are multiplied by a bunch of coefficients: A1, A2, A3 and the x terms are multiplied by another bunch of coefficients B0, B1, B2, B3.

These coefficients determine the locations of our poles and zeros. Ignoring all scalings and time delays for now, if we know the position of poles and zeros of our analog compensator (which we do), all we have to do to create an equivalent digital one is to calculate these 7 coefficients using the following equations:

$$A_1 = -\frac{\left(-12+T_s^2\,\omega_{p2}\,\omega_{p3}-2\,T_s\left(\omega_{p2}+\omega_{p3}\right)\right)}{\left(2+T_s\,\omega_{p2}\right)\left(2+T_s\,\omega_{p3}\right)}$$

$$A_2 = \frac{\left(-12+T_s^2\,\omega_{p2}\,\omega_{p3}+2\,T_s\left(\omega_{p2}+\omega_{p3}\right)\right)}{\left(2+T_s\,\omega_{p2}\right)\left(2+T_s\,\omega_{p3}\right)}$$

$$A_3 = \frac{\left(-2+T_s\,\omega_{p2}\right)\left(-2+T_s\,\omega_{p3}\right)}{\left(2+T_s\,\omega_{p2}\right)\left(2+T_s\,\omega_{p3}\right)}$$

$$B_0 = \frac{\left(T_s\,\omega_{p0}\,\omega_{p2}\,\omega_{p3}\left(2+T_s\,\omega_{z1}\right)\left(2+T_s\,\omega_{z2}\right)\right)}{\left(2\left(2+T_s\,\omega_{p2}\right)\left(2+T_s\,\omega_{p3}\right)\omega_{z1}\,\omega_{z2}\right)}$$

$$B_1 = \frac{\left(T_s\,\omega_{p0}\,\omega_{p2}\,\omega_{p3}\left(-4+3\,T_s^2\omega_{z1}\,\omega_{z2}+2T_s\left(\omega_{z1}+\omega_{z2}\right)\right)\right)}{\left(2\left(2+T_s\,\omega_{p2}\right)\left(2+T_s\,\omega_{p3}\right)\omega_{z1}\,\omega_{z2}\right)}$$

$$B_2 = \frac{\left(T_s\,\omega_{p0}\,\omega_{p2}\,\omega_{p3}\left(-4+3\,T_s^2\omega_{z1}\,\omega_{z2}-2T_s\left(\omega_{z1}+\omega_{z2}\right)\right)\right)}{\left(2\left(2+T_s\,\omega_{p2}\right)\left(2+T_s\,\omega_{p3}\right)\omega_{z1}\,\omega_{z2}\right)}$$

$$B_3 = \frac{\left(T_s\,\omega_{p0}\,\omega_{p2}\,\omega_{p3}\left(-2+T_s\,\omega_{z1}\right)\left(-2+T_s\,\omega_{z2}\right)\right)}{\left(2\left(2+T_s\,\omega_{p2}\right)\left(2+T_s\,\omega_{p3}\right)\omega_{z1}\,\omega_{z2}\right)}$$

I appreciate that at first glance these conversion equations may look big and intimidating, but the good news is that there is NOTHING within these equations that we do not know. We will now demonstrate this with a real life numerical example. Let us assume that we have designed an analog Type III compensator for a 200kHz Buck converter which has the following poles and zeros:
Fz1 = 1.21323 kHz
Fz2 = 1.61764 kHz
Fp2 = 6576.65 kHz
Fp3 = 100 kHz
Fp0 = 625 Hz

Where Fz1 and Fz2 are our zeros, Fp1 andFp2 are compensator pole and Fp0 is our pole at origin.

Let us now calculate our first coefficient (A1) from the equation above. Yes, I appreciate that this is a long equation but please have a look to see if there is anything in this equation that we do not know. We know everything!



Ts is our sampling interval and in our case is 5us for a 200kHz switching frequency and and are our compensator poles in analog world which we know to be Fp2 = 6576.65 kHz, Fp3 = 100 kHz (don't forget to convert to radians).

Therefore we can calculate A1 accurately to be 1.590703155656.

Now please take a look at the other intimidating coefficient equations. As with the A1 equation, even though these are long equations there is nothing within them that we do not know and therefore we can easily calculate all of them. Substituting our analog poles and zeros into the above equation and setting Ts to 5us, we have:
B0 = (+1.212026610403)
B1 = (-1.106625987416)
B2 = (-1.209779932536)
B3 = (+1.108872665284)
A1 = (+1.590703155656)
A2 = (-0.410251039699)
A3 = (-0.180452115956)

You can now see that we have a simple LDE, similar to the LDE of our previous simple op-amp compensator of the previous article and therefore we can easily get our MCU to calculate it.

As a reminder our output y[n] is our new PWM duty and our input x[n] is the difference between the demand output voltage and the real measured output voltage from the ADC:

$y[n] = A_1\,y[n-1] + A_2\,y[n-2] + A_3\,y[n-3] + B_0\,x[n] + B_1\,x[n-1] + B_2\,x[n-2] + B_3\,x[n-3]$

Our design is complete and this equation should behave almost exactly the same as the analog Type III compensator with the aforementioned poles and zeros.

The Digital Equivalent LDE for an Analog Type II Compensator
The circuit diagram of a standard Type II compensator is Figure 2.

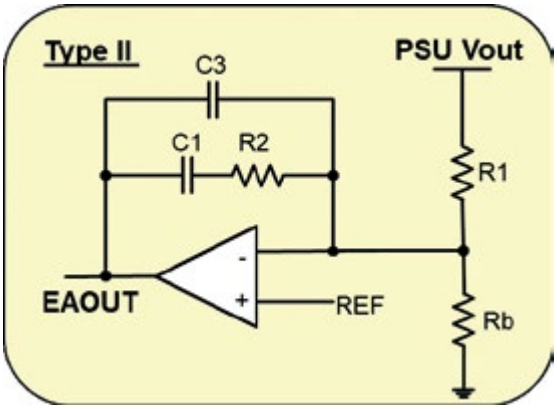


Figure 2: Analog Type II compensator

You can see that the only difference between a Type II and a Type III is the omission of R3 and C2 from the Type III circuit. All this means is that the transfer function of our Type II has one less pole and one less zero as shown:

$$H_c(s) = \left(\frac{\omega_{p0}}{s}\right) \times \frac{\left(\frac{s}{\omega_{z1}} + 1\right)}{\left(\frac{s}{\omega_{p2}} + 1\right)}$$

The linear difference equation for the Type II in digital world has 2 poles and 2 zeros and therefore it is called a 2-pole, 2-zero (2p2z) controller.

Any time in analog world we use a Type II in digital world we can use a 2p2z

$y[n] = A_1\, y[n-1] + A_2\, y[n-2] + B_0\, x[n] + B_1\, x[n-1] + B_2\, x[n-2]$

Our 2p2z LDE only has 5 coefficients (instead of 7 for 3p3z). These are given below:

$$B_0 = \frac{\left(T_s\, \omega_{p0}\, \omega_{p2} \left(2 + T_s\, \omega_{z1}\right)\right)}{\left(2\left(2 + T_s\, \omega_{p2}\right)\omega_{z1}\right)}$$

$$B_1 = \frac{\left(T_s^2\, \omega_{p0}\, \omega_{p2}\right)}{\left(2 + T_s\, \omega_{p2}\right)}$$

$$B_2 = \frac{\left(T_s\, \omega_{p0}\, \omega_{p2} \left(-2 + T_s\, \omega_{z1}\right)\right)}{\left(2\left(2 + T_s\, \omega_{p2}\right)\omega_{z1}\right)}$$

$$A_2 = \frac{\left(-2 + T_s\, \omega_{p2}\right)}{\left(2 + T_s\, \omega_{p2}\right)}$$

$$A_1 = \frac{4}{\left(2 + T_s\, \omega_{p2}\right)}$$

Again even-though the equations are long, you can see that provided that we have our poles and zeros in analog world and our sampling interval Ts, there are no unknowns and we can calculate everything.

Impact of Scalings and Time Delays
The LDE that we derived is the digital equivalent of the op-amp transfer function, but there will be various elements within the digital power supply that add a constant scaling factor to the gain plot.

For example if the maximum output of our power supplies is 6.6V and our ADC which samples it can only tolerate 3.3V then we have add a “divide by two” potential divider. This scaling factor of 0.5 needs to be taken into consideration or our gain bode plot and therefore our cross-over frequency will be off by a factor of 0.5. Similarly all pure time delays, for example the time taken from the time we sample our output voltage with the ADC to the time we update our PWM, add phase delays to our phase plot. Therefore, we will end up with less phase margin than we expected.

So far we have ignored the impact of various scalings and time delays. The good news is that all these are all easily calculated and we cover them all in the next article. We will also provide a step-by-step design and verify with complete experimental results.

Concluding Remarks
In this article we introduced the digital linear difference equations that emulate analog Type II and Type III compensators. We provided all the equations necessary to calculate all the coefficients

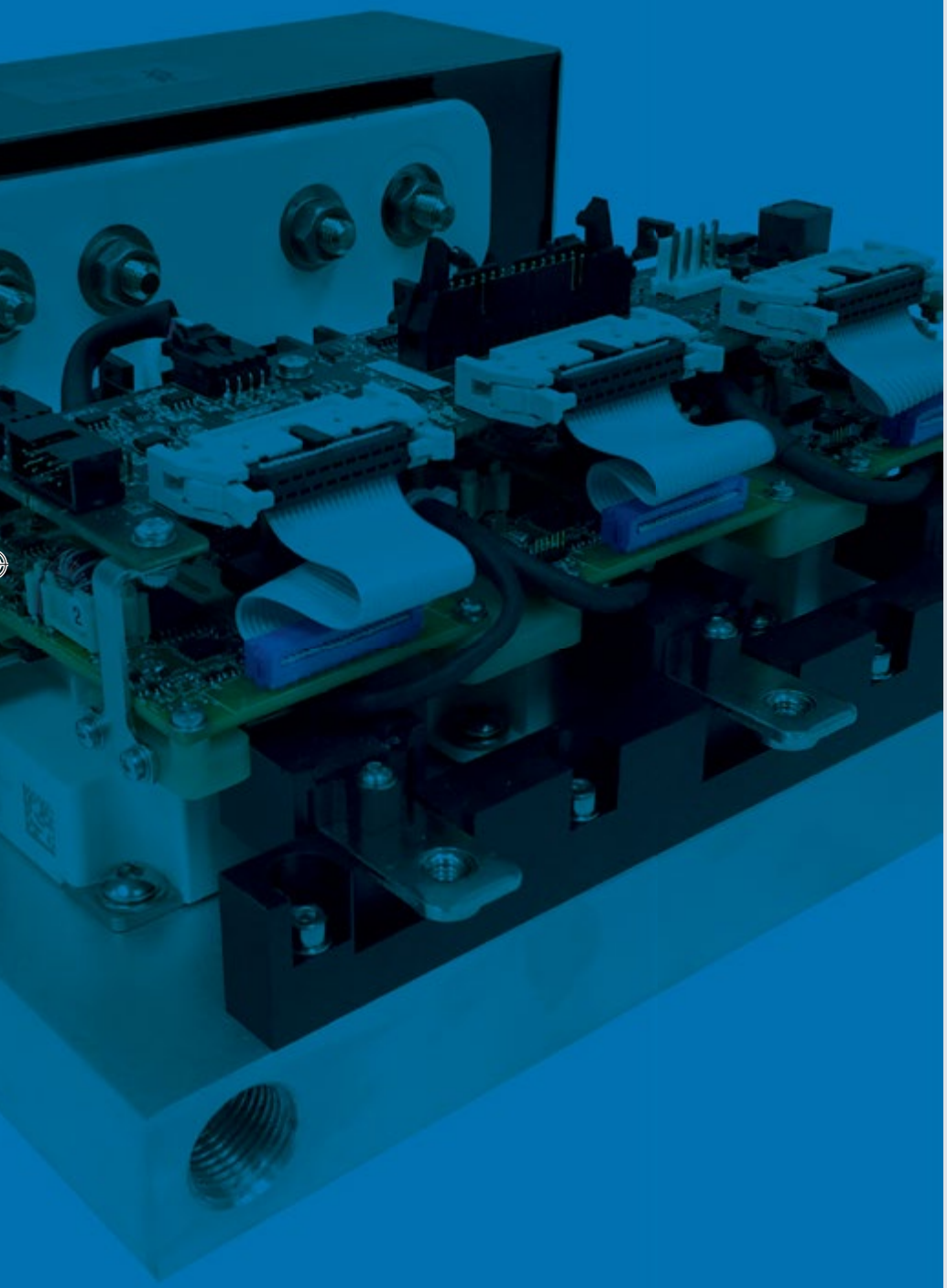
We proposed that although the coefficient equations can be big, provided that we know our analog poles and zeros and the switching/sampling frequency we can easily calculate them. To prove the concept, using a numerical example we showed exactly how all the coefficients can be calculated. Finally, we briefly discussed the impact of various scaling factors and time delays on our loop response in terms of gain and phase plots.

In the next article we will detail exactly how to calculate and compensate for ALL scalings and phase losses to get a near perfect match between analog and digital. We will then present a complete step-by-step numerical design example, implement this design in real life and provide experimental results to show that the theory matches with practice.

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A High Temperature Gate Driver for Half Bridge SiC MOSFET 62mm Power Modules

Today, wide bandgap semiconductors, in particular Silicon Carbide (SiC), are ramping up as early adopters amongst automotive OEMs are moving to this more and more mature technology offering higher efficiency and increased power density. For industrial applications, more people are also attracted by the benefits of SiC Power Transistors. In order to take full advantage of fast switching and low losses SiC MOSFETs, two main challenges remain: getting well optimized power modules featuring low parasitic inductances and having a robust and fast gate driver to reliably and efficiently drive them.

By Pierre Delatte, CTO, CISSOID S.A.



Figure 1: CMT-TIT8243 high temperature high voltage isolated Gate Driver for 62mm SiC MOSFET power modules



Figure 2: CMT-TIT8243 high temperature high voltage isolated Gate Driver

This article presents a new gate driver solution answering the key requirements of SiC MOSFET drive:

- Fast switching capability (high dV/dt) for high efficiency
- High switching frequency for high power density
- High Voltage Robustness
- Safe & Reliable Operation

Fast Switching

SiC MOSFETs allow fast switching, i.e. high dV/dt, and hence low switching losses. For a given device, switching losses can be reduced by decreasing the external gate resistors (see Figure 3). This increases the peak gate current and dV/dt. So, a gate driver must be able to deliver high peak gate current to enable low switching losses.

It is worth to know that SiC MOSFET power modules are generally internally damped in order to limit the dV/dt and to avoid ringing inside the module. For example, CAS300M12BM2 module [2] has an internal gate resistor of 3 Ohms. With driving voltages of +20V/-5V, the internal gate resistor limits the peak gate current to 8.3A. It is generally recommended to add a minimum external resistance, e.g 2.5 Ohms, to avoid any ringing. This means that the peak current is in practice limited to 4.5A. With a maximum Peak Gate Current of 10A at 125°C, the CMT-TIT8243 Gate Driver can drive 1200V/300A SiC MOSFET modules at the maximum dV/dt and then the minimum switching losses.

Parameter	Conditions	Min.	Max.	Units
Peak gate current	Rgate_on=Rgate_off= 0Ω, Ta=125°C	10		A
Max average gate current	Ta=125°C, V+=20V, V-=-5V	95		mA
Positive driving voltage	-40 to 125°C, from 0 to max load	19.4	20.6	V
Negative driving voltage	-40 to 125°C, from 0 to max load	-5.2	-4.8	V
Parasitic capacitance	Between High-Side and Primary		10	pF
Max dV/dt		50		kV/µs
Drain-Source Voltage			1200/1700	V
Isolation voltages	(50Hz, 1min)	3.6		KVrms
Creepage/clearance		14/12		mm
Steady Operating Temperature		-40	125	°C

Table 1: CMT-TIT8243 Gate Driver main characteristics



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As high dV/dt is desired to reduce SiC MOSFET switching losses, it makes the design of the gate driver challenging. Indeed, high dV/dt across the parasitic capacitances of the isolation barrier, i.e. the power transformer and the signal isolators, generates high common mode current that can disturb the gate driver operation and can generate unwanted behaviour like parasitic turn-on or turn-off. CMT-TIT8243 Gate Driver has been designed to provide robustness against high dV/dt: the power transformer has been optimized for low parasitic capacitance in order to minimize common mode currents. The total parasitic capacitance is < 10pF between high-side driver and primary side, including power transformer and isolators. CMT-TIT8243 is guaranteed to operate properly at dV/dt > 50KV/µs.

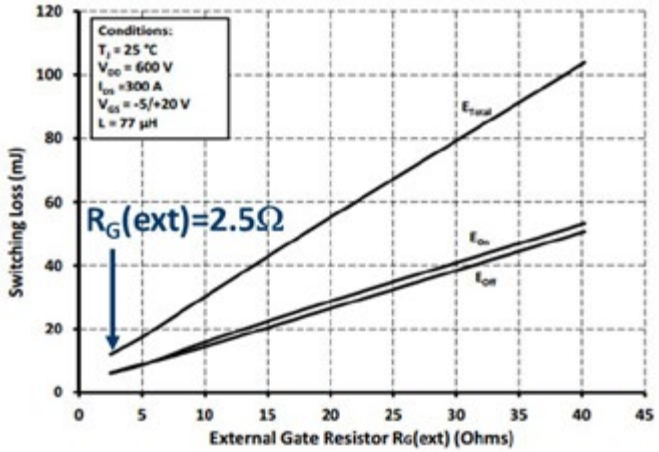


Figure 3: Switching losses versus the external gate resistance for CAS300M12BM2 module [2]

CMT-TIT8243 Gate Driver also features a RS-422 differential interface for input PWM signals to improve signal integrity during fast transitions of the power stage. With parasitic capacitances lower than 10pF between primary and secondary, with dV/dt up to 50KV/µs, common mode currents are still close to 0.5A; this level of common mode current could disturb inputs signals if a single-ended interface would be used. Figure 4 shows double pulse switching of the CMT-TIT8243 gate driver and CAS300M12BM2 module at 250A/600V. Figure 5 shows high-side switch turn-on with dV/dt > 40kV/µs and clean gate signals.

High switching frequency

Thanks to low switching losses, SiC transistors allows to increase the switching frequency of power converters while keeping the cooling of power devices under control. This reduces the size of filters and transformers and allows to drastically decrease the size and the weight of the power converter. To secure high frequency switching, the isolated DC-DC converter of the gate driver must be able to supply enough average gate current, which is calculated as the total gate charge multiplied by the switching frequency.

CMT-TIT8243 Gate Driver can supply an average gate current of 95mA per channel. With 1200V/300A SiC MOSFET modules having a total gate charge of about 1µC at 800V/300A [2], this means that the gate driver can operate at a switching frequency of 92KHz. In practice, the maximum switching frequency will be constrained by the switching losses in the power module rather than by the gate driver.

SiC MOSFET technology also helps to achieve high power density thanks to higher operating junction temperature. As the power density inside the converter increases, the ambient temperature also increases. If people are putting a lot of effort in cooling down the power modules, they often neglect the cooling of the gate driver. With an ambient operating temperature of 125°C with no derating in terms of maximum average gate current, CMT-TIT8243 Gate Driver offers thermal headroom for high power density converters and so eases their thermal and mechanical design.

Having a stable and accurate positive driving voltage is important as the On Resistance of SiC MOSFET decreases with the gate-to-source voltage. Having to deal with important variations of the positive driving voltage implies to take larger margins in the thermal design of the power converter. CMT-TIT8243 gate driver has an accuracy better than 5% for the positive driving voltage which eases the thermal design of the power stage.

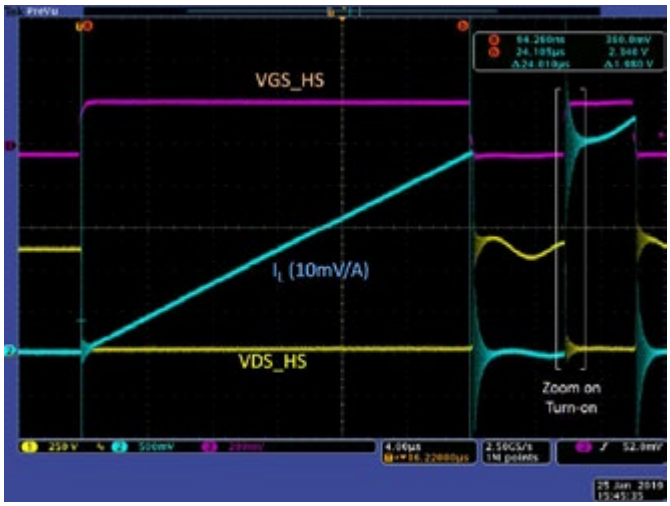


Figure 4: Double pulse switching with CMT-TIT8243 gate driver and CAS300M12BM2 module [5]

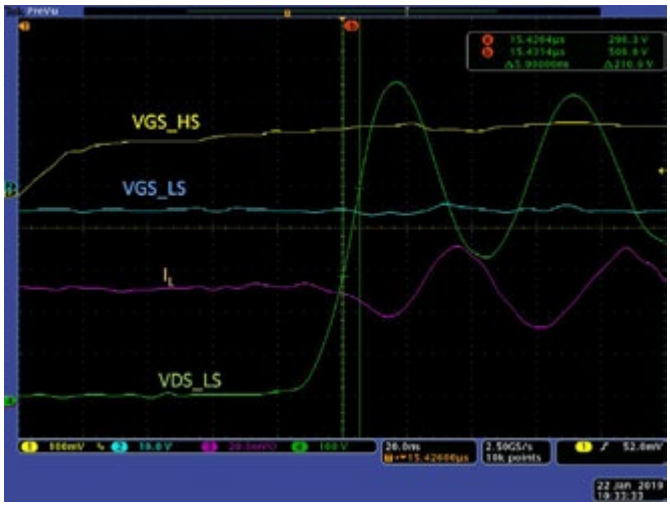


Figure 5: dV/dt>40KV/µs at turn-on with CMT-TIT8243 gate driver and CAS300M12BM2 module [5]

High Voltage Robustness

SiC technology brings the best benefits at blocking voltages above 600V. Also, high dV/dt and high dI/dt create voltage overshoots across the parasitic inductances inside the power loop, including the power module, the busbar and the DC bus capacitor. The gate driver is also submitted to these high voltages and must guaranty a high isolation.

CMT-TIT8243 gate driver has high isolation voltages offering safety margin in harsh voltage environments:

- Inter channel Isolation
  (High-Side to Low-Side) > 3600 Vrms (50Hz, 1min)
- Low-side channel isolation
  (Low-Side to Primary-Side) > 3600 Vrms (50Hz, 1min)
- High-side channel isolation
  (High-Side to Primary-Side) > 3600 Vrms (50Hz, 1min)

It has also been designed with high isolation distances for safe operation in polluted environments:

- Creepage > 14 mm
  (Primary to any secondary, between secondaries)
- Clearance > 12 mm
  (Primary to any secondary, between secondaries)

Safe & Reliable Operation

Power transistors need to be turned off with a negative voltage in order to prevent a parasitic turn-on during the transition. However, this negative voltage needs to be well controlled as too negative gate bias can affect the long-term reliability of the gate oxide of SiC MOSFET [6]. CMT-TIT8243 gate driver has an accuracy better than 5% for the negative driving voltage.

If protections against fault is critical for gate drivers, it is even more for driving fast switching devices like SiC MOSFETs or GaN transistors. Key protections functions are:

- Undervoltage Lockout (UVLO): CMT-TIT8243 Gate Driver monitors the input primary supply voltage as well as the secondary output voltages of the isolated DC-DC converter and reports a fault when they are below the programmed threshold. Hysteresis prevents false fault event.
- Anti-overlap: this function forces a minimum non-overlapping between high- and low-side PWM signals in order to prevent turning on at the same time High-Side and Low-Side power switches.
- Active Miller Clamping (AMC): implements a bypassing of the negative gate resistor after turn-off to protect the power MOSFETs against parasitic turn-on. This function is very helpful with fast-switching SiC MOSFETs generating high current through the Cgd Miller capacitance.
- Desaturation detection: at turn-on, checks after blanking time that the power MOSFET drain-source voltage is below a threshold. If not, it likely means that a short-circuit had occurred in the power branch and the active transistor must be turned off. A fault must be reported to the controller.
- Soft Shut-down: in case of fault, a slow turn-off of the power transistor is implemented to minimize overshoots due to high dI/dt.

Conclusion

A new isolated high-voltage gated driver board optimized of 62mm SiC MOSFET power modules has been presented. Its extended temperature rating at 125°C (Ta) offers thermal headroom for the design of high-density power converters. High peak gate current enables fast switching and low losses while high average gate current support high-frequency switching. High voltage isolation and protection functions make the gate driver to safely operate in harsh electrical environments.

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Specialising Performance: Collaboration Gets it Right with Custom Power Magnetics

Holistic Design Approach Improves Efficiency, Reduces Risk and Costs

Off-the-shelf magnetic components are often a compromise solution for any application, both electrically and mechanically. To achieve ideal performance at minimum cost, custom inductors or transformers may be a better alternative, with greatest benefit realised when user and supplier work together closely.

Headline specifications such as inductance, turn ratios and resistance are only part of the story; expertise helps identify other relevant parameters – critical to tooling options for the right fit components, from the outset of the design.

By Peter F Vaughan, Technical Director, TT Electronics



Prioritizing magnetics design

There's an argument that magnetic components should be considered first in any power electronics design. Often the largest components and the most difficult to terminate, these complex devices have the potential to set the overall mechanical arrangement of the product.

At the same time, it can be tempting to overlook the specification of magnetic components based on long-established technologies until later in the design process, instead exploring more enticing digital techniques and exotic wide band-gap semiconductors that promise near-zero losses, while device application notes often show magnetics as a deceptively simple and ideal components based on just an inductance value. With this thinking, all designers need to know is the current in the circuit – take a quick look in the catalogues to determine corresponding parts with inductance and current ratings to match. So, all set, right? Invariably the answer is no, as real magnetics have many secondary parameters that are often not specified for standard parts in catalogues and which affect circuit performance dramatically. This is especially true in designs looking to achieve highest efficiency in the smallest size and cost. In these scenarios, dropping in a standard part is not likely to drive optimum performance. Customised components are typically a better fit; however, designers must understand the complexities of magnetics including a range of parameters that impact performance, cost, and potential trade-offs required throughout the device's design.

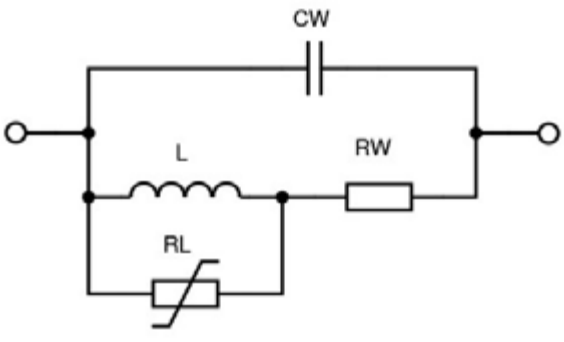


Figure 1: Simplistic inductor equivalent circuit

Magnetics have many parameters

It's feasible to have a store of resistors and capacitors – a broad slate of options from which engineers can choose to support their new designs, or perhaps even 'design around' without compromising overall product performance. Yet magnetic components are different (Figure 1). Depending on the application, factors such as inductance L, current rating, winding resistance RW, non-linear core losses RL, winding capacitance CW, leakage field, self-resonance, saturation characteristics and more might be crucial parameters. This would be for an inductor, but transformers require still more considerations including winding ratios, isolation/safety ratings, mutual inductance, inter-winding capacitance, and more. Many parameters vary with temperature and drive level and are in turn interdependent. All types have a wide range of possible mechanical formats. The permutations multiply dramatically – and while distributors of standard parts may stock popular variants, it is unlikely that any single option will fit all requirements exactly. Custom parts add value and should be considered.

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Inductor specifications

For optimum design, details about current flows and available space are insufficient specifications to provide to a custom magnetics supplier. For example, the discussion should include a specification for inductance tolerance. Calculations will yield a required inductance; a wider acceptable range makes for easier manufacturing and lower cost, especially at high inductance values. The current waveform should also be specified; DC only produces ohmic losses, but any AC components generate core losses that are of strong frequency and level dependent. Core saturation must be avoided but is an instantaneous effect, so peak value of any AC current should also be specified. For example, it is quite common for converters using synchronous rectification to have a large proportion of AC current superimposed on DC in output filter inductors (Figure 2). For standard parts, maximum rated current is the DC value specified for an inductance drop of a certain percentage, which varies between manufacturers. A drop of 30% at rated current would not be uncommon, demonstrating the onset of saturation which might be disastrous in a practical circuit. Specifying a minimum inductance with a current waveform is advisable.

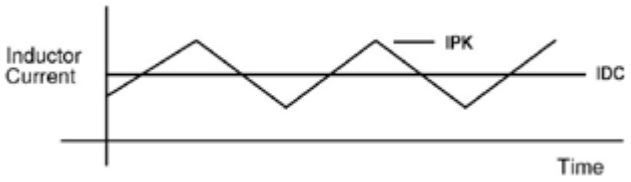


Figure 2: Typical buck converter inductor current with a high AC components

Even saturation has its characteristics. For instance, ferrite cores lose inductance suddenly at a threshold current but other types, such as iron powder, drop their value more gradually. If transient overloads are possible, this might be more desirable although powder has higher AC losses than ferrite, a situation in which a supplier can advise ideal trade-offs.

Operating temperature is a major consideration. For standard parts, maximum surface temperature rise is normally rated but the point of measurement varies. The limit can be reached for different reasons as well, either because of ohmic losses, core losses with AC bias, or a combination of both. Specifying the actual current waveform and a maximum ambient temperature allows the supplier's design team to select wire gauges and core materials. These can be selected to ensure acceptable surface temperature rise for the materials used in a given ambient.

Leakage field around an inductor may also represent a system issue, producing EMI and coupling to other components. While it would be difficult to specify an acceptable level, it is useful to tell a supplier that it might pose a problem. This would steer the design towards a solution that offers an element of self-shielding. Drum cores are especially bad for external field but are very low cost while enclosed structures, such as pot-cores or some E-cores, are much better yet more expensive. The required inductance will affect the decision – if it is high, drum cores with their inherent large gap would require many turns of thin wire with high consequent resistance and losses. An ungapped E-core, for example, would need fewer turns, allowing thicker wire and a reduction in losses. Suppliers can assist by marking the 'start' pin of a wire-wound inductor, which is an inner winding layer. This pin can then be the noisier connection, often a switching node, so that the outer or quieter layers of the winding act to some extent as an electrostatic shield (Figure 3).

While a circuit design may indicate a certain inductance value, it is worth considering whether the natural variation of the manufactured part can be used to advantage. For example, DC chokes with iron powder cores have inductances that strongly vary with current. Some types might double their nominal inductance at light load. In this scenario, buck converters with diode rectifiers would enter discontinuous mode at lower load currents, benefitting designs by supporting stability and improving secondary output cross-regulation. Collaboration with suppliers will increase insight on these effects and advocate choosing cores that may provide this advantage.

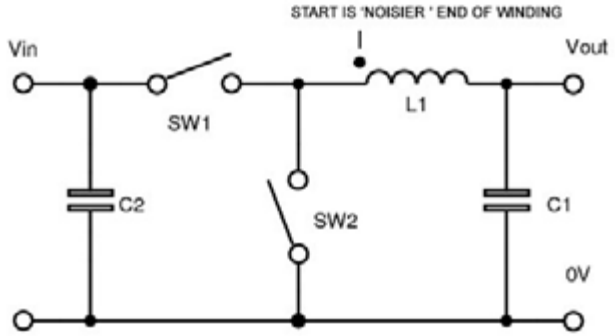


Figure 3: Noisy end of an inductor as innermost layer for shielding effect

Self-resonance is also an important consideration, as self-capacitance of windings can resonate with winding inductance at relatively low frequencies and may affect circuit stability. Winding methods can be employed, however, to keep the resonant frequency high. For example, toroids with single layer windings provide favourable results.

Resonance may provoke high voltages across inductors, but wire insulation is usually sufficient. There are instances however, when an inductor does need a high voltage rating. For example, non-isolated buck converters dropping rectified mains to low voltage DC are common. In this case, their inductors experience up to ~370V switched at high frequency across their terminals. Wire and termination insulation must be appropriate and even the core may be a source of breakdown due to different materials having varying resistivity. Again, an experienced supplier can guide an ideal approach.

Transformer specifications

Power transformers are even less standard and have more parameters to consider (Figure 4).

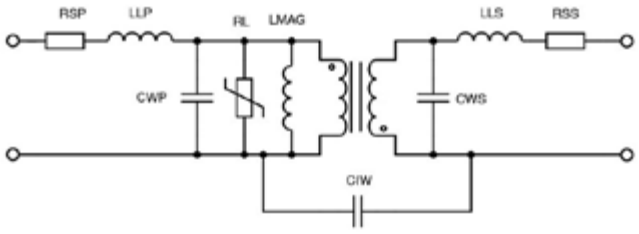


Figure 4: Transformer equivalent circuit

Parasitic transformer characteristics, such as leakage inductance LLP and LLS, can affect circuit performance dramatically, sometimes for the better. Some resonant converter topologies require a minimum value and a simplistic design would integrate this as a separate, discrete component. It could be built-in to the transformer; however, this requires judicious placement of windings and core gaps. Expertise is critical here, ensuring design viability while maintaining other specifi-

cations and isolation ratings that save the cost and space of discrete external components.

Designing for an exact isolation rating is a skill that a custom magnetic suppler will often possess, with knowledge of the creepage and clearance requirements for various safety standards. Materials used should be in an approved insulation system[1] which makes agency acceptance much easier. Designers can save significant resources by tapping into a supplier-recommended combination of wire, tape, plastics, varnish, etc., that are proven to be compatible.

Custom magnetics suppliers will sometimes support power converter reference designs – an excellent way to achieve the promised performance from a specific PWM IC, for example, with low-cost electromagnetics.

Taking advantage of existing tooling and buying power

Specialist magnetics manufacturers often rely on unique tooling for high performance bobbins and cores. Further, these bobbin and core shapes may be more affordable if the supplier is already purchasing in volume for multiple clients.

It's also likely that these engineering teams have already addressed the same issues you're facing in your application. Their specific skills have been honed, such as ultra-fine wire-winding and edge-winding or forming helical coils from flat copper stock.

Eliminate risk with specialised design skills and experience

Given these complexities, the perfect power magnetics components for your robust or critical application are unlikely to be found in a catalogue listing. Collaboration is ideal in developing an optimum solution. Where it may appear that designs can choose between E-cores, toroids, drum cores and more with through-hole and surface-mounts, a specialist supplier's design team can advise when there are electrical trade-offs between each of these choices. Considering the overall system helps determine the best fit magnetics components, yielding system-wide savings by improving efficiency, assembly time, reliability, functionality, and, of course, unit cost.

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[2] www.ttelectronics.com

About the Author

Peter F Vaughan, Technical Director, TT Electronics

Peter has been developing switch-mode power supplies and magnetics components since 1983. He has held the role of Chief Designer for the TT Electronics Barnstaple facility since 1991, and is responsible for custom design of transformers and inductors from 4kW 50Hz, 3-phase 400Hz, filter and smoothing inductors for 20kHz comms-on-power diplexers, and RF inductors to 2MHz.

www.ttelectronics.com



900 A 1200 V EconoDUAL™ 3 Has Highest Power Density and Performance Using New IGBT7

The development of the new semiconductor generation targets a current density increase with the aim to reduce system costs for inverter manufacturers. It is crucial that the new technology be implemented in a given module footprint to facilitate the upgrade of existing inverter systems. This approach leads to a fast market penetration.

By Klaus Vogel and Christoph Urban, Infineon Technologies

For this to happen, the switching characteristics of the improved IGBTs and diodes have to fit the characteristics of the selected module housing. This is true especially with regard to oscillation behavior, since the module current is higher, and the reduction of module stray inductance is limited. At the same time, improving the housing is an important consideration to be able to handle higher currents and temperatures.

For the user of the new device, the benefits are clear: higher inverter output current for the same frame size, and avoidance of paralleling of IGBT modules. Both of these advantages help to simplify inverter systems and to lower costs. In this paper, the technical aspects of the new EconoDUAL™ 3 with TRENCHSTOP™ IGBT7 for general-purpose drives application will be discussed.

Target application

One target application for the new IGBT7 generation is the general-purpose drive (GPD) application in a power range above 90 kW. It is important to take into consideration the typical application parameters to understand the improvement levers to achieve a benefit compared to the predecessor IGBT4 technology. Typically, switching frequencies for GPDs in the power range above 90 kW are in the range of 2 to 2.5 kHz [1,2]. Most inverter manufacturers use advanced modulation methods such as discontinuous pulse width modulation (DPWM) [3] that leads to a reduction of switching losses by half compared to traditional continuous modulation [4].

For the IGBT7 development and for the following study, a switching frequency of 1 kHz and 2.5 kHz, both as continuous PWM, are selected to evaluate the new technology. The results are thus valid for higher switching frequencies using DPWM. Furthermore, a characteristic of this application is the use of an air-cooled heatsink of extruded aluminum at a maximum ambient temperature of 40°C. The nominal current of the GPD inverter is dimensioned taking into account normal and heavy-duty overload pulses at different overload current levels. Therefore, the maximum allowed IGBT operation temperature has also to take into consideration this type of operation.

Finally, the maximum steepness of the voltage slope ($du/dt_{10\text{-}90\%}$) during IGBT turn-on and turn-off is typically limited to maximum 5 kV/µs due to the motor winding lifetime and drive-shaft corrosion [5] as well as to electromagnetic compatibility (EMC). A simulation using the above-mentioned application parameters is implemented with the power electronic module FF60012ME4_B72 and the results are shown in figure 1.

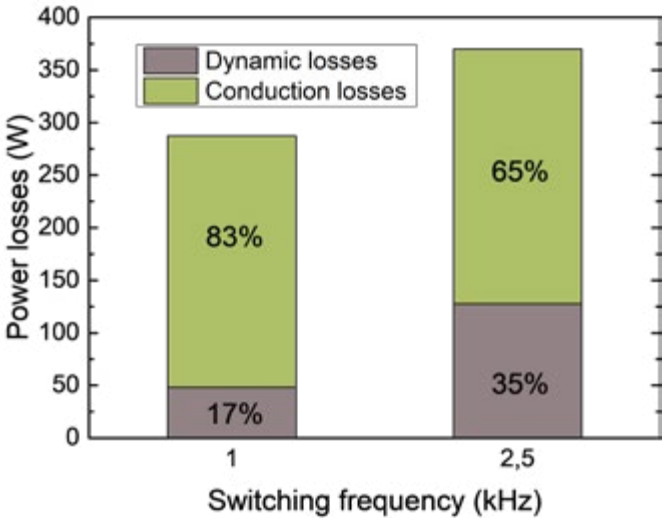


Figure 1: Loss distribution FF600R12ME4_B72 at 350 A and typical GPD conditions for this power class

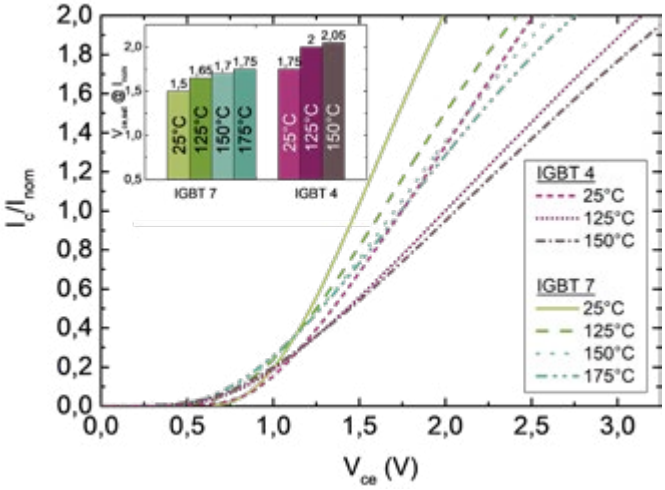


Figure 2: Normalized output characteristics of the 1200 V TRENCHSTOP™ IGBT4 medium power compared with the 1200 V TRENCHSTOP™ IGBT7, measured at Vge=15 V

It becomes visible that the conduction losses of the IGBT and diode predominate over the dynamic losses. At 1 kHz these losses represent 83%, and at 2.5 kHz 65% of all semiconductor losses. This, together with the fact that the switching speed for electrical-motor-related applications cannot be increased above 5 kV/µs, leads to the conclusion that the main lever for device optimization is the static loss reduction.

Static losses

The corresponding normalized output characteristics of the IGBT7 micro-pattern trench MPT technology and the IGBT4 are presented in figure 2 for temperatures 25°C, 125°C and 150°C; and for the TRENCHSTOP™ IGBT7 additionally 175°C.

A reduction of $V_{CE,sat}$ from 2.05 V to 1.70 V by 350 mV at nominal current is observed when comparing both IGBT technologies, which demonstrates the optimization of the device.

Dynamic switching

The turn-on losses (E_{on}) of the 900 A IGBT7 module are lower than those of the 600 A IGBT4 module when a similar collector current is turned on. In fact, the reduction of the saturation voltage and the given device softness result in higher turn-off losses for the 900 A IGBT7 compared with the 600 A IGBT4 at similar collector currents. In figure 3, the values are presented for both chip technologies.

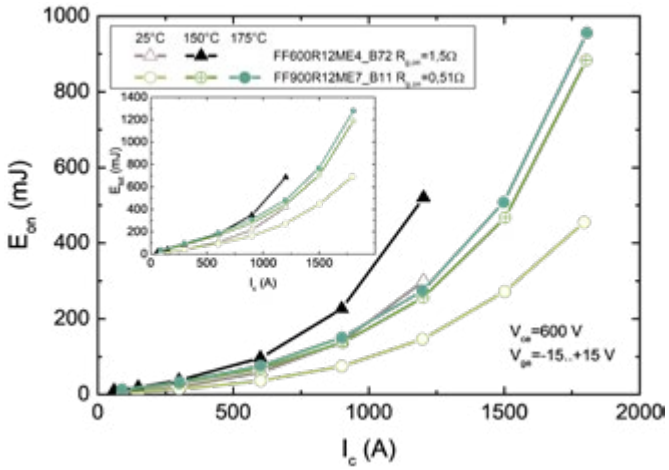


Figure 3: Turn-on losses E_{on} of the FF600R12ME4_B72 and the FF900R12ME7_B11 as a function of the collector current I_c. The insert shows E_{tot}, the sum of E_{on} and E_{off}

The chosen external gate resistances coincide with the data sheet values, which have been defined in such a way that switching without cut-off oscillations of the IGBT and diode at 25°C is ensured. Moreover, quite similar du/dt values are present for the FF600R12ME4_B72 and the FF900R12ME7_B11 at those gate resistances for turn-on as well as for turn-off. As a result, the total IGBT losses (E_{tot}) which are the sum of E_{on} and E_{off} remain nearly the same (insert in figure 3). Especially, below 600 A, both modules show identical losses.

IGBT and FWD junction temperature specification

While the IGBT4 has a specified absolute maximum temperature of $T_{vj,op}$ equal to 150°C, without differentiation between continuous and overload operation, the IGBT7 $T_{vj,op}$ specification is made taking into account the typical overload scenarios specified by the drives manufacturers, and can cover the 3 seconds as well as the 60 seconds overload pulses. For continuous operation, the IGBT7 is specified for 150°C and for overload operation 175°C for a maximum of 60 seconds. Details about the specification is described in [6].


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Application tests and results

All the characteristics of the newly developed FF900R12ME7_B11 described above will lead to an improvement in performance compared to the FF600R12ME4_B72 device. To evaluate and compare the performance of these two devices, a series of application tests was performed, and the temperatures evaluated with an infrared camera. The test parameters were set taking into account the information described in Chapter 1 and listed in Table 1:

Topology	H-Bridge
Heatsink	Air cooled heatsink
Switching frequency	1 and 2.5 kHz
Modulation method	Continuous PWM
Gate-Emitter voltage	-8 V to +15 V
DC-Link voltage	621 V
Modulation index	0.95
cos phi	0.9
$du/dt_{10\text{-}90\%}$	< 5 kV/µs
IR-camera picture rate	30 pictures per second
Ambient temperature	20°C* (40°C)

*Table 1: Typical GPD parameters used to compare IGBT7 with IGBT4 in the application. *The required ambient temperature of 40°C cannot be adjusted with the test setup.*

Output current and temperature reduction

The results of the experiment are exemplary for a switching frequency of 1 kHz visualized in figure 4.

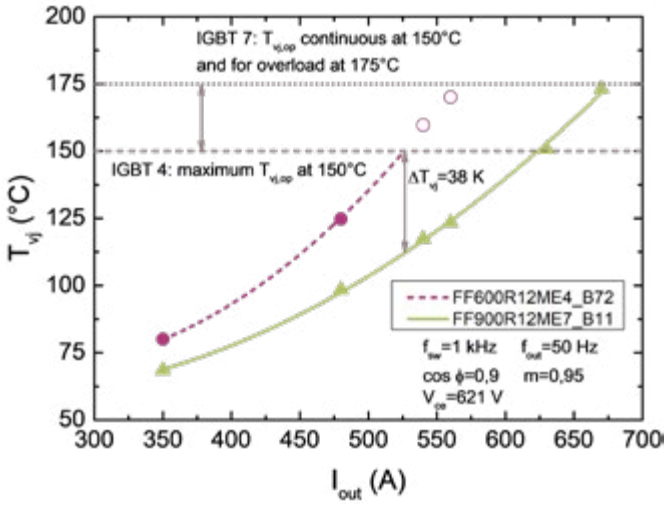


Figure 4: IGBT junction temperature as a function of output current at 1 kHz and conditions described in table 1

It becomes visible that at 1 kHz continuous PWM and the same output current, the module using the IGBT7 technology operates at 38 K lower temperature compared to the IGBT4 device. Pushing the new module to the limit of the specified temperature leads to 150 A higher output current. At 150°C the IGBT7 still has the advantage of 95 A more compared with the IGBT4.

Also at 2.5 kHz continuous PWM modulation, the benefit of the new technology is significant: 33 K lower temperature at the same current and 70 A at 150°C, and 110 A at 175°C more maximum output current are possible.

DC-terminal temperature reduction

Figure 5 illustrates the temperature reduction achieved using the new housing of the FF900R12ME7_B11 compared with the FF600R12ME4_B72.

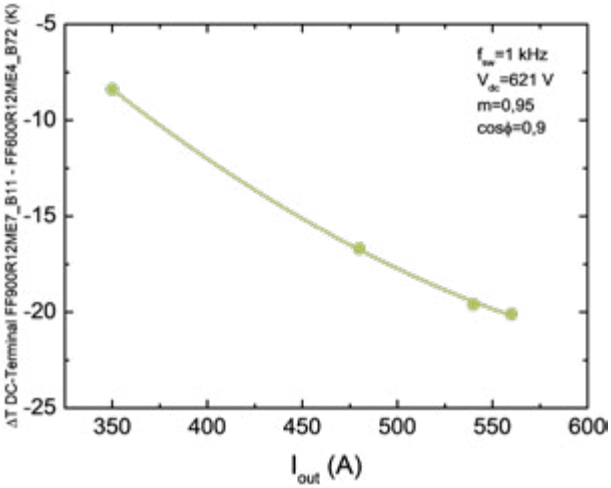


Figure 5: Temperature improvement comparing the DC-busbar temperature of the new and former housing

The new housing of the FF900R12ME7_B11 module leads to a temperature reduction of up to 20 K on the DC busbar compared to the FF600R12ME4_B72 at the same output current

GPD frame size

In this part of the test, the parameters regarding output current for normal duty (ND) and heavy duty (HD) of a GPD manufacturer [1] were selected to evaluate the maximum possible frame size current for the different technologies. The parameters are listed in table 2.

	Frame size 370 A (A)	Frame size 477 A (A)
Rated current I_{ND}	370	477
Normal-duty 60 s 1.1 x I_{ND}	407	525
Normal-duty 3 s 1.5 x I_{ND}	555	716
Rated current (I_{HD})	312	370
Heavy-duty 60 s 1.5 x I_{HD}	468	555
Heavy-duty 3 s 2 x I_{HD}	624	740

Table 2: Selected parameter to test the frame size capability of the two modules.

The rated output current was applied on the semiconductor at the conditions described in table 1, at 2.5 kHz. The temperature of the entire system was in steady state before overload current application. The thermal behavior of the system is shown in the example in figure 6. The IGBT4 solution is at the temperature limit with frame size 370 A. During the 3 seconds heavy- duty overload pulse, the IGBT T_{vj} achieves a value of 142°C.

The IGBT7 device is able to fulfill the requirements of the 477 A frame size. At all required current levels, the FF900R12ME7_B11 is still within the IGBT7 specification presented [6]. Since the ambient temperature in the test was 20°C instead of the required 40°C, the achieved results are valid for the purpose of comparison. Hence, inverter manufacturers can achieve the same output current at 40°C

by using an improved heatsink, using discontinuous PWM, and/or reducing the switching frequency.

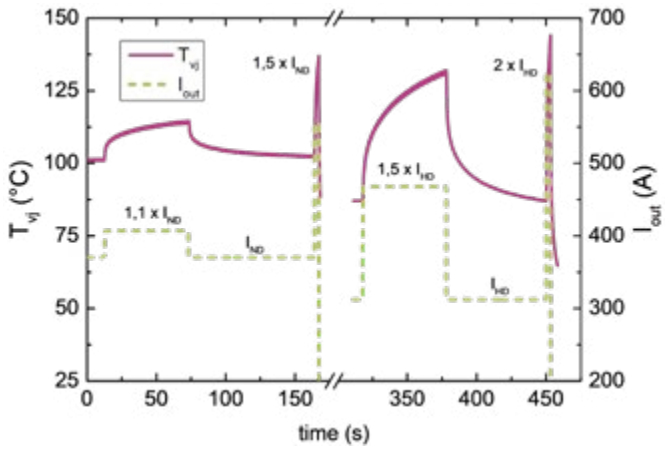


Figure 6: Frame size 477 A, FF900R12ME7_B11 device: Measurement results at rated current ND and HD, normal duty and heavy-duty overload pulses.

Summary

The newly developed chipset of IGBT7 and emitter-controlled 7 diode is user-friendly and optimized to fulfill the general-purpose drives (GPD) requirements. A significant reduction of static losses, good controllability, sufficient softness at all application-relevant current levels, and high short-circuit capability has been achieved. The improvement in the EconoDUAL™ 3 housing and the new temperature specifications for covering the drives overload requirement result in a high degree of freedom for the inverter design engineer.

The conducted application tests have demonstrated impressively an improved performance when compared to the former generation. The new FF900R12ME7_B11 achieves 38 K lower temperature compared to the FF600R12ME4_B72 module at the same current. Alternatively, up to 150 A higher output current can be achieved. Bearing in mind the typical GPD normal-duty and heavy-duty design criteria, a frame size jump from 370 A to 477 A is possible with the EconoDUAL™ 3 housing using IGBT7 instead of IGBT4.

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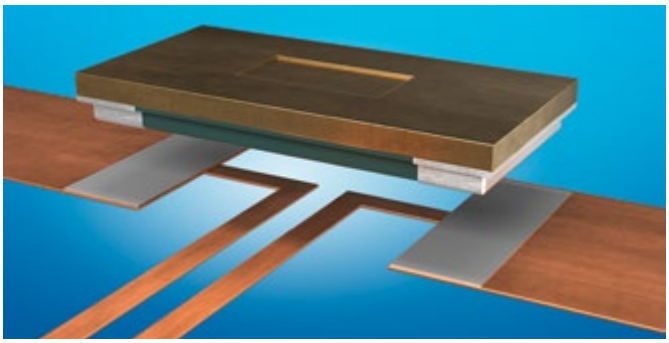
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Range of 1-to-6 mOhm Precision Resistors

Isabellenhütte has developed a range of precision resistors in standard sizes with resistances ranging from 1 to 6 mOhm for applications which require small and low-ohmic shunts. In terms of their construction, the components are also less complex than the current ISA-PLAN®resistance families. And yet, they offer the same performance quality: very good long-term stability, a low temperature coefficient, and low thermoelectric voltages. With the FMx shunt family, Isabellenhütte has now plugged a gap in the standard size range for precision resistances. It has not been possible with the previous product ranges to realize the usual S (2512), P (2010) and K (1206) standard sizes in the resistance range from 5 to 1 mOhm. The impetus for this development was provided by increasing demand for these resistances as well from a wide range of industries, including the automotive sector (for in-car chargers and assistance systems) and industry (for BLDC drive units), but also from the consumer market (e.g. for white goods). The large cross-sectional areas required for low-ohmic components have been achieved by a change in construction, and the production process has also been significantly simplified.



www.isabellenhuette.de

Ultra-Compact Automotive-Grade MOSFETs

ROHM announced the development of ultra-compact 1.6x1.6mm size MOSFETs that deliver superior mounting reliability. The RV4xxx series is AEC-Q101 qualified, ensuring automotive-grade reliability and performance under extreme conditions. ROHM's original package processing technology enables the miniaturization of automotive components, such as ADAS camera modules, that demand high quality. In recent years, the growing number of vehicle safety and convenience systems such as ADAS cameras has emphasized the challenge of limited space to accommodate these systems, and spurring the demand for smaller components. To meet this need, bottom electrode type MOSFETs that can be miniaturized while maintaining high current are increasingly attracting attention.



However, for automotive applications optical inspection is performed during the assembly process to ensure quality, but in the case of bottom electrode components solder height cannot be verified after mounting, making it difficult to confirm mounting conditions.
ROHM has a proven track record of developing and introducing new products ahead of market trends, and such is the case with the new ultra-compact MOSFETs. This time, ROHM has become the first in the industry to ensure the minimum solder height (130µm) required for vehicle applications by utilizing original Wettable Flank formation technology. The result is a consistent solder quality – even for compact products – enabling automatic inspection machines to easily verify solder conditions after mounting.

www.rohm.com

Power Switching Regulator Extends Battery Life

Texas Instruments introduced an ultra-low-power switching regulator with the industry's lowest operating quiescent current (IQ) at 60 nA – 1/3 that of the nearest competitive device. The TPS62840 synchronous step-down converter delivers very high light-load efficiency of 80% at 1-µA load, which can enable designers to extend the battery life of their systems, or use fewer or smaller batteries to shrink their overall power supply solution size and reduce cost. Additionally, the new DC/DC converter's wide input voltage (VIN) range of 1.8 V to 6.5 V supports a variety of battery chemistries and configurations. These features plus its selectable functions enable the device to help engineers solve critical design challenges in many battery-powered, always-on industrial and personal electronics applications – including narrow-band Internet of Things (IoT), grid infrastructure equipment and wearables – that require more flexibility, an extended wireless range, improved accuracy and reduced electromagnetic interference (EMI). The TPS62840 joins TI's portfolio of highly integrated, low-IQ DC/DC converters that enable designers to maximize power delivery in the smallest possible solution size.



www.ti.com

Source Down Packaging Technology

Alpha and Omega Semiconductor Limited (AOS) introduced the "Source Down" in a DFN 5x6 package in combination with a 40V Shield-Gate Technology (AlphaSGT™). AOS' innovative flipchip know-how achieves the Source Down capability and this packaging technology offers a very low package resistance and inductance. The AOE66410 is ideally suited in telecommunications applications for secondary rectification (SR), in half bridge configuration for BLDC motor applications, and battery management where paralleling is important. The AOE66410 (40V), has the same form factor of a standard DFN 5x6 package but the Source pad has the largest connection to the PCB. This will enable power supply designers to parallel devices more easily and have a larger thermal area to dissipate any losses. The AOE66410 has a 1mOhms max at 10Vgs with a maximum drain current of 100A at 25°C case temperature. "Source Down can offer a significant improvement in PCB layout and simplify new parallel designs, which are suited for high-power telecommunication power supplies," said Peter H. Wilson, Marketing Director of the MOSFET product line at AOS.



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EMI-Filter Inductors Matched to DC/DC Converters

Dengrove Electronic Components can solve power supply designers' EMC-compliance challenges with the IRLS series of surface-mount line inductors from RECOM. Intended for use in filters to meet EN 55011 Class A or Class B EMC standards, the inductors are pre-tested and matched with RECOM DC/DC converters to pass not only conducted noise but also radiated interference limits over the full frequency range.



Using an RLS series inductor provides extra confidence that products will pass compliance tests when submitted to an independent laboratory, ultimately ensuring fast certification for rapid time to market and lower development costs. In contrast, typical inductors for power supply filter applications are often tested for conducted emissions only and can display differing performance at various test frequencies, potentially delaying certification and incurring extra re-engineering and re-testing costs. The RECOM RLS series inductors are RoHS and REACH compliant and available now in inductance values from 3.9µH to 100µH and rated current from 0.63A to 1.89A.

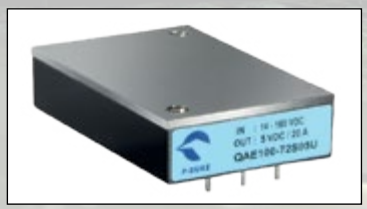
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600V Three-Phase Gate Driver with Smart Shutdown

The STMicroelectronics STDRIVE601 3-phase gate driver for 600V N-channel power MOSFETs and IGBTs provides state-of-the-art ruggedness against negative voltage spikes down to -100V and responds to logic inputs in a class-leading 85ns. Featuring smart-shutdown circuitry for fast-acting protection, the STDRIVE601 turns off the gate-driver outputs immediately after detecting overload or short-circuit, for a period determined using an external capacitor and resistor. Designers can set the required duration, using large C-R values if needed, without affecting the shutdown reaction time. An active-low fault indicator pin is provided.



The STDRIVE601 replaces three half-bridge drivers to ease PCB layout and optimize the performance of 3-phase motor drives for equipment such as home appliances, industrial sewing machines, and industrial drives and fans. All outputs can sink 350mA and source 200mA, with gate-driving voltage range of 9V-20V, for driving N-channel power MOSFETs or IGBTs. Matched delays between the low-side and high-side sections eliminate cycle distortion and allow high-frequency operation, while interlocking and deadtime insertion are featured to prevent cross conduction. Fabricated in ST's BCD6S offline process, the STDRIVE601 operates from a logic supply voltage up to 21V and high-side bootstrap voltage up to 600V.

www.st.com

Shunt for Electric Vehicles

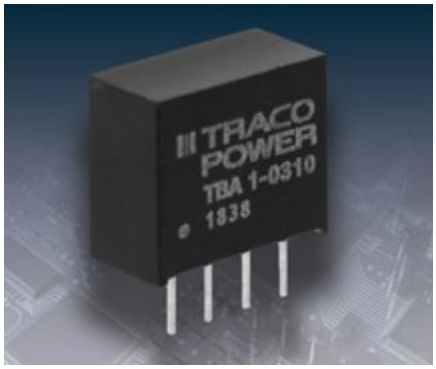
Electromobility is steadily gaining ground in the automotive industry. With the presentation of its new BAX shunt, Isabellenhütte is now taking due account of the requirements that this trend is imposing on components for high-power battery management systems. In the last year, demand for high-performance shunts for use in electric vehicles has skyrocketed. This is down to the pace of development in the electromobility sector. Currents of up to 1,000 amps flow through high-voltage batteries with voltages of up to 800V, such as those installed in electric vehicles. Such extremely high power loads require resistors with a larger construction and lower resistance values to keep power losses to an absolute minimum. Which is why the Isabellenhütte has developed the BAX specially for the automotive industry. Alongside the BAS, the BAX shunt is the largest low-ohmic shunt in the company's product portfolio and thus also the most powerful. The exceptionally low-ohmic BAX shunt is currently available in two variants. One with a resistance value of 0.02 mOhm, and the other with an equivalent value of 0.005 mOhm, with the aim of reducing power losses to an absolute minimum. With dimensions of 84 mm by 36 mm and a thickness of 4 mm, the BAX has a generous cross-section and is thus designed for currents of up to 1,000 A.



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Improved Characteristics at Lower-Costs for DC-DC Converter

TRACO POWER has announced the release of their TBA 1 series of 1-watt DC/DC converters in the industry standard SIP-4 package measuring 0.46 x 0.24 x 0.38". This style of DC/DC converter is widely used to provide isolation between low-power circuits and has long been the most common type of converter. The series provide enhanced performance characteristics enabling engineers to achieve design improvements while taking advantage of reduced costs. The TBA 1 improves isolation from the standard 1,000VDC up to 1,500 VDC; expands the full Load operating temperature range to -40°C to +85°C (older designs require de-rating); includes integrated short-circuit protection; increased efficiencies up to 82% (typically 5% lower on older designs); and improved reliability up to 2 million hours (per MIL-HDBK-217F at +25°C, ground benign). Standard features include 3.3 / 5 / 12 / 24 V inputs with ±10% input range; and single outputs of 3.3 / 5.1 / 12 / 15 VDC. These drop-in replacement designs allow engineers to take advantage of these improved characteristics in both new and existing applications. All models comply with IEC/EN/UL 62368-1 / 60950-1 safety standards and are supported by TRACO POWER's 3-year warranty.



www.tracopower.us

Film Capacitors with Terminals of Different Heights

Film capacitors of the Energy Cap series from FTCAP, a MERSEN company, convince not only with their very low inductance, robust design and long life. Another feature of these foil capacitors is that they are available with terminals of different heights. This allows faster and easier mounting on busbars – without the need for compensating spacers. "As part of the Mersen Group we are increasingly working on perfect compatibility between Mersen busbars and FTCAP capacitors", explains André Tausche, Managing Director of FTCAP. "The Energy Cap series offers a decisive inherent advantage in this respect: These capacitors are available with terminals of different heights, for adaptation to the different levels of the busbar to ensure a solid and reliable connection." This enables operation at consistently high quality – also because it eliminates the need for compensating spacers, which often results in contact resistance because the spacers are made of a different material. Another advantage: Users can use the same screws for both terminals, since they have the same thread depth. Due to in-house manufacturing of the contact elements and terminals by FTCAP, any desired height is possible – at the price of standard terminals. The terminals can be designed with female threads or male threads.



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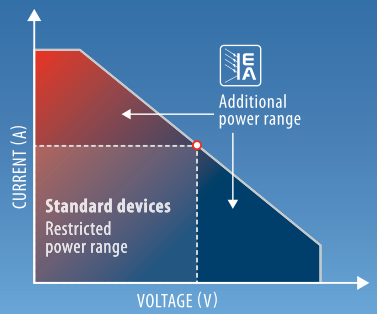
Autoranging, regenerative, bidirectional, many interface options, up to 2.000VDC, 1.000A, 30kW



PS/PSI 3000 and 9000, EL 3000 and 9000:
Desk top and tower design, DC laboratory power supplies devices and electronic loads 100W up to 1500W, 0-40V up to 0-750V, up to 60A



PS/PSE/PSI 9000 and EL/ELR 9000, PSB 9000/10000:
Programmable DC Laboratory Power Supplies and electronic loads, uni- or bidirectional, conventional or mains regenerative, from 0-40V up to 0-2000V, 0-1kW up to 0-30kW, up to 1000A



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650V SiC FET Packages

UnitedSiC has added two new TO220-3L package options to its growing range of hard-switching UF3C FAST series of 650V SiC FETs. The products offer RDS(on) values of 30mohms (UF3C065030T3S) and 80mohms (UF3C065080T3S). The three-leaded, industry-standard TO220-3L package features enhanced thermal characteristics made possible by a sintered-silver packaging technology developed by UnitedSiC. The devices will appeal to designers who are seeking a more powerful performance in a 3-lead TO220 package option for applications such as EV charging, PV inverters, switch mode power supplies, power factor correction modules, motor drives and induction heating. Both SiC FET products are based on a unique UnitedSiC 'cascode' circuit configuration, in which a normally-on SiC JFET is co-packaged with a Si MOSFET to produce a normally-off SiC FET device. The device's standard gate-drive characteristics allows a true "drop-in replacement" to Si IGBTs, Si FETs, SiC MOSFETs or Si superjunction devices on existing designs in which designers can expect a performance increase with lower conduction and switching losses, enhanced thermal properties and integrated gate ESD protection. In the case of designs, the UnitedSiC FETs deliver increased switching frequencies to gain substantial system benefits in both efficiency and reduction in size, and cost of passive components, such as magnetics and capacitors.



www.unitedsic.com

Programmable Power Supply Series

TDK Corporation announces the introduction of the TDK-Lambda 1U Full-Rack GENESYSTM 1.7kW AC/DC Programmable Power Supply Series. This platform provides the user with a choice of ten different models, ranging from 10V-170A to 600V-2.8A, that have advanced performance and functionality well suited for Design, Test and Measurement in the Laboratory/R&D environment and address broad market segments including Automotive, Aerospace, Semiconductor, Industrial and Renewable/Alternative Energy. Built into a lightweight 1U high, 19" (483mm) wide rack-mountable chassis, the 1.7kW Power Supply Series offers five embedded front panel setup menus that address Digital Communication, Protective Functions, Operating Configuration, System Configuration, and System Triggering. These embedded menus offer user-selectable functions including Internal Resistance simulation and Slew-Rate control of Output voltage/current and have the capability to generate, store, recall and activate up to four on-board Arbitrary waveform profiles.

All models can operate in Constant-Current (CC), Constant-Voltage (CV) as well as the newly offered Constant-Power (CP) limit and have conversion efficiencies up to 90%. Operation from a wide-range single-phase AC Input (85VAC to 265VAC) is standard along with built-in Power Factor Correction (0.99 typical) and cooling fan speed control (for reduced audible noise and extended life).



www.us.tdk-lambda.com

Oscilloscopes up to 2GHz Bandwidth

With the introduction of the MSO8000 high-performance digital oscilloscope family, Rigol announced a significant addition to its UltraVision II oscilloscope portfolio including their self-designed chipset. With bandwidths from 600 MHz, 1 GHz and 2 GHz (BW usable for 2 channel) and a maximum sampling rate of 10 GS/s, the MSO8000 series is ideally suited for high speed and instantaneous signal acquisition and analysis. Typical applications include automated testing in factories, serial bus protocol analysis in automotive electronics, electronic circuit measurement, switching power measurement and analysis in the power field and many more. All devices feature a very large 10.1 inch capacitive color touch screen with 256 intensity levels and color grade for precise and clear signal presentation. For recording and processing of measuring large amounts of data, a memory depth of up to 500 million points is available, and with a waveform capture rate of up to 600,000 wfms/sec, the user can capture, display and evaluate fast signal sequences with up to 450,000 frames. The MSO version of these oscilloscopes has also been extended with additional professional functions. The instruments feature an integrated measurement method with real-time eye diagram and jitter analysis software, highlighting the jitter trend for digital analysis.



www.rigol.eu

6 W Multi-Blade Power Adapter

CUI's Power Group announced the introduction of a next-generation 6 W wall plug-in ac-dc power supply with interchangeable ac blades designed for global use. The SMI6B series features an ultra-compact package measuring 1.85 x 1.36 x 1.04 in (47 x 34.5 x 26.5 mm), while complying with the US DoE Level VI and EU CoC Tier 2 efficiency regulations as well as the new IEC 62368-1 safety standard for ICT and AV equipment.



With ac blade options for North America, Europe, the United Kingdom, Australia, and China, this multi-blade power adapter offers no-load power consumption less than 0.075 W, a universal input voltage range of 90 to 264 Vac, and single output voltages from 5 to 15 Vdc. The series further carries over current and short circuit protections as well as a wide range of safety approvals that include UL/cUL, GS, RCM, CCC, PSE, and CE.

Complying with FCC Part 15B Class B limits for EMI/EMC, the SMI6B also features a variety of standard dc output connector options, including USB Type C and Micro B. These features and approvals combine to make this high efficiency external power adapter the ideal solution for keeping consumer, industrial, and mobile electronics in compliance around the world.

www.cui.com

Step-Down Switching Mode Regulator

Mouser Electronics is now offering the Power by Linear™ LTM4700 µModule® regulator from Analog Devices. The step-down switching mode regulator combines very high power with energy-efficient performance to help reduce data center infrastructure cooling requirements. Analog Devices LTM4700 µModule regulator is a dual 50 A or single 100A step-down DC/DC regulator solution that incorporates fast analog control loops, precision mixed-signal circuitry, power MOSFETs, inductors and supporting components. The module's innovative heatsink packaging technology enables increased server density and boosts data center throughout and computational power with minimal impact on



system size and cooling costs. The 15 × 22 mm device integrates analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and EEPROM and features remote configurability and telemetry-monitoring of power management parameters over a PMBus protocol. The device operates over an input voltage range of 4.5 V to 16 V, with a digitally supported output voltage range of 0.5 V to 1.8 V. The µModule's architecture enables system designers to combine up to eight devices, delivering up to 800 A of load current to meet the higher power needs of data center processors, including FPGAs, ASICs, GPUs and microcontrollers. Applications include cloud computing, high-speed computing and optical networking systems, communication infrastructure, and PCIe boards, as well as medical, industrial, and test and measurement equipment.

www.mouser.com

Current Sensor Approach for Aircraft Electrical Systems

TT Electronics announced an innovative approach to developing customised solutions for the harsh environment requirements of the aerospace and defence market. Building on the company's existing range of current sensor modules, this new and highly diverse modular technique leverages Hall-Effect and Rogowski sensors, as well as amplifiers and digital converters. Through harnessing TT's extensive design engineering expertise, the process allows module customisation within on-going, developing, upgraded and retro-fit programmes to meet economic, high reliability and specific requirements of proprietary solutions.

Ambient temperature ranges of -55°C to +125°C and a 30A to 2000A AC or DC capability make these current sensor modules ideally suited for electrical systems, generators and motor drive applications. With a generic single-phase configuration, these TRL5 standard circuit boards can be coated, fully potted, built into a housing, or re-configured into a multi-phase product. Such flexibility of design enables the customer to select key sensor parameters to create their very own unique fit. "The measurement of current is vitally important in flight critical aerospace power and instrumentation systems. In these applications, interpretation is reliant on the accuracy of the data provided



by these solutions," said Ben Fox, Business Development Director, TT Electronics. "Taking TT's modular current sensing approach, customers can now utilise their very own uniquely adapted high reliability solution for their tailored requirements.

www.ttelectronics.com

Raising the Bar of High-Accuracy Measurement

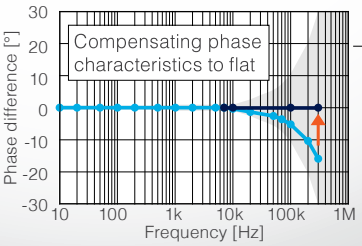
ECCE IEEE EPE '19 ECCE EUROPE www.EPE2019.com
Sept. 2-5
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New 2000A AC/DC Current Sensor CT6877

- Wide frequency bandwidth DC to 1MHz
- ±0.04 accuracy





The Flagship Power Analyzer PW6001

- Phase shift correction function
- 5MS/s, 18-bit resolution
- ±0.02 accuracy*

*combined accuracy of ±0.07% rdg. even with current sensor

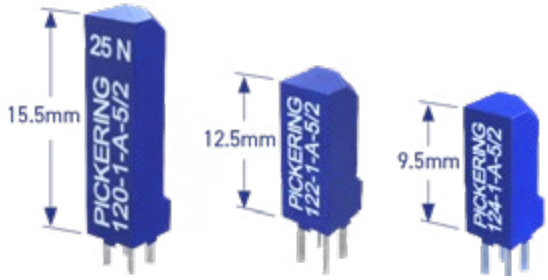
HIOKI

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hioki@hioki.eu / www.hioki.com

10W Reed Relay for Space-Restricted Applications

Pickering Electronics introduced a 10W member of its successful 4mm2TM product family. Like other reed relays in the family, Series 122 devices occupy a PCB footprint of only 4mm x 4mm, facilitating the highest packing density currently available. Series 122 relays measure 12.5mm in height and are rated with a switching current of 0.5A at 10W. 3V and 5V coils are available. Fast operate and release times, typically 150 µs or less, make Series 122 relays ideal for high speed test systems such as A.T.E. switching matrices or multiplexers. The 1 Form A (SPST) Normally Open (NO) Energize-to-make devices feature highest-quality, instrumentation-grade sputtered-ruthenium switches and plastic packages with internal mu-metal magnetic screening to avoid the risk of magnetic interaction issues in densely-packed applications. Devices have an insulation resistance of greater than 1012Ω and are 100%-tested for dynamic contact resistance to guarantee performance.

Other members of the family include the Series 120 which has a switching rating of up to 1A at 20W and a height of 15.5mm and the Series 124 which has a lower 9.5mm profile and a slightly lower rating of 0.5A at 5W.



www.pickeringrelay.com

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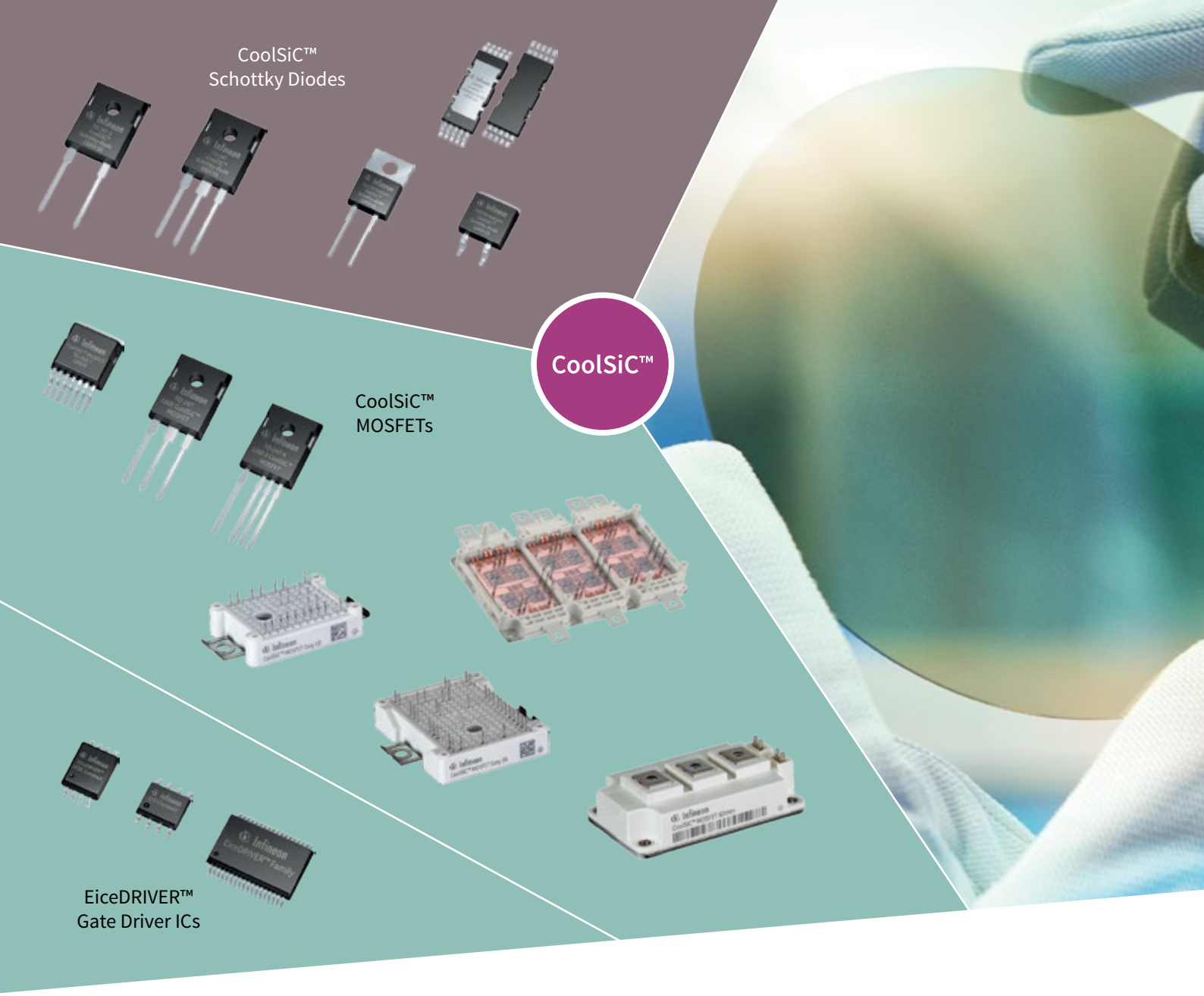
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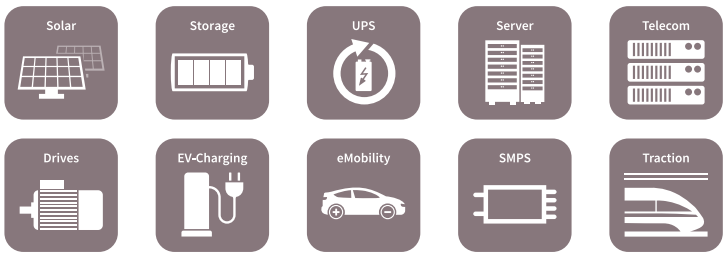
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