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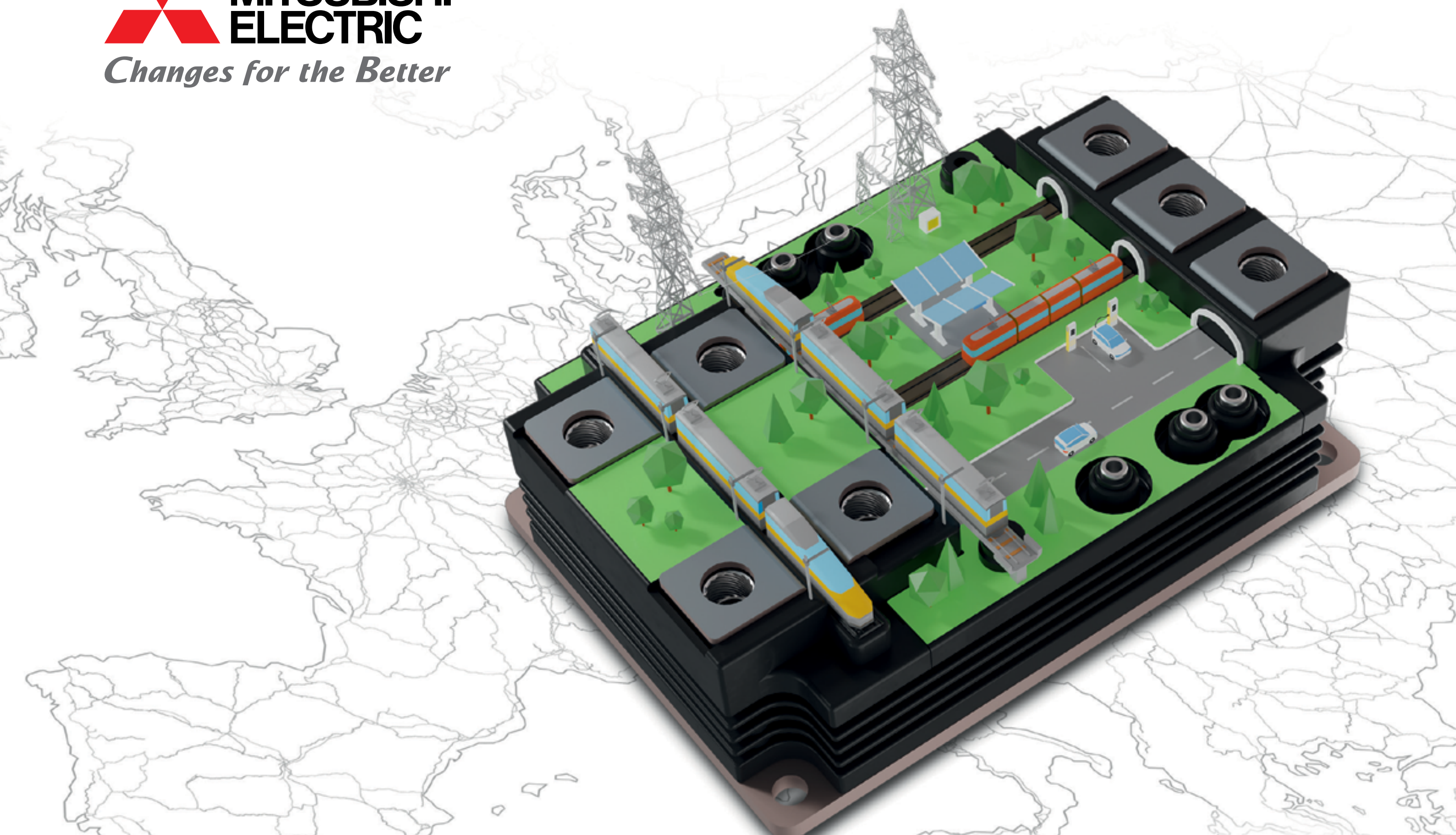
Bodo´s Power Systems®

Electronics in Motion and Conversion

September 2024



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KEY FEATURES

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- **Secant inductance** L_{sec}(i) and L_{sec}(∫Udt)
- **Flux linkage** ψ(i)
- **Magnetic co-energy** W_{co}(i)
- **Flux density** B(i)
- **DC resistance**

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APPLICATIONS

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- **Development, research** and **quality inspection**
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- **High sample rate and very wide pulse width range** => suitable for all core materials

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DPG10-2000B	2 to 2000A	1350J *new model*
DPG10-2000B/E	2 to 2000A	2750J *new model*
DPG10-3000B/E	3 to 3000A	2750J
DPG10-4000B/F	4 to 4000A	8000J
DPG20-10000B/G	10 to 10000A	15000J

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Content

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From Adele to APEC and WBG

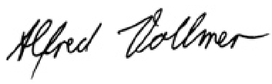
As you may know I live in Munich / Germany, and during a recent evening cycle ride in the east side of the city I suddenly heard music playing. Having recently read the local newspaper, I knew immediately where it was coming from: the British artist Adele was performing the first of ten European concerts in a giant stadium which has been designed and built exclusively for these ten concerts. So, I cycled by the fence to get a glimpse of the giant, very impressive LED wall, which was 220 m wide and 17 m high while listening to the crisp and clear music. Imagine an LED wall measuring 3,740 square meters with about 100,000 LEDs per square meter. Every square meter of such an LED wall consumes an average of more than 1 kW, a maximum of over 3 kW. So, this LED wall consumes roughly between 4 and 12 MW. Just imagine that a 10 % energy saving here could result in a saving of 400 kW to 1.2 MW. I did this very basic calculation to demonstrate that it is always worth making designs power efficient – even the smallest ones.

This giant LED wall for the Adele concerts is located on the outskirts of the Munich Messe fairground, where Electronica will take place from November 12-15. Our editorial team will be present for the duration of the event and also at APEC 2025, which takes place in Atlanta, Georgia March 16-20, 2025. Don't forget that the 2025 APEC date was changed earlier this year, so please double-check that you have the correct date in your diary and also on your website.

Between Electronica and APEC, there is another important event taking place, Bodo's Wide Bandgap Event. We are currently preparing the line-up for the panel discussion on the first day, as well as the program for the sessions on the second day, where we will once again run two sessions in parallel – one covering Silicon Carbide and the other Gallium Nitride. As at previous successful events, we plan to ignite a kind of firework of SiC and GaN technology presentations which will inspire the audience. However, we will also schedule in plenty of time for breaks to network, visit the table-top exhibition and exchange information. We will share further information at the end of September, at bodoswbg.com. In terms of location, for this December event, we didn't need to build an outdoor arena with a giant LED wall as Bodo's Wide Bandgap Event 2025 will take place December 3-4, 2024, at the Munich Airport Hilton.

Bodo's magazine is delivered by postal service to all places in the world. It is the only magazine that spreads technical information on power electronics globally. We have EETech as a partner serving our clients in North America. If you speak the language, or just want to have a look, don't miss our Chinese version at bodospowerchina.com. An archive of the magazine with every single issue is available for free at our website bodospower.com.

My green tip of the month:
Try to make your designs as energy efficient as possible. I know it's a truism, but just a few thoughts, even about a concert, can make us realize how important every percentage of power savings is.



Events

Solar & Storage Live Zurich 2024
Zurich, Switzerland September 17 – 18
www.terrapinn.com/exhibition/solar-storage-live-zurich

ESREF 2024
Parma, Italy September 23 – 26
www.esref2024.org

INNOTRANS 2024
Berlin, Germany September 24 – 27
www.innotrans.de

ICSCRM 2024
Raleigh, NC, USA September 29 – October 4
www.icscrm-2024.org

IEEE PEMC 2024
Pilsen, Czech Republic
September 30 – October 3
www.ieee-pemc2024.org

Industry Tech Days 2024
Online September 30 – October 4
www.allaboutcircuits.com/tech-days/fall-2024

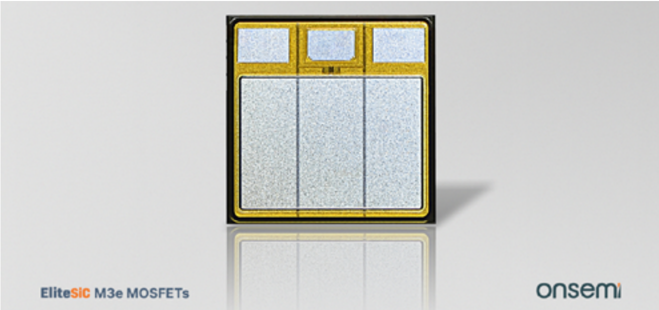
ECCE 2024
Phoenix, AZ, USA October 20 – 24
www.ieee-ecce.org

WiPDA 2024
Dayton, OH, USA November 4 – 6
www.wipda.org

electronica 2024
Munich, Germany November 12 – 15
https://electronica.de

Supply Agreement: SiC MOSFETs for EVs

onsemi has signed a multi-year deal with Volkswagen Group to be the primary supplier of a complete power box solution as part of its next-generation traction inverter for its Scalable Sys-



tems Platform (SSP). The solution features silicon carbide-based technologies in an integrated module that can scale across all power levels – from high power to low power traction inverters to be compatible for all vehicle categories. Based on the EliteSiC M3e MOSFETs, onsemi's power box solution is said to be able to handle more power in a smaller package which significantly reduces energy losses. The inclusion of three integrated half-bridge modules mounted on a cooling channel will further improve system efficienc by ensuring heat is effectively managed from the semiconductor to the coolant encasement. This leads to better performance, improved heat control, andincreased efficiency, allowing EVs to drive further on a single charge.

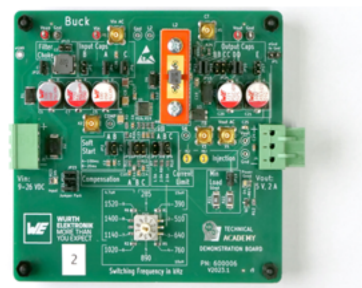
www.onsemi.com

Several Changes in Management

After more than 25 years at Schurter, the current Managing Director (MD), Rolf Hausheer, will retire at the end of 2024. He handed over the position of MD of Schurter AG to Steffen Lindner on 1 July 2024. Steffen Lindner is already acting as the General Manager & Vice President EMEA. Rolf Hausheer's career at Schurter began in April 1999 as the Head of Procurement. As of 2009, he was appointed to the management team, taking responsibility for Supply Chain Management, including Sourcing, Customer Service, and Warehouse. Since February 2024, Rolf Hausheer has been leading Schurter AG as MD ad interim. Despite the additional responsibility as MD, he retained leadership of Supply Chain Management and supported the strategic direction of the company as Co-Program Management Officer. Furthermore, as of July 2024, Steffen Lindner has assumed the role of MD of Schurter AG. He already manages the Schurter group company in Germany and oversees all company activities in EMEA, including Product Management, Engineering, Sales, and Production. Simultaneously, responsibility for Supply Chain Management has been handed over to Oswald Fiegl, the acting COO. Rolf Hausheer is now focusing on organizational projects within the company's strategy.

www.schurter.com

Testing Procedure for Determining Dielectric Strength



Würth Elektronik has developed a testing procedure for determining the maximum operating voltage of molded inductors. The manufacturer of electronic and electromechanical components introduces developers to the electrical property of dielectric strength and what happens if it is exceeded in an application note. The molded inductors from the Power Magnetics product portfolio (e. g., WE-MAPI, WE-XHMI, WE-LHMI) are now successively supplemented with the value of the maximum operating voltage Vop as a new parameter in the specifications. Based on the testing procedure, Würth Elektronik defines the maximum operating voltage V_{op} in its data sheets. This represents the voltage at which an inductor can be operated continuously in the application without impairing performance, risking damage or overheating the inductor. The operating voltage is therefore a limit value for the input voltage, up to which the inductor can be used reliably in an application without irreversible damage. The test concept examines the behavior of inductors up to their voltage limits under realistic conditions in a DC/DC full-bridge converter (voltage transients of up to 60 V/ns and frequencies of up to 2 MHz). The approximate voltage limit is firstly evaluated using a short-term test. The operating voltage is then defined on this basis and verified in a long-term test.

www.we-online.com

SEMICON Southeast Asia 2025 to be Held in Singapore

SEMICON Southeast Asia will return to its roots in Singapore in 2025 to commemorate its 30th anniversary. With more than 18,000 delegates expected to attend from the region and around the world, SEMICON Southeast Asia has become a key platform for

industry leaders, innovators, and decision-makers to connect, collaborate, and drive innovation. This special edition of the event will take place at Sands Expo & Convention Centre from 20 – 22 May 2025. Themed "Stronger Together", SEMICON Southeast Asia 2025 will feature insights into the latest industry developments, trends and innovations, and critical areas including sustainability, artificial intelligence (AI), chiplet technology, and workforce development. Since 2015, SEMICON Southeast Asia has been hosted in Malaysia, contributing significantly to the growth and advancement of the semiconductor industry in the region.

www.semiconsea.org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SIC Research Cooperation between Industry and University

Sanan Semiconductor has entered into a Research Partnership with the Institute for Power Electronics (LEE) at FAU Erlangen-Nürnberg university. This research will focus on advanced innovation in power electronic systems focusing on SiC technology. "Sanan Semiconductor is a vertically integrated SiC supplier with inhouse development and manufacturing of SiC substrates, epitaxial wafers, Diode/MOSFET dies and packaged products. This partnership with one of Germany's leading research institutes for SiC puts Sanan Semiconductor in a strong position", says Mr. Tony Chiang, CEO of Sanan Semiconductor. Dr. Ming-Che Kao, General Manager of Sanan Europe comments: "Europe is a key market for us, and this partnership aims at strengthening our system innovation." Dr. Ajay Poonjal Pai, Head of WBG Innovation, adds: "Compared to traditional Silicon-based technologies, SiC offers significant efficiency and power density improvements in various applications. Despite the increasing adoption of SiC in power electronic applications, several system-level barriers still inhibit the full potential of SiC. This collaboration is a step towards overcoming these barriers." Prof. Martin März, Director of the institute says, "We are pleased to have a strong partner in Sanan, whose innovative SiC devices will enable us to advance into new performance regions."

www.sanan-semiconductor.com

PCIM Europe 2025: Call for Papers

Starting now, experts from the realms of business and academia can submit their abstracts on a wide range of topics in power electronics for a chance to speak at the PCIM Conference 2025. This call for papers will be open until 15 October 2024. The PCIM Conference gives authors of first-time publications the opportunity to present their work to an international audience of more than 900 representatives from the business and scientific sides of power electronics. All those accepted will have their articles published in the PCIM Conference proceedings and databases like IEEE Xplore, IET Inspec Direct, Knovel, and Scopus. In addition, presenters at the PCIM Conference will benefit from the immediate feedback they receive from both the industry and the academic world – and they will be able to make a number of contacts in the power electronics community in the process. The PCIM Conference offers a several options to present: From 20-minute talks on the conference stages via poster presentations offering direct interaction directly with other attendees up to half-day seminars. This year's best submissions will be recognized in five categories by the Best Paper Award, the Young Engineer Award, and the Young Researcher Award.

https://pcim.mesago.com

SiC Power Semiconductor Fab in Malaysia

As global decarbonization efforts drive demand for power semiconductors, Infineon Technologies has officially opened the first phase of a new fab in Malaysia that will become the world's largest and most competitive 200-millimeter silicon carbide (SiC) power semiconductor fab. Malaysian Prime Minister YAB Dato' Seri Anwar Ibrahim and Chief Minister of the state of Kedah YAB Dato' Seri Haji Muhammad Sanusi Haji Mohd Nor joined Infineon CEO Jochen Hanebeck, to symbolically launch production.

The highly efficient 200-millimeter SiC power fab will strengthen Infineon's role as the global leader in power semiconductors. The first phase of the fab, with an investment volume of two billion euros, will focus on the production of silicon carbide power semiconductors and will include gallium nitride (GaN) epitaxy. SiC semiconductors have revolutionized high-power applications because they switch electricity even more efficiently and enable even smaller designs. SiC semiconductors increase efficiency in electric vehicles, fast charging stations and trains as well as renewable energy systems and AI data centers. 900 high-value jobs will be created already in the first phase. The second phase, with an investment of up to five billion euros, will create the world's largest and most efficient 200-millimeter SiC power fab. Overall, up to 4.000 jobs will be created with the project.

www.infineon.com

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Opening of Wafer Testing Site in Malaysia

Melexis has opened its largest wafer testing site worldwide in Kuching, Sarawak, Malaysia. This expansion also increases Melexis' presence in the Asia-Pacific region. The expansion in Malaysia is said to allow the company to fulfil the growing global demand for semiconductors, which is expected to double in the next decade. It hosts 90 semiconductor wafer test equipments used to test ICs. Melexis will use the site for edge sensors and edge drivers aimed at current and future applications in the mobility, sustaWinability, robotics, and health areas. Placing the facility in Kuching - Sarawak - Malaysia, member of the Association of Southeast Asian Nations (ASEAN), between Eastern and Western markets and next to X-FAB's wafer foundry, one of Melexis' key suppliers, is a strategic move to streamline logistics and help reducing the company's ecological footprint. The 4-storey building, designed by, both award-winning, Belgian architect Sebastian Mortelmans and Sarawakian architects DNA, covers a ground surface of 4,500 square metres, making it the largest Melexis wafer testing site worldwide. The modern design referencing local longhouse architecture, incorporates energy-saving systems including a solar installation that can generate 30.000 kWh per month. The facility is designed with future expansions in mind.

www.melexis.com

President of Energy Business

Effective from the beginning of August 2024, Per Erik Holsten is the president of ABB Energy Industries. He moves into the role from the position of hub manager for Northern Europe at ABB Energy Industries. Per Erik succeeds Brandon Spencer, who has become president of the ABB Motion business area. Per Erik offers vast experience within the energy sector, from traditional sources through to key energy transition industries including hydrogen, offshore wind and Power-to-X. Per Erik Holsten holds an MBA of International Business from the University of East London, UK. He also studied Engineering at Sør-Trøndelag University College (HiST), Norway.

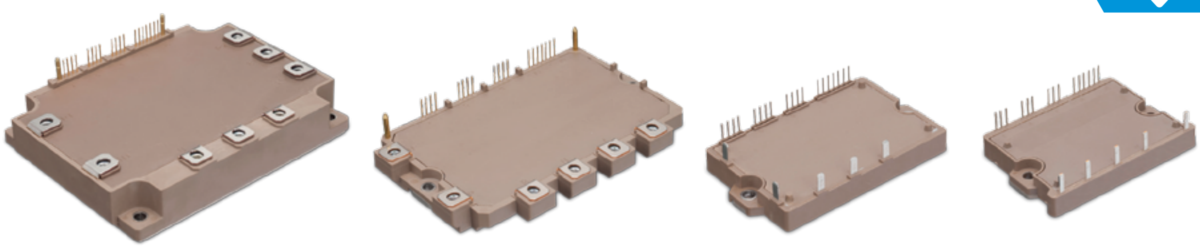
www.abb.com

Supply Chain for Power Devices based on AlN established

In order to make the ultra-wide band gap (UWBG) technology AlN accessible to industry in the medium term, the related existing activities in Germany have been combined in a strategic cluster. The aim is to establish a German value chain for AlN-based technology and to build up an international leadership position in this increasingly economically important field. The Ferdinand-Braun-Institut (FBH), the Fraunhofer Institute for Integrated Systems and Device Technology IISB and the company III/V-Reclaim PT GmbH drive this initiative together. They cover the entire value chain, starting with the growth of AlN crystals using the Physical Vapor Transport (PVT) process, to wafering and polishing of epi-ready AlN-wafers, and the epitaxy of the functional device layers, up to the fabrication of transistors for power electronics and millimeter-wave applications. For the first time, the consortium has now successfully demonstrated the practical implementation of a value chain for AlN devices in Germany and Europe. The first transistor generations produced with these wafers already show promising electrical properties, such as a breakdown voltage of up to 2200 V and a power density superior to SiC as well as GaN-based power-switching devices. Compared to established silicon devices, AlN/GaN HEMTs, as they

have now been successfully produced on AlN wafers, offer up to three thousand times less conduction losses than with silicon and are around ten times more efficient than SiC transistors.

www.iisb.fraunhofer.de



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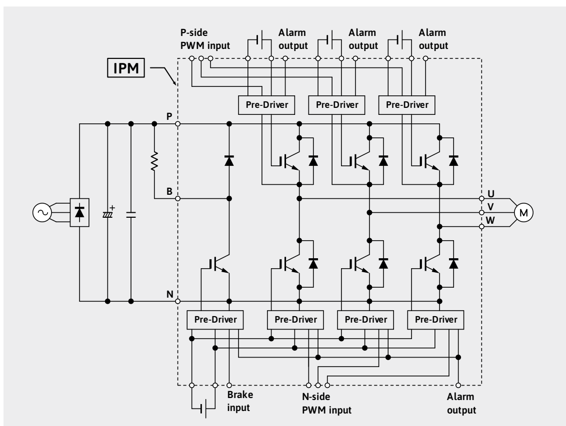

www.fujielectric-europe.com

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Claus A. Petersen retiring from Semikron Danfoss

It is a very well-known name in the power electronics industry that is handing over the presidency of Semikron Danfoss to Dominic Dorfner on September 1.

When Claus A. Petersen began his career at Danfoss in 1984, wind and solar energy combined to produce 0,05 terawatt-hours. This year it will most likely surpass 4,000 terawatt-hours – a factor 80,000 in 40 years. When he was put in charge of the newly established Danfoss Silicon Power in 1998, the first commercial Silicon Carbide product was still three years from hitting the market. And when he was appointed president of the at the merger that established Semikron Danfoss in 2022, the third-largest car-manufacturer in the world exclusively produced EVs.

It is more than fair to say, that the power electronics world has evolved significantly on Claus' watch.

Says Claus A. Petersen: "It has been a historical development, and I can't help but be proud of what this entire sector that Semikron Danfoss is a part of, has done for a more sustainable future. And more importantly what it will do in the coming years. What has happened and will happen with renewable energy, electrification of transport, and – just as important – the efficiency in industry products and the ability to produce more with less energy consumption, is astonishing."

Sailing, Wine fields, Golf – and Power Modules

When Claus A. Petersen retires from the role of President for Semikron Danfoss he expects to have more time for some of the favorite pastimes. One of them is the business he spent more than 40 years helping develop.

"I expect to spend more time on the sea on a sailboat, which is one of the best ways of relaxing in my opinion, and something I've done in the past and will start doing again. I expect to lower my golf-handicap, or at least I hope to. I also have a vineyard in Denmark, and producing wine is something I will also spend more time doing. It is both a great, and sometime frustrating hobby business. In that way, it is not unlike power electronics, where right now the market is challenged which is frustrating. But it is also a fundamental enabler for a greener future, and what is better than that? But I was also very pleased when asked to join the board of directors of Semikron Danfoss. I think power modules is still my biggest passion," Claus says with a big smile.

Sailing is a favorite pastime for Claus A. Petersen – one he expects to spend more time on when retiring on September 1, 2024.

On September first, Dominic Dorfner will take over the role as president for Semikron Danfoss. (We plan an extensive interview with Dominic Dorfner in the November issue of Bodo's Power.)

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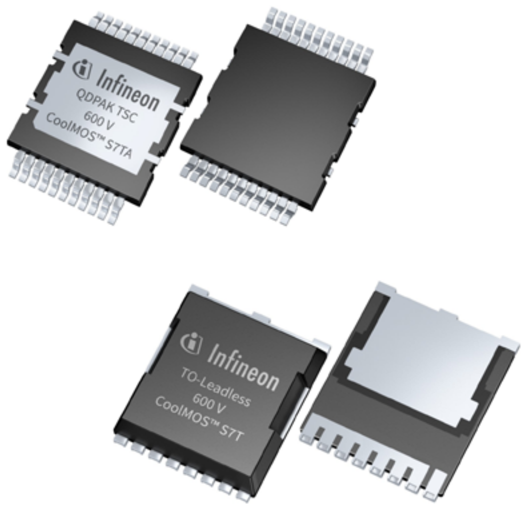

Infineon's new CoolMOS™ S7T and S7TA family of industrial and automotive-grade products come with a high-precision, integrated temperature sensor to read junction temperatures to enable seamless diagnostics at the lowest system cost. To increase the temperature sensitivity, the sensor is implemented as a series connection of three diodes [1]. The embedded sensor of the S7T/S7TA o ers a 40 percent increase in accuracy and a 4x faster response-time compared to standalone onboard NTC sensors.

Infineon has also optimized the SJ technology for best-in-class R_{on} × A, that results in very low power dissipation. The optimization also allows for easy and rapid scalability. This significantly reduces conduction losses without adversely affecting the BOM cost. The optimization results in CoolMOS™ S7/S7TA SJ MOSFETs with $R_{DS(on)}$ as low as 10 mΩ, available in TOLL and Q-DPAK (top-side and bottom-side-cooled) packages [2]. The family enables optimal utilization of the power transistor, resulting in enhanced performance and precise control of the output stage. For example, in 2 A solid-state relays (SSR), this improves power dissipation by 2x compared to traditional electromechanical relays (EMR) and by 5x compared to TRIAC SSRs. Moreover, their advanced control capabilities and the ability to implement protection features selectively to channels makes them well suited for multiple-output SSR applications like PLCs.

SSRs and solid-state circuit breakers (SSCB), as the names indicate, have no mechanical contacts for high-current switching/commutation. This makes them more reliable because of arc-free switching as well as lesser wear and tear over their lifetimes. To further improve the performance of SSRs and SSCBs, S7T devices provide faster reaction times that reduces the fault protection time from milliseconds to microseconds compared to electromechanical solutions. Additionally, they help to eliminate maintenance and manual diagnostics due to arc-free operation, and reduce space by removing the arcing chamber.

In automobiles, especially in electric and hybrid vehicles, there is an increasing trend of electrifying auxiliary loads. To improve the reliability of these loads, eFuses are being increasingly used for their benefits such as being maintenance-free with configurable overload-detection and easy diagnostics. Similar to SSCBs, eFuses are also expected to switch off in an arc-free manner during failures. This is why the automotive-graded versions, S7TA are available in voltages up to 600 V, making them usable in such 400 V systems.

Click or scan the QR code to learn more about Infineon's CoolMOS™ S7/S7T families for low-frequency switching applications. Available for automotive applications as CoolMOS™ S7A/S7TA.

References

[1] Infineon Technologies AG: UM165057 (2022); Automotive high-voltage electronic fuse demonstrator; V 1.0 https://www.infineon.com/cms/en/product/power/mosfet/automotive-mosfet/600v-800v-n-channel-automotive-mosfet/600v-coolmos-s7a/

[2] Infineon Technologies AG: AN111546 (2024); 600 V CoolMOS™ S7 with temperature sense; V 1.0 https://www.infineon.com/cms/en/product/power/mosfet/n-channel/500v-950v/600v-coolmos-s7/

www.infineon.com

How a Unifull SiC Power Module Reduces Carbon Emissions in the Transportation Sector

This article presents the latest developments on 3.3 kV SiC power modules. Improvements in the chip and packaging design allow lower losses and higher switching frequencies of SiC converters. At the same time, ruggedness against bipolar degradation and high-humidity operation has been confirmed.

By N. Soltau, D. He, Mitsubishi Electric Europe B.V., Germany and R. Tsuda, S. Yamamoto, Mitsubishi Electric Corporation, Japan

Introduction

For our common goals of reducing carbon emission and becoming carbon neutral, the railway infrastructure is of strategic importance for decarbonizing the transportation section. However, still today many diesel railcars are in operation, especially when railway lines are not electrified. In Europe (EU-27), these non-electrified lines account for 43% of the federal railway networks [1].

Recently, battery trains allow locally CO_2-emission-free transport even on non-electrified or partly electrified lines [2]. For these battery trains, Silicon-Carbide (SiC) converters allow efficiency increase of the drive train and more regenerated braking energy. Hence, SiC is a perfect match for battery trains to increase range, shrink battery size and reduce operational costs.

Since many years, Mitsubishi Electric has gained field experience with SiC power modules in railway applications. The first traction converters with Mitsubishi's hybrid SiC power modules have been deployed in 2013. In 2015, the first traction converter with Full-SiC power modules has started field operation. In 2022, more than 55 different train types in Japan use SiC traction inverters, predominantly with Mitsubishi Electric's SiC power modules [3].

In May 2023, Mitsubishi Electric has firstly announced availability of their newly developed 3.3 kV SiC power module with embedded Schottky barrier diode (SBD) and 800 A current rating. Embedding the SBD allows unipolar operation to avoid bipolar degradation. Moreover, this device allows substantial switching loss reduction and lower thermal resistance compared the previous 3.3 kV SiC power modules. Finally, in June 2024, Mitsubishi Electric has announced two additional power-module variants with embedded SBD rated for 200 A and 400 A.

This family of newly launched SBD-embedded SiC power modules is called Unifull™. It is dedicated for the use in cutting-edge railway converters; be they auxiliary, battery or traction converters.

Outstanding Performance

Mitsubishi Electric's new Unifull™ modules exert a superior switching performance compared to their previous generation of SiC modules. It is achieved through optimized chip design, increased switching speed and reduced switching delay time [4]. This results in 67% reduction in switching energy when comparing the Unifull™ FMF800DC-66BEW with the predecessor FMF750DC-66A at nominal condition. Furthermore, the packaging technology for the Unifull™ power modules has been improved by using an aluminum-nitride substrate in combination with a low R_{th} solder. This reduces the thermal resistance from junction to case for a better thermal performance [4].

To compare the performance of the new Unifull™ modules with the predecessor SiC module FMF750DC-66A, a simulation has been performed considering the operating conditions given in Figure 1. It can be observed that the FMF800DC-66BEW enables higher output current and thus, higher output power for the whole switching frequency range of the simulation compared to the FMF750DC-66A. For example, the output current can be increased by 62% considering 7 kHz switching frequency and given operation conditions. Alternatively, the switching frequency could be increased for example from 2 kHz to 7 kHz while achieving the same output current. Hence, the new Unifull™ FMF800DC-66BEW allows users to either increase the output current or the switching frequency significantly.

Furthermore, when comparing the new 400 A rated Unifull™ module FMF400DC-66BEW under the same operation conditions, simulations show that it can also outperform the FMF750DC-66A due its superior switching performance. Hence, users might consider to replace the FMF750DC-66A with a 400 A rated Unifull™ power module.

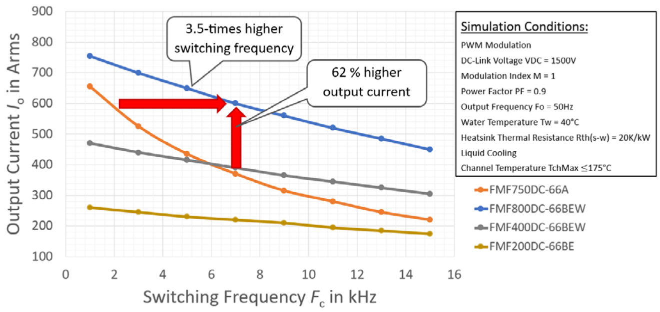

Figure 1: Achievable output current in dependency of the switching frequency of the Unifull™ SiC power module and previous generation of 3.3 kV SiC power module

Embedding SBD Structure for Avoiding Bipolar Degradation

Bipolar degradation refers to an undesired degradation mechanism in SiC devices, in which stacking faults expand from basal plane dislocations. This expansion of stacking faults is caused by bipolar currents. Bipolar degradation will cause an increase of the on-state resistance $R_{DS(on)}$ of the SiC device. This effect is particular crucial for high-voltage SiC devices (i.e. blocking voltage of 3.3 kV or higher). Due to the thicker epi-layer in such high-voltage devices, stacking faults can compromise a larger area. Although an SiC MOSFET itself is a unipolar device, its intrinsic body diode is a bipolar device. Therefore, the operation of the body diode is to be avoided because its bipolar current may lead to growing stacking faults and bipolar degradation.

In the past, Mitsubishi Electric addressed this degradation mechanism by mounting unipolar SiC Schottky Barrier Diode (SBD) chips next to the SiC MOSFET chips (cf. Figure 2 (a)). Since the forward

voltage of the SBD is substantially lower than the threshold voltage of the SiC body diode, the SBD will conduct the reverse current and bipolar current flow through the MOSFET's body diode is avoided. From the beginning, Mitsubishi Electric has used this method for their high-voltage SiC devices. Today we see that the effectiveness of this method has been proven by the many years of reliable field operation in SiC railway converters.

However, mounting additional SBD chips take up valuable space inside the power module. Nevertheless, we cannot compromise on the quality and reliability of our SiC power modules. Therefore, Mitsubishi Electric has developed the new MOSFET chip with embedded SBD.

Figure 3 shows the chip structure of an conventional SiC MOSFET in comparison with the SBD-embedded MOSFET. From Figure 3 (b) it is evident that the SBD shorts the body diode. This prevents bipolar currents and with it bipolar degradation. Furthermore, there is no need for adding dedicated SiC SBD chips. This also saves valuable space inside the power module.

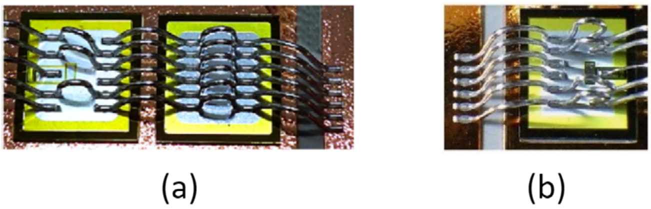

Figure 2: (a) Conventional MOSFET chip and SBD chip in parallel; (b) Unifull™ SBD-embedded MOSFET chip

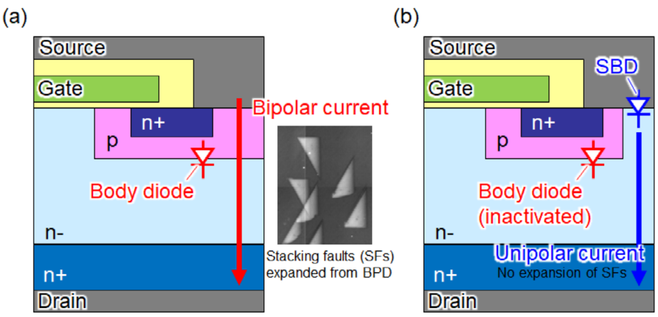

Figure 3: (a) Conventional SiC MOSFET with intrinsic body diode; (b) Unifull™ SBD-embedded MOSFET with deactivated body diode

Surge Current Improvement by BMA Cells

In case of converter failures, a high surge current might flow through the power semiconductor devices for a short time period. The excessive loss energy by the exceptionally high current and the caused temperature increase may result in a device failure. Therefore, the device's surge current capability is a key parameter for the module's reliability.

It is known that connecting multiple SBD-embedded MOSFET chips in parallel results in a lower surge current capability compared to the expected combined capability of all the parallel chips due to a current crowding phenomena at one single chip. In order to increase the surge current capability of the SBD-embedded MOSFET technology, Mitsubishi Electric has developed a novel structure called the bipolar mode activation cells (BMA cells) to enhance the surge current capability [5].

In a normal surge current scenario for SBD-embedded MOSFET chips without the BMA cells, the surge current would slowly increase at the embedded SBD. This initial unipolar current flow I_{sd} causes a voltage increase V_{sd} based on the SBD characteristics. However, with increasing surge current and thus, increasing voltage drop, the parasitic bipolar diode of the corresponding chip will be activated after its threshold voltage has been reached.

This will cause a bipolar current flow druing the surge current event resulting in a conductivity modulation in the drift region due to the injection of minority carriers and thus, leading to a voltage decrease of V_{sd} as seen in Figure 4 (a). The voltage transition point from unipolar to bipolar current flow is defined as the snapback voltage V_{snap} and may vary between different chips based on their SBD width. In an exemplary case of 4 parallel connected chips (cf. Figure 4 (b)), chip A has a lower V_{snap} compared to the other 3 chips called B. The bipolar current will start to flow at the lowest V_{snap} chip A due to its lower resistance compared to the other chips which did not reach their V_{snap} voltage yet. Consequently, chip A takes over the whole surge current resulting in a current crowding phenomena. Therefore, the whole surge current capability is just determined by the surge current capability of a single chip with the lowest V_{snap}. Unfortunately, V_{snap} already differs around 1 V when the SBD width is just varying by 0.1 µm. Due to the manufacturing process and its tolerances, it is very difficult to produce chips with an uniform V_{snap} among all chips resulting in an overall low surge current capability of a normal SBD-Embedded MOSFET module.

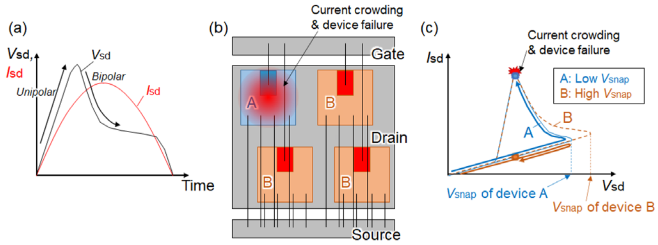

Figure 4: (a) Source-Drain Current I_{sd} and Source-Drain Voltage V_{sd} under surge current condition; (b) Example of four parallel connected SBD-MOSFET chips; (c) I_{sd} vs V_{sd} characteristic of the example [5]

Using the novel BMA cell structure from Mitsubishi Electric, the tolerances in the V_{snap} between the parallel connected chips can be compensated [5]. By filling an embedded-SBD area partly with a p-body, a pn-diode is created in place of a normal SBD. This BMA cell is shown in Figure 5 (a). In case of a surge current event, the current will initially flow through the neighboring SBD cells as a unipolar current. When the fault current reaches a certain level, the BMA cells become active. Due to the bipolar current flow through the BMA cell, the minority carriers will cause a conductivity modulation of the drift layer at the BMA cell and its vicinity due to the diffusion of the carriers inside the cell. Thus, the drift layer resistance at the adjacent SBD cells near the BMA cell will decrease due to the conductivity modulation which leads to a higher current density at the JFET region of the adjacent cells. Consequently, the applied voltage at the JFET region and thus, the voltage at the parasitic body diode of the cell will increase until its threshold voltage, leading to an activation of the cell's bipolar current flow. The activation of the bipolar current flow in the SBD cell will again lead to the activation of the bipolar current flow of its adjacent SBD cells based on the same principle, causing a propagation of the bipolar operation to all cells. This is shown in Figure 5 (b). Thus, the BMA cell allows a stabilization of V_{snap} and causes all cells to take over the surge current due to the bipolar propagation instead of the current crowding at one single chip.

The Weibull plot in Figure 6 (a) shows that using the BMA cell technology allows the SBD-embedded SiC MOSFETs to reach a similar surge current capability to that of usual body diode operated SiC MOSFETs. Additionally, the comparison of the chip surface after a surge current test with and without BMA cells is shown in Figure 6 (b). Without BMA cells, the failure is concentrated on one single chip which has the lowest V_{snap}. However, the chips with BMA cells show damage across all chips indicating to a more uniform distribution of the surge current. Therefore, the concept of the BMA cells has been proven as intended. To achieve the surge current capabil-

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ity improvement, it has been shown that using 0.2% of the active area for the BMA cell is already sufficient [5].

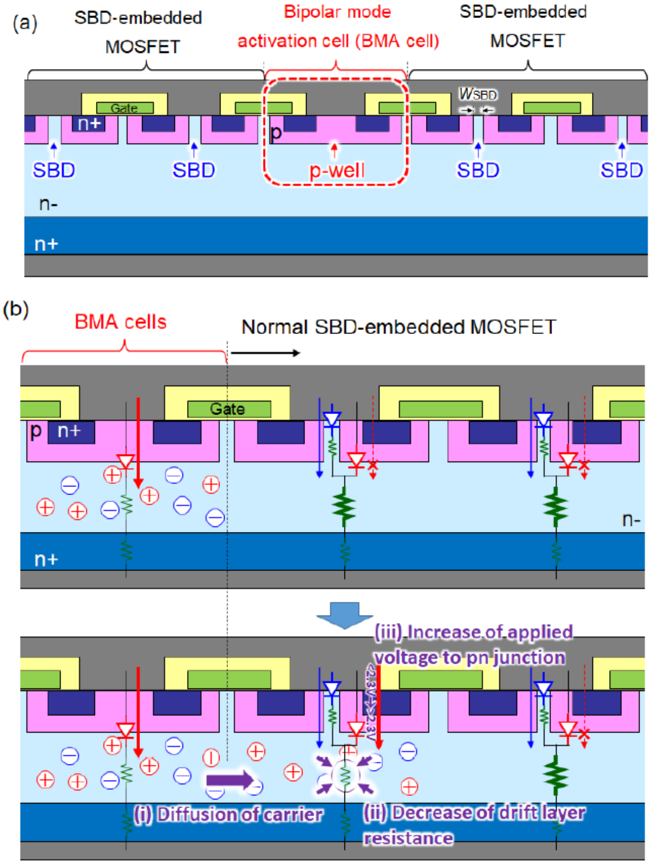

Figure 5: (a) Cross-Sectional View of the BMA cell; (b) BMA cell during a surge current event [5]

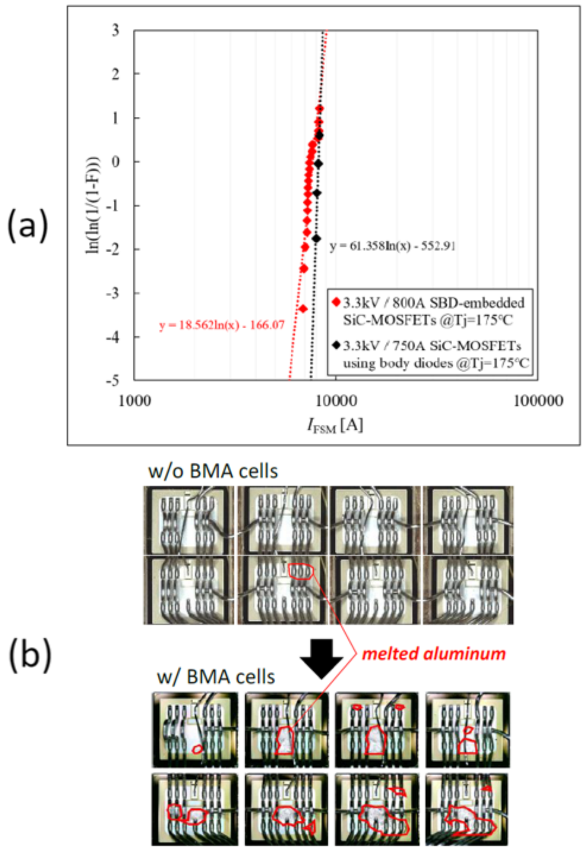

Figure 6: (a) Weibull plot of surge current measurement results; (b) Failed chips after surge current capability evaluation [7]

The BMA cell is only active in irregular events to improve surge-current capability. During normal operation however, the BMA cell does not activate, so that no bipolar current through the parasitic body diodes and thus, no risk of bipolar degradation occurs.

Increased Ruggedness against Bipolar Degradation

To validate the ruggedness of the new Unifull™ power modules against bipolar degradation, we have performed a repetitive surge current test in which we applied 50 surge pulses with a peak current density of approximately 550 A/cm² for 10 ms to different MOSFET chips. Afterwards the device operate in "normal operation" for one week to allow stacking fault expansions. "Normal operation" in this case means 10 kHz switching frequency, 1 µs dead time, 100 A/cm² current density at 150°C.

In order to investigate the impact of the bipolar degradation during these surge current events, the relative ratio ΔR_{ON} of R_{ON} before and after an excessive surge current test has been evaluated. This ratio can be directly correlated to the expansion area of the stacking faults. Figure 7 illustrates the cumulative frequency of the ΔR_{ON} ratio after a repetitive surge current test combined with normal operation. Under the given conditions, the conventional MOSFET already reaches a 20% R_{ON} increase with a probability of around 1%. In the contrary, the SBD-embedded MOSFET's probability for 10% R_{ON} increase is around 10^{-11} [6].

Again, this clearly underlines the higher reliability of the Unifull™ SBD-embedded SiC MOSFET compared to a conventional MOSFET.

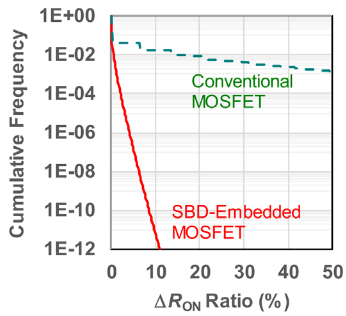

Figure 7: Cumulative frequency of R_{ON} increase after repetitive surge current operation and one week of normal operation [9]

Excellent Humidity Robustness

Especially for railway applications, there is a legitimate caution regarding operation at high humidity. Since the power modules are not hermetically sealed, vapor might diffuse into the power module and eventually reach proximity of the power electronic chips. This might cause degradation and unexpected device failure in the field.

It has been the goal of an ECPE working group (consisting of major power-electronics manufacturers, railway converter designers and end users) to assess the risk of high humidity and to develop a testing scheme to confirm humidity robustness of power semiconductors. Recently, the ECPE guideline PSRRA 01 has been published and with it the HV-H3TRB testing scheme [7].

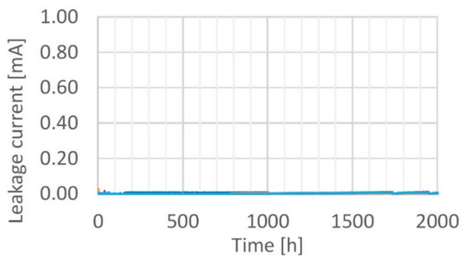

Figure 8:
Confirmation of humidity robustness according to HV-H3TRB test

Type Name	Rated Voltage	Rated Current	Isolation Voltage	Maximum channel temperature (T_{chmax})	Connection	Dimensions (WxDxH)
FMF800DC-66BEW	3.3 kV	800 A	6.0 kV_{rms}	175° C	2in1	100x140x40 mm
FMF400DC-66BEW		400 A				
FMF200DC-66BE		200 A				

Figure 9: Unifull™ product family

According to this guideline, the FMF800DC-66BEW has been tested at a temperature of 85°C and 85% relative humidity for 2000 hours. Although, ECPE guideline demands a drain-source voltage of 1950 V, we have performed the test with 2100 V to confirm our extensive quality margin. The test results, presented in Figure 8, confirm that there is no leakage current increase over the 2000 hours testing time. We have, moreover, confirmed the stability of electrical characteristics of the device after the test. These test results confirm the excellent humidity robustness of the new Unifull™ SiC power modules.

Lineup

The Unifull™ product family features Mitsubishi Electric's third generation High-Voltage SiC chip technology in the standardized LV100 package with 6 kV isolation voltage. Due to the symmetrical and low inductive package design, an optimal utilization of the SiC technology is provided.

Figure 9 shows the lineup of the Unifull™ product family. The Unifull™ modules are available for 3.3 kV blocking voltage for current ratings from 200 A to 800 A. Target applications for this product group are especially applications with high requirements in performance and reliability. This includes auxiliary converters as well as low and high power traction converters in railway applications.

Conclusion

Today, 43 % of the European railway lines are not electrified. Since diesel trains are no longer to be used in future, battery trains are a solution to further decarbonize the transportation sector. For such application, the Unifull™ 3.3 kV SiC power modules are a perfect match.

These devices offer drastically reduced switching losses and lower thermal resistance. This enables power converters with higher power density and higher efficiency. Furthermore, we have confirmed the ruggedness of these devices again bipolar degradation and operation at high humidity.

Of course, Unifull™ 3.3 kV SiC power modules can also be used in other applications that have the highest demands on efficiency, power density and reliability.

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USB-C Adoption and the Evolution of System Architecture for Embedded Applications

An overview of USB-C PD systems, design challenges, and solutions using Infineon's portfolio of USB-C PD microcontrollers

USB-C ports have become the connector of choice for consumer electronics and soon will be the default connector. Government regulators have standardized power connectors in order to ensure interoperability and reduce e-waste. A case in point here is the European Union, which has made USB-C ports standard for all mobile devices beginning 2024. According to the EU directive, "USB-C will become the standard port for all smartphones, tablets, cameras, headphones, portable speakers, and handheld videogame consoles".

By Anand Kannan, Senior Product Marketing Manager for EZ-PD™ PMG1 High-Voltage Microcontrollers, Infineon

As the world transitions to USB-C-based DC power sources, more and more applications are expected to need a USB-C-based DC power source and sink. This versatile interface has become the preferred choice for new designs due to its reversible connector, support for high-speed data transfer, and ability to deliver power up to 240 W bidirectionally. As industries embrace USB-C, system architectures are evolving to accommodate the enhanced capabilities of this technology. Changes are needed in the system architecture of products originally powered by barrel connectors and there are challenges in implementing USB-C PD-based systems. This article explores Infineon's solutions to streamline USB-C PD implementation — for both AC to DC (source-side) wall adapters and sink-side devices — along with tools and resources for system designers to make the transition easier.

The shift to USB-C in embedded systems

Embedded systems, ranging from consumer electronics to industrial automation, benefit heavily from bidirectional power flow, allowing devices to both send and receive power, simplifying the design of power management circuits and reducing the need for multiple connectors.

But the adoption of USB-C brings complexity to the system architecture for devices with multiple USB-C ports. Traditional architectures require extensive circuitry and multiple components to manage power delivery (PD) and data transfer. However, new system architectures are emerging, especially from Infineon, offering integrated solutions supporting all USB-C functions with fewer components.

Infineon's EZ-PD™ PMG1 HV MCU: Facilitating the transition

Infineon Technologies has been at the forefront of this transition with its EZ-PD PMG1 high-voltage (HV) microcontrollers (MCUs). These MCUs are designed specifically to streamline the integration of USB-C into embedded applications. PMG1 HV MCUs support USB-PD 3.1 Extended Power Range (EPR), enabling power delivery up to 240 W, which is critical for applications like PC docks, IoT devices, and e-bikes.

Since hardware alone does not make up the full solution, other building blocks are critical for a smoother transition in design. Recognizing this, Infineon's hardware products are tightly integrated with software and support. For example, PMG1 HV MCUs offer a unified firmware view and are supported by Infineon's ModusToolbox™, which simplifies the development process. This allows designers to rapidly prototype and deploy systems with USB-C

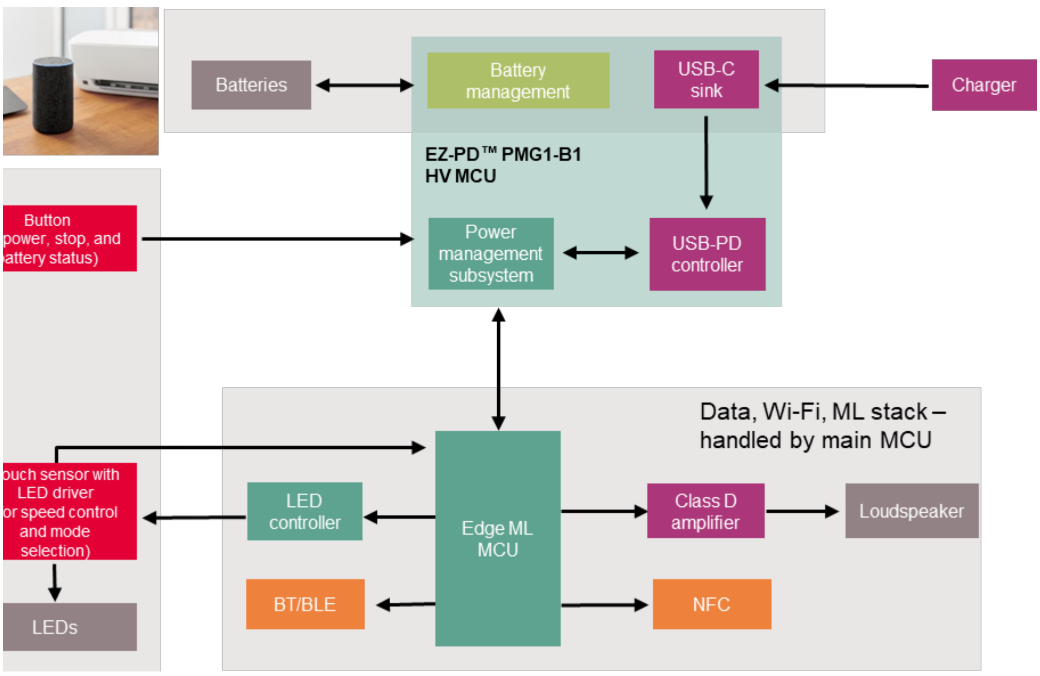

Figure 1: Smart speaker block diagram

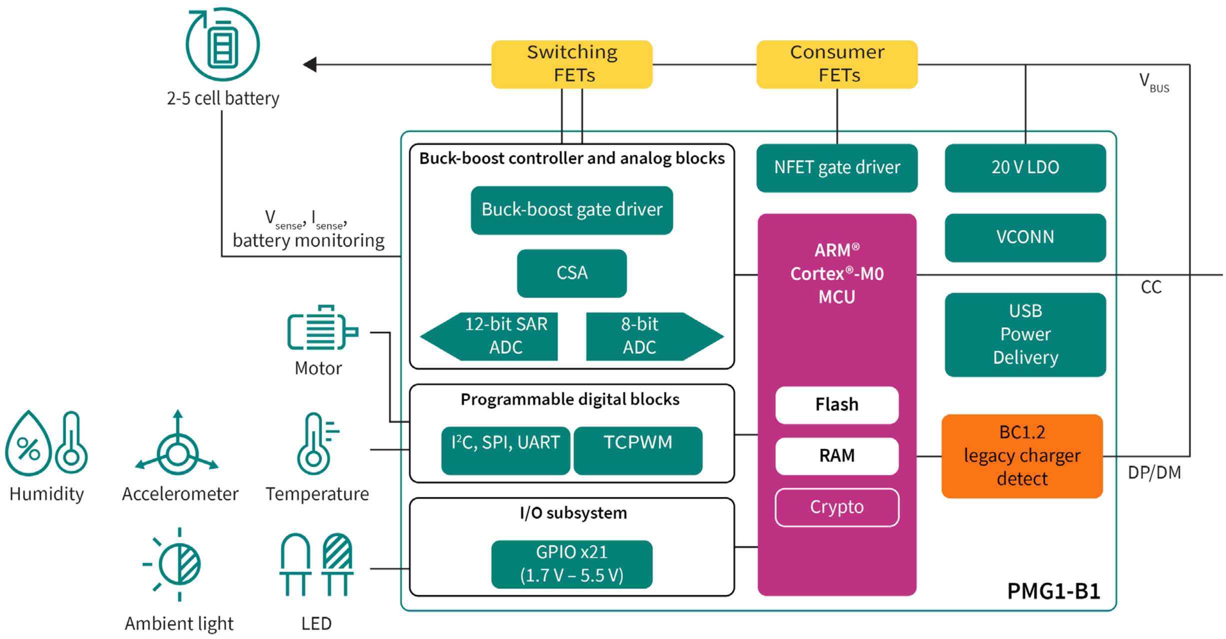

Figure 2: EZ-PD PMG1-B1 HV MCU

connectivity. All the hardware blocks, such as the Full-Speed USB device controller, a crypto engine for authentication, and analog resources like ADCs and comparators are all easy to program as well as update or upgrade via ModusToolbox.

Impact on system architecture

AC/DC power adapters that were originally designed for a barrel connector-based charging method provided a fixed voltage and current. In industrial battery-powered applications, the battery charging was generally handled by an external AC/DC adapter. With the introduction of USB-C power adapters, the USB-C PD voltage can vary. Products powered through USB-C need a buck-boost battery charger to convert the VBUS voltage available on USB-C connector to the system voltage. In addition, there are high-voltage protection features needed to protect the system from cable shorts or malfunctioning AC/DC adapters. Most of these systems also need a system microcontroller to perform the product functions.

As an example, Figure 1 shows the block diagram of a typical smart speaker powered by a USB-C PD port. The main MCU is typically used for data connectivity to the cloud, running NLP algorithms, and fetching and playing the music on the speakers. These MCUs require more processing speed and computing horsepower, necessitating their move to lower node process geometries. As process geometries go lower, it becomes inefficient to handle high power. PMG1 high-voltage MCUs handle all the high-voltage power management and system management functions, providing an efficient BOM for the system.

A battery-powered sensor hub that requires power and connectivity can now use a single PMG1 HV MCU to manage USB-C ports, sensor inputs, and display [1]. This consolidation of functions into a single chip not only simplifies the design but also enhances the reliability and performance of the system. PMG1 HV MCUs include features like on-chip secure protection and system-level ESD protection, ensuring robust operation in various environments.

Infineon's EZ-PD PMG1 MCUs come with a suite of integrated protection features that are crucial for maintaining system integrity and safety. These features include overvoltage protection (OVP) and overcurrent protection (OCP), essential for preventing damage to the MCU and connected devices. The OVP is designed to protect against voltage surges on the VBUS line, ensuring that the voltage does not exceed a specific threshold. PMG1 MCUs implement OCP to monitor and limit the current through the VOUT line, preventing damage due to overcurrent conditions. Both of these are particularly important for USB-C applications where varying power levels are negotiated. Being integrated into the MCU, these protection features do not adversely impact the product BOM.

In addition to OVP and OCP, PMG1 MCUs also support other system-level fault protection features, such as:

- **VBUS undervoltage protection (UVP):** Protects the system when the voltage drops below the minimum operational level
- **VBUS to communication channel (CC) short protection:** Prevents damage if the VBUS line is accidentally shorted to the CC line
- **Over-temperature protection:** Utilizes an integrated ADC circuit and an internal temperature sensor to protect against high-temperature conditions
- **External thermistor support:** Enables connector and board temperature measurement, providing a comprehensive thermal management solution

These integrated protection features in PMG1 MCUs enable designers to create robust and reliable USB-C applications without additional external components. This integration not only simplifies the design process but also contributes to a smaller form factor and cost savings in the overall system design. Both of these are major considerations for product managers as end users prefer lighter and less expensive products.

Battery charging with EZ-PD PMG1-B1

Taking the integration further, PMG1-B1 MCU stands out with its built-in buck-boost battery charge controller. This block enables the MCU to implement a battery charging system that supports various charging modes such as constant current (CC), constant voltage (CV), pre-charge, and trickle charge. This versatility is crucial for maintaining the battery health and ensuring efficient charging, thereby increasing the product lifetime. The buck-boost block can handle battery configurations up to 5 cells (5S), making it suitable for a wide range of portable devices.

Because of the charge controller, the MCU can negotiate up to 100 W (20 V at 5 A) Power Delivery contract with a USB-C source, which is substantial for most portable electronic devices. Additionally, PMG1-B1 supports a wide input voltage range of 4 V to 24 V with 40 V tolerance, allowing it to cater to various battery technologies and capacities.

PMG1-B1 also provides flexibility in designing the power management system to optimize efficiency and minimize electromagnetic interference (EMI) with a programmable switching frequency ranging from 150 kHz to 600 kHz. For solutions with product variants that require a shorter design cycle, the wide power and EMI ratings of PMG1-B1 are beneficial in using the same design with minor modifications, reducing the stress on logistics as well.

Software flexibility

As mentioned earlier, a design solution is incomplete without software to extract the highest performance from the hardware. The PMG1 MCU portfolio is designed to facilitate a seamless transition between different MCUs within the family without extensive firmware rewrites.

Having a multitude of firmware can make the development process complex, making it harder to migrate applications from one MCU to another. To streamline the development process and reduce the application migration time, PMG1 offers a unified firmware view — letting designers use the same code base across different devices in the family.

Another blockage that slows down the development process is a lack of good resources — especially if every product has its unique development tools. To counter that, Infineon's ModusToolbox offers a comprehensive set of tools compatible across the PMG1 MCU portfolio, including configurators and middlewares to create a common and easily portable code base.

To make it easier for designers to transition to new hardware, it is necessary to ensure that the application code can remain largely unchanged, even when the underlying hardware changes. PMG1 MCUs are supported by a hardware abstraction layer (HAL), which provides a set of APIs that abstract the hardware specifics, again with the intent of reusing the code base.

For the least friction for designers, the existing firmware should be easy to run on new hardware with minimal effort, especially for products that are regularly updated. Therefore, newer MCUs in the PMG1 family are designed to be backward-compatible with their predecessors, ensuring that existing firmware runs on new hardware with minimal changes.

All of these features are integrated into the ModusToolbox software package for ease of designing applications, making it easier to switch between MCUs within the family.

In addition, comprehensive support material such as detailed documentation and application notes are readily available.

These tools and features for Infineon's PMG1 MCU portfolio significantly reduce the development effort required when moving products to different MCUs within the family. This flexibility allows customers to scale their products up or down based on performance needs and cost considerations while maintaining a consistent development environment and minimizing firmware changes.

Apart from MCUs, Infineon offers other products to complete the design, including (but not limited to) MOSFETs, memory solutions, gate drivers, and isolators.

Learn more about Infineon's USB solutions at https://www.infineon.com/cms/en/product/universal-serial-bus/ or at https://www.infineon.com/cms/en/applications/ to see solutions for specific applications.

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Improving Reverse Recovery Time with 100V Breakdown Voltage by Adopting a Trench MOS Structure

ROHM recently introduced its YQ SBD (Schottky Barrier Diode) series, for use in automotive, commercial, and industrial applications in which efficiency and low heat generation are key.

By Hiroyuki Ogurisu, Technical Product Marketing Manager, Rohm

Schottky Barrier Diodes (SBD) have several key features that differentiate them from p-n junction diodes. First is how they are constructed: In p-n junction diodes, the junction is formed between p-type and n-type semiconductor materials, whereas SBDs have a metal-semiconductor junction. Because the metal-semiconductor junction has a smaller potential barrier for the flow of current compared to p-n junction diodes, they have a lower forward voltage drop (lower VF). This, in turn, leads to faster and more efficient switching, making SBDs an excellent choice for high-frequency applications such as power supplies and rectifiers. SBDs also have a higher reverse leakage current than p-n junction diodes, and have almost zero TRR (Reverse Recovery Time), allowing them to switch between conducting and non-conducting quickly.

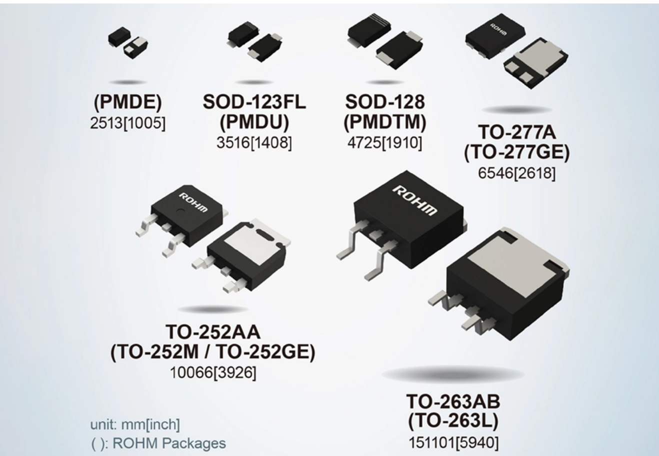


Figure 1: ROHM's YQ Schottky Barrier Diodes (SBD) lineup offers options for a variety of applications from automotive to industrial

Schottky diodes are often used in applications where fast switching speeds, low forward voltage drop, and low reverse recovery time are critical — such as rectification, clamping, and protection circuits in power supplies, voltage regulators, and RF circuits. The major issues for SBDs involve heat: temperature sensitivity as their forward voltage drop increases with temperature due to the generated heat. This also leads to problematic inefficiencies.

Trench MOS Structure

The two basic types of MOS (Metal-Oxide Semiconductor) structures used for SBDs are planar and trench, as compared in Figure 2. In general, trench MOS structures (compared to planar structures) exhibit low resistance in the epitaxial wafer layer during forward bias, leading to low V_F. During reverse bias, I_R is reduced because the electric field concentration is mitigated.

The planar MOS structure comprises a metal layer, Schottky metal layer, and an oxide film over an N- epitaxial layer on top of a N+ substrate wafer, all stacked on one another. The trench MOS structure comprises a metal layer on top of a Schottky metal layer. Beneath that is the epitaxial layer with trenches enclosed within an oxide film and containing polysilicon layer. Beneath the epitaxial N-layer is the substrate layer.

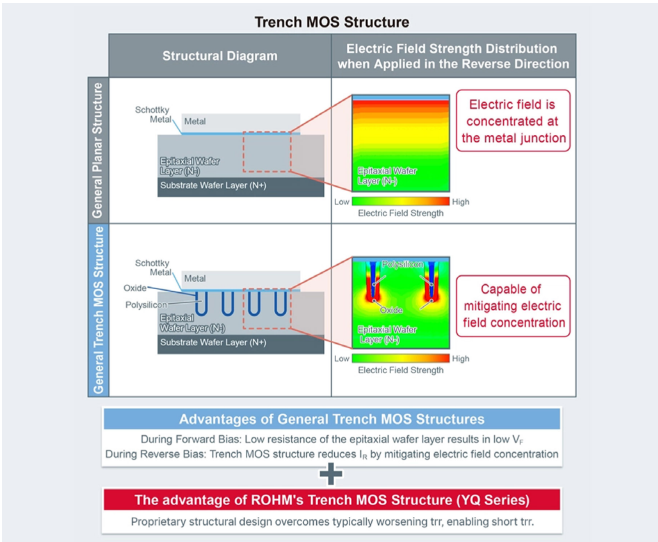


Figure 2: Comparing the planar MOS structure to the trench MOS structure.

In addition, Figure 2 illustrates the electric field distribution when applied in the reverse direction. In the traditional planar structure, the electric field is concentrated at the metal junction; however, ROHM's proprietary trench structure mitigates the electric field concentration with the highest field strength occurring where the oxide film contacts the epitaxial N- layer. The electric field concentration is unlikely to occur when applied in the reverse direction. The epitaxial layer exhibits low I_R even with low resistance; when applied in the forward direction, it exhibits low resistance, and a lower V_F is achieved, leading to higher efficiencies in rectification applications.

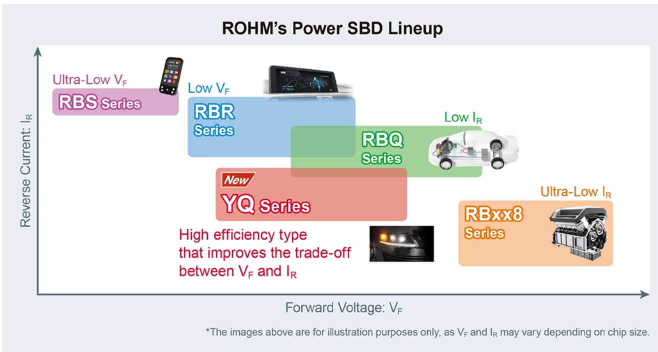


Figure 3: ROHM's power SBD lineup, including the YQ series.

New RoHM YQ Series SBD

ROHM has introduced the new YQ series SBD with a 100V breakdown for power supply and protection circuits in automotive, industrial, and consumer applications. As Figure 3 illustrates, the YQ series is part of the ROHM power SBD lineup.

ROHM's proprietary trench MOS structure simultaneously reduces VF and IR for reduced power losses, including reduced loss when used in forward bias applications. The overall switching loss is reduced by approximately 26% compared to general trench-type MOS products. They also exhibit a class-leading trr (reverse recovery time) of 15ns, which reduces trr loss by about 37% when used in switching applications. The YQ series also runs less risk of thermal runaway.

Performance

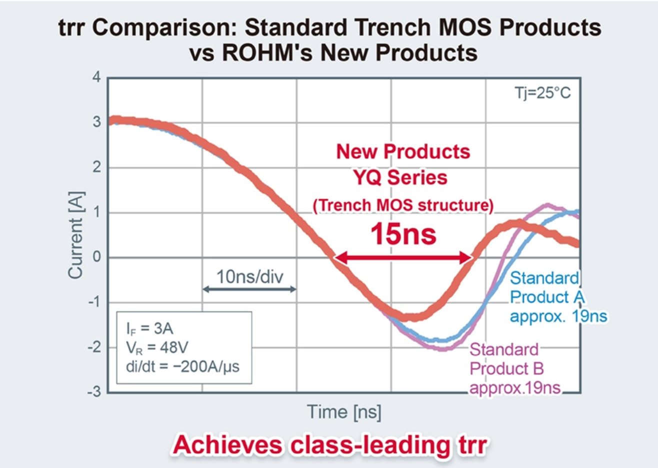


Figure 4: Comparing the trr of the YQ series to two equivalent power SBD solutions.

ROHM SBDs already have a reputation for greater miniaturization, lower losses in applications for the automotive, industrial, and consumer equipment markets, and reduced V_F and I_R. The ROHM YQ series achieves a class-leading trr of 15ns when compared to 19ns for standard trench MOS products (I_F of 3A and V_R of 48V), as shown by the chart in Figure 4. Note that this was for I_F = 3A, V_R = 48V, and di/dt = -200A/µs.

Figures C and D compare the results of the I_F-V_F and capacitance-VR characteristics for the TO-277 package products in the 100V/10A class for the ROHM YQ10RSM10SD and the equivalent power SBDs from three other companies.

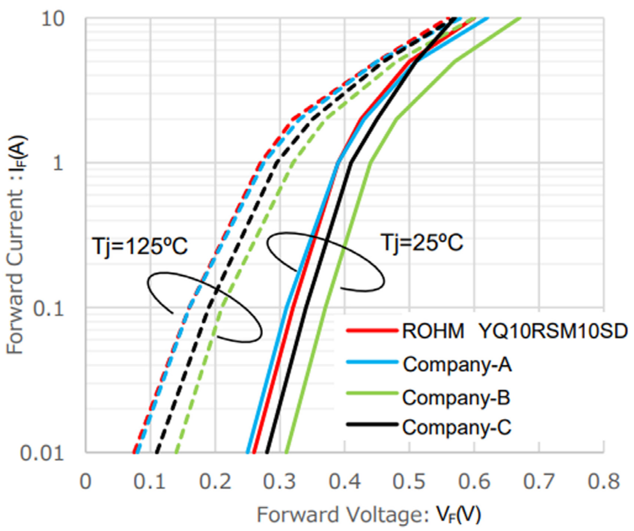


Figure 5: Forward current vs forward voltage for the ROHM YQ10RSM10SD compared to three other equivalent SBD solutions.

Figure 5 shows that the ROHM YQ10RSM10SD has one of the lowest V_F characteristics, nearly equivalent to the Company A product, which implies that these two SBDs have the lowest conduction loss. In contrast, the V_F of Companies B and C products are higher by approximately 10-20%, leading to higher conduction losses than the ROHM YQ10RSM10SD and Company A.

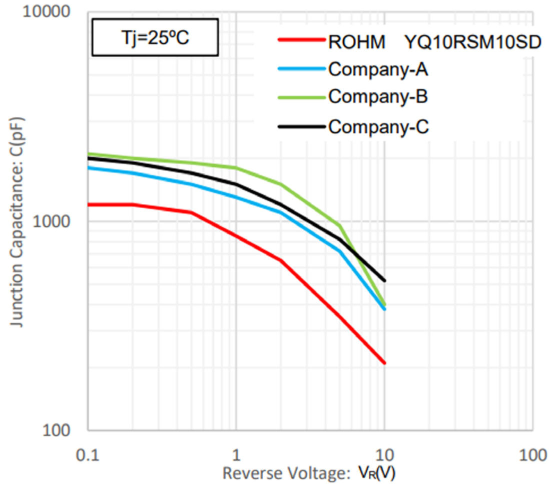


Figure 6: Junction capacitance vs reverse voltage for the ROHM YQ10RSM10SD compared to three other equivalent SBD solutions.

Based on the capacitance VR characteristics shown in Figure 6, the ROHM YQ10RSM10SD has the lowest switching loss due to having the smallest capacitance (approximately half), when compared with products A, B, and C.

YQ Series SBD Lineup and Technical Specifications

Figure 7 shows the YQ lineup based on packaging, with a summary of key technical specifications.

Package	I_O(A)	V_{RM}(V)	Tj max(℃)
PMDE 2.5×1.3×0.95mm	1A 2A		
SOD-123FL (PMDU) 3.5×1.6×0.8mm	2A 3A		
SOD-128 (PMDTM) 4.7×2.5×0.95mm	2A 5A		175
TO-277A 6.5×4.6×1.1mm	3A 15A	100	
TO-252AA 10.0×6.6×2.2mm	20A		150
TO-263S 13.1×10.1×4.5mm	20A 60A		

Figure 7: The ROHM YQ SBDs lineup.

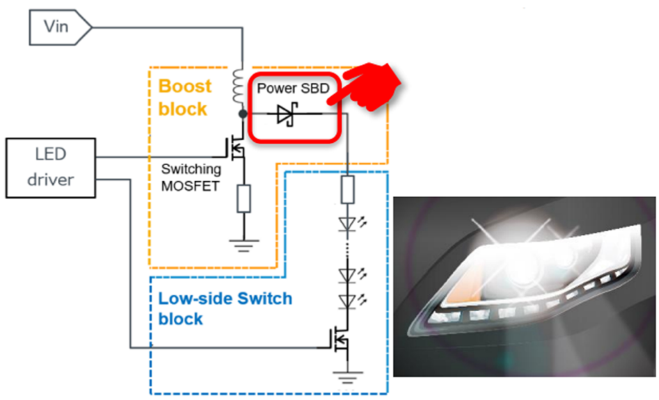
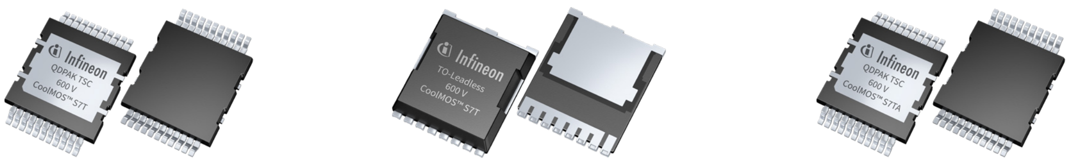


Figure 8. Circuit for rectifying the boost block in the peripheral circuitry of automotive LED headlamps.

INDUSTRIAL and AUTOMOTIVE

SJ MOSFET with integrated temperature sensor



Optimized SJ MOSFET for solid-state relay, circuit breakers and eFuse applications

- Built-in high precision temperature sensor
- Lowest $R_{DS(on)}$ of 10 mΩ in Q-DPAK top-side cooled and TOLL package
- 40% increase in sensing accuracy and 4 times faster response-time
- Eliminates or reduces heat sinks in solid-state design

More information here

Infineon

Applications

There are numerous applications for ROHM's YQ series of SBDs, including automotive LED headlamps, xEV DC-DC converters, power supplies for industrial equipment, and lighting.

Use Case: Automotive Headlamps

One common application for the type of SBDs found in the YQ series is rectifying the boost block in the peripheral circuitry of automotive LED headlamps. The circuitry is shown in Figure 8, where the SBD power MOS is outlined in red, the boost block in yellow, and the low-side switch block in blue.

Such circuits for automotive LED headlamps are energized under a sealed condition, meaning temperatures can become very high. To further complicate matters, the number of bulbs in automotive headlamps has increased, and the size of circuit boards has decreased in recent years — leading to harsh heat generation conditions and very high temperatures.

A power SBD for this type of application should exhibit low V_F and I_R with excellent heat dissipation to reduce the possibility of thermal runaway risk, which is what the YQ power SBD achieves.

Based on results from the LED Headlamp Evaluation board, when a standard trench MOS product is compared to the ROHM YQ series product (see Figure 10), the trr loss is reduced by approximately 37%, and the switching loss is reduced by 26%.

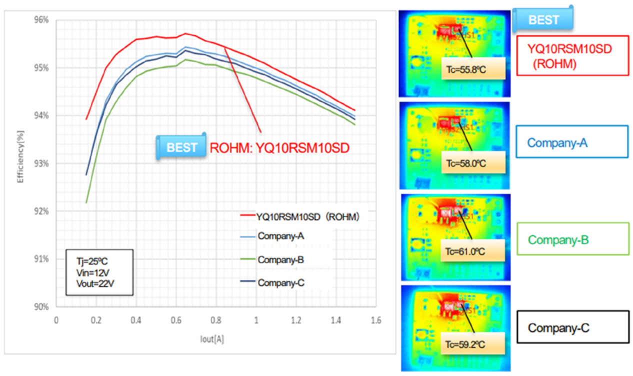


Figure 11: Comparison results of the efficiency and package surface temperature using the ROHM YQ10RSM10SD to an equivalent solution from three other companies, A, B, and C.

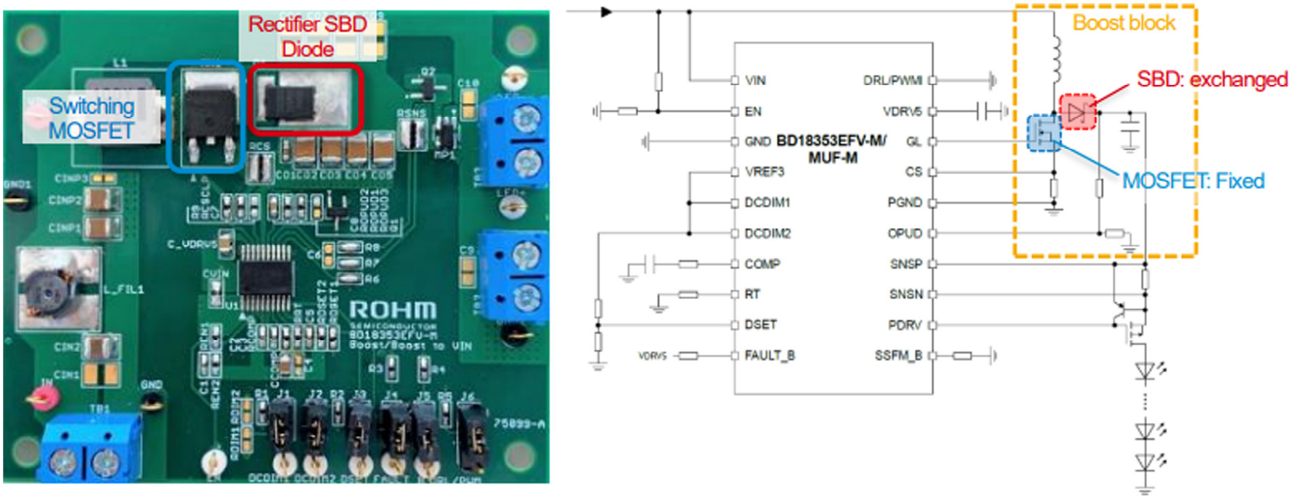


Figure 9: Picture of the evaluation board and circuit diagram.

Using the ROHM automotive LED driver BD18353EFV-M[2]and its evaluation board, as shown in Figure 9, the power conversion efficiency and heat generation of a ROHM YQ10RSM10SD (100V/10A/TO-277) were compared to similar products from other companies. Figure 9 outlines the switching MOSFET in blue, and a ROHM RD3P-100SNFRA (100V/10A/TO-252) was used. Figure 10 shows the evaluation board and circuitry used. This evaluation was performed by exchanging the rectifier diode, outlined in red, in the boost block.

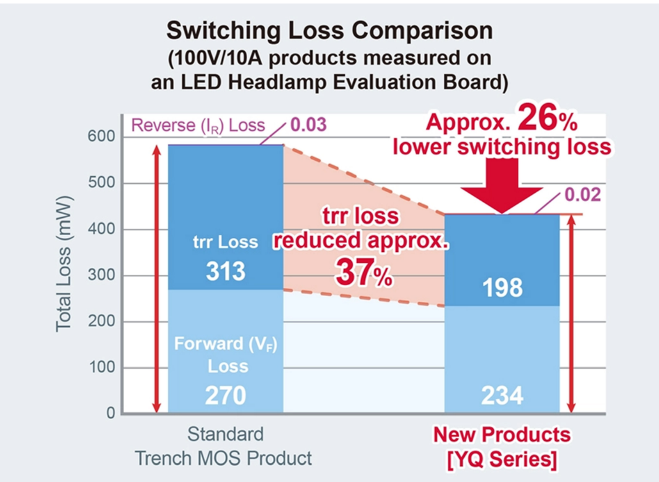


Figure 10: Switching loss comparison measured on an LED headlamp evaluation board.

Figure 11 shows the efficiency and package surface temperature Tc results. First, it was confirmed that YQ10RSM10SD (with excellent VF and capacitance characteristics) has the highest power conversion efficiency and keeps Tc the lowest at 55.8°C. The efficiency of B and C are significantly lower, and the Tc is significantly higher at 61.0°C and 59.2°C (respectively) even with the same package, due to a high V_F. Even though A has a V_F characteristic equivalent to the ROHM YQ10RSM10SD, efficiency is lower, and Tc (58.0°C) is higher because of its higher switching losses.

Conclusion

ROHM's new YQ SBD series has a proprietary trench MOS structure that offers several benefits over traditional p-n junction solutions. One is a tradeoff between I_R and V_F that leads to better efficiency and less heat generation. These 100V breakdown SBDs provide industry-leading trr and are ideal for protection and power supply circuits used in industrial, automotive, and consumer applications.

Sources

- Figure 2; 3 &4: https://www.rohm.com/news-detail?news-title=2024-02-15_news_sbd&defaultGroupId=false
- Figure 5; 6; 7; 8; 9 & 11: https://fscdn.rohm.com/en/products/databook/applinote/discrete/diodes/yq_sbd_automotive_an-e.pdf
- Figure 10: https://www.rohm.com/documents/11303/12540685/img2.webp/7495a33a-047d-be20-31c1-92bfc2854ca4?t=1707958811858

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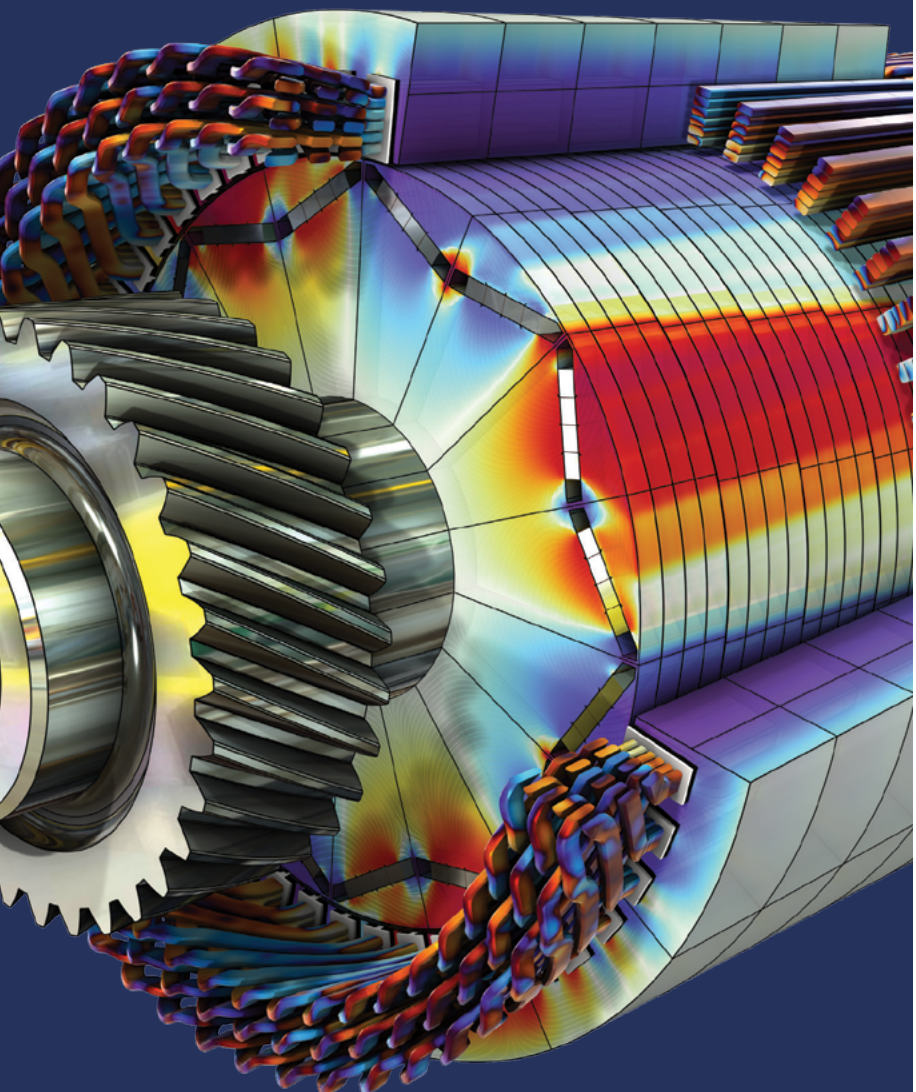
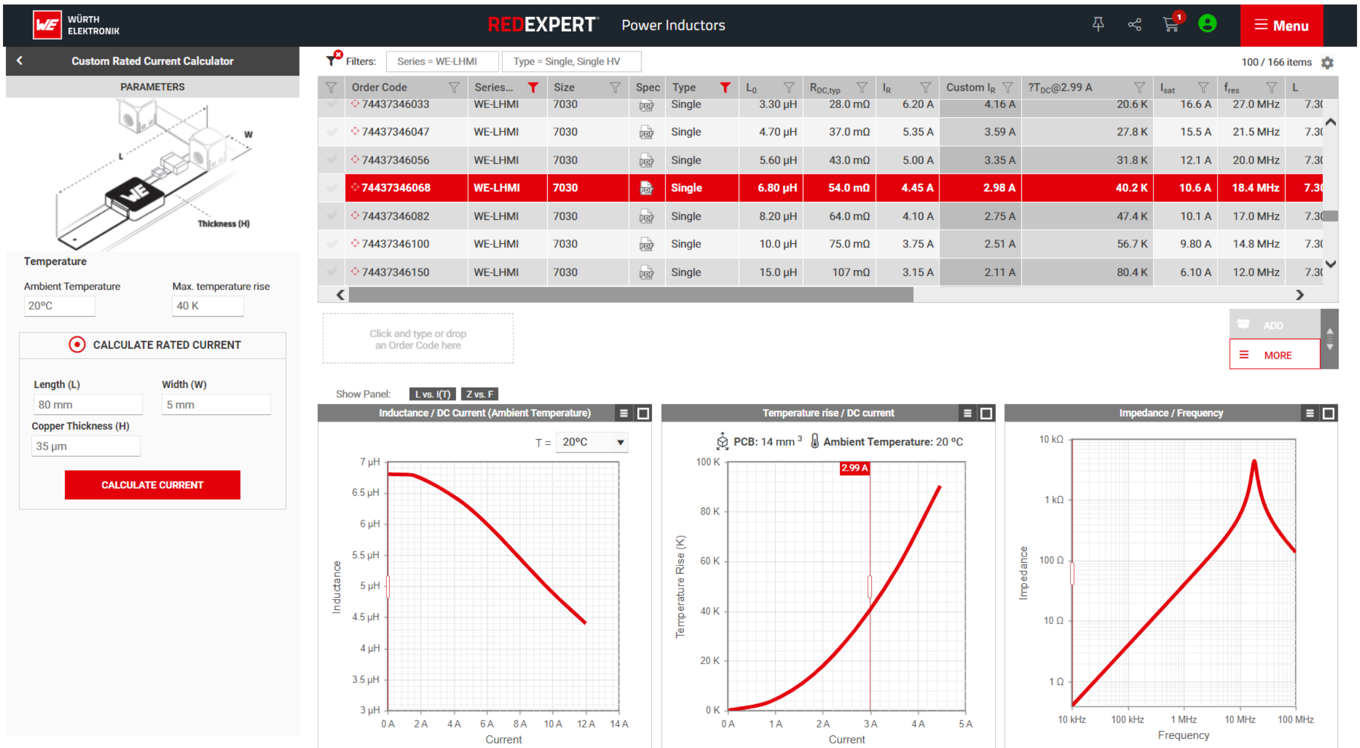


Determine Rated Current for Your Application

By determining the rated current for power inductors in your application, components can be selected with greater optimality. A new online tool from Würth Elektronik considers the impact of the circuit board when calculating the rated current of power inductors, giving you a dynamic datasheet value.

By Dr. Richard Blakey, Modelling and Simulation Manager, Würth Elektronik



The definition of rated current continues to vary between passive component manufacturers in the power electronics industry, despite the adoption of IEC standard 62024-2 which specifically describes how rated current should be measured. Because of this, misconceptions can still arise about what this parameter actually represents and how design engineers can use it. Is it an absolute parameter? Are rated current values from different manufacturers directly comparable?

The answer to these questions is no. As a result of this, it is possible that parts from some manufacturers appear better at first glance than others. However, design and component engineers should always try to fully understand how a manufacturer is measuring their components for reporting rated current parameters and not accept the parameters at face value.

With this in mind, Würth Elektronik has developed a thermal model that calculates the rated current of power inductors given a specific size of PCB. This will allow design and component engineers the ability to explore how the rated current of parts is affected by different dimensions PCBs.

Impact of PCB dimensions on rated current

An explanation of the thermal behavior of power inductors can be found in the application note ANP096 – What do rated current values mean? [1] How the PCB trace dimensions have an influence on the inductor temperature rise are described in the referenced application note. To summarize, wider traces and increased copper thickness (PCB cross section) will reduce the thermal resistance, increasing the flow of conducted heat from the inductor. As the surface area of the PCB increases, the thermal convection and radiation resistance is reduced increasing thermal convection and radiation transfer to the ambient environment. In this scenario of increasing dimensions, more heat can be transferred to the environment via the PCB, lowering the operating temperature of the inductor. This also means that a higher current can now feasibly be applied to the part to reach the same temperature as when a PCB with smaller dimensions is used. Now we can conceive how PCB dimensions can affect the reported value of rated current in datasheets. Again, test measurement PCBs with large dimensions may be used to misrepresent rated current values and this information may not be specified in datasheets, leaving room for misinterpretation by design and component engineers. This is demonstrated in ANP096.

Rated current calculator

In order to define the rated current for components when measured on different size PCBs, Würth Elektronik has made its Rated Current Calculator available online through RedExpert [2], which allows the user to input the desired PCB dimensions (Figure 1).

After the PCB dimensions have been input by the user, a Custom I_R column is added to the parameter table (Figure 2) in addition to the temperature rise chart being updated to reflect the new PCB dimensions (Figure 3).

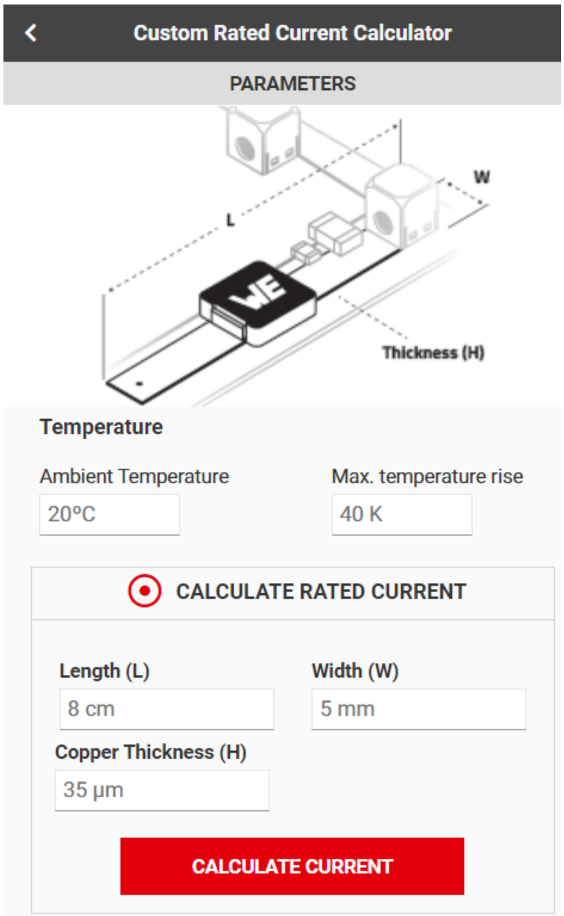


Figure 1: User interface of the Rated Current Calculator with IEC62024-2 Class A 5 mm dimensions entered.

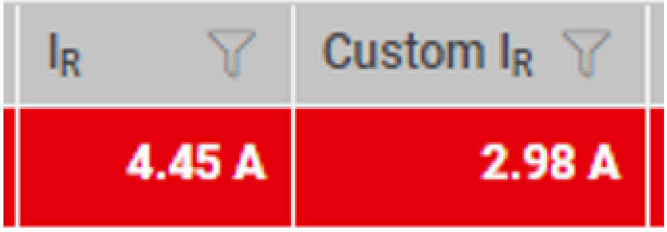


Figure 2: Datasheet Rated Current (left) and Custom Rated Current value (right) based upon dimension entered in the user interface.

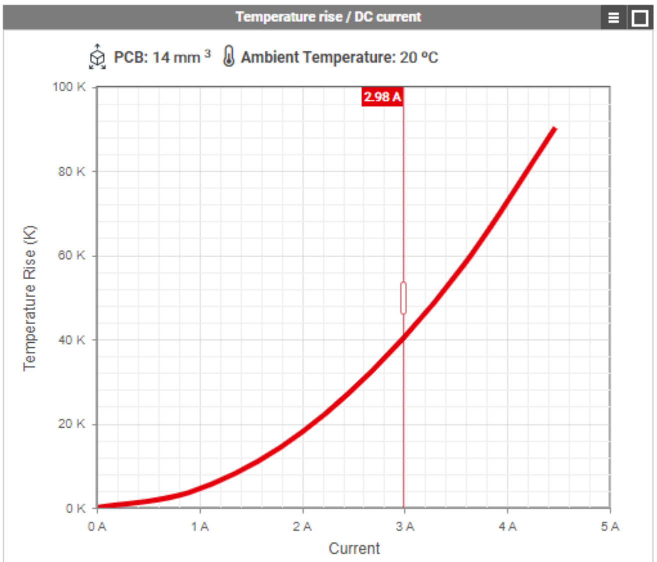


Figure 3: Temperature rise chart based upon dimension entered into user interface.

These calculations are based on a statistical model which is based on and verified by component measurements using different sized PCBs. In this way the user can now view the calculated rated current for Würth Elektronik power inductors on different sizes of PCB, whether that be for comparisons with other power inductors or to estimate the rated current of a part when soldered to the application PCB. It should be noted that when used to estimate the rated current in the target application, it should be remembered that other components will contribute to the heat distribution in the PCB. These components could increase the temperature of the PCB, such as the IC and capacitors or in the case of heat sinks lower the temperature of the PCB.

Consider the WE-LHMI (744 373 460 68) which has a rated current of performance rated current of 4.45 A (Figure 4). This is measured on an IEC 62024-2 $I_{Class\ C}$ PCB. The graph displays the temperature rise as a result of the DC current for this component on the $I_{Class\ A}$ 5 mm, $I_{Class\ C}$, and $I_{Class\ D}$ PCB. In addition the chart displays the output from the Rated Current Calculator from the RedExpert user interface available online as the data points. As can be seen, the calculated values are comparable to those gathered from component measurements.

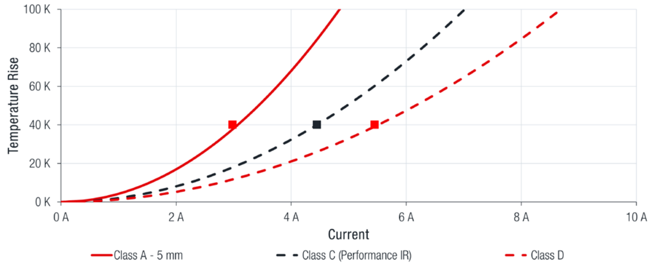


Figure 4: Self heating comparison of WE-LHMI 744 373 460 68 on different IEC 62024-2 PCBs and the calculated current for a 40K temperature rise using the Rated Current Calculator (data points).

This comparison demonstrates how the Rated Current Calculator calculates the rated current with relative accuracy when compared to rated current measurements. It also demonstrates how the rated current of a part is highly reliant on the PCB dimensions with the inductor being able to be operated at even higher currents than the rated current on the datasheet. Additionally, it demonstrates that I_{RP} are numbers to compare and guide in the selection of inductors before prototyping. It should be remembered that these are basic parameters, considering only DC currents with no additional heat generating parts on the PCB. In real conditions, AC losses and the thermal effects of surrounding components would also have to be considered. The actual temperature rises seen in the end applications will vary considerably dependent on the conditions.

Rated current based on PCB dimensions

Rated current values found on datasheets serve as a guide for the selection of power inductors. However, the temperature rise in power inductors can be influenced by the PCB dimensions on which they are tested. These are not always comparable between all manufacturers giving a false sense of what the rated current values actually represent.

Comparing similar parts from different manufacturers on the same PCBs reveals that the thermal performance is almost analogous. To this end, Würth Elektronik has devised an online Rated Current Calculator which can determine the rated current of Würth Elektronik power inductors on a PCB size of the user's choosing. This allows a rated current value to be estimated for the users end application or to compare inductors with competitor components.

References

[1] Blakey, R.; Gerfer, A.: What do rated current values mean? Application Note ANP096 from Würth Elektronik: www.we-online.com/ANP096

[2] RedExpert Rated Current Calculator: https://redexpert.we-online.com/redexpert/#/module/4/dr/ANP138

[3] Blakey, R.: Custom Rated Current Calculator. Application Note ANP138 from Würth Elektronik: www.we-online.com/ANP138

About the Author

Dr. Richard Blakey, after graduating from the University of Central Lancashire (UK) with a degree in biomedical sciences (2010), moved to Liverpool John Moores University (LJMU) where he earned a PhD with a thesis titled "Development of Dielectric Spectroscopic Resonant Sensors for Biomedical and Industrial Applications" (2014). Following this, he worked at a number of universities and research centres around Europe before moving to Würth Elektronik eiSos in 2017 as an Application Engineer where he is responsible for component and application modelling and simulation.

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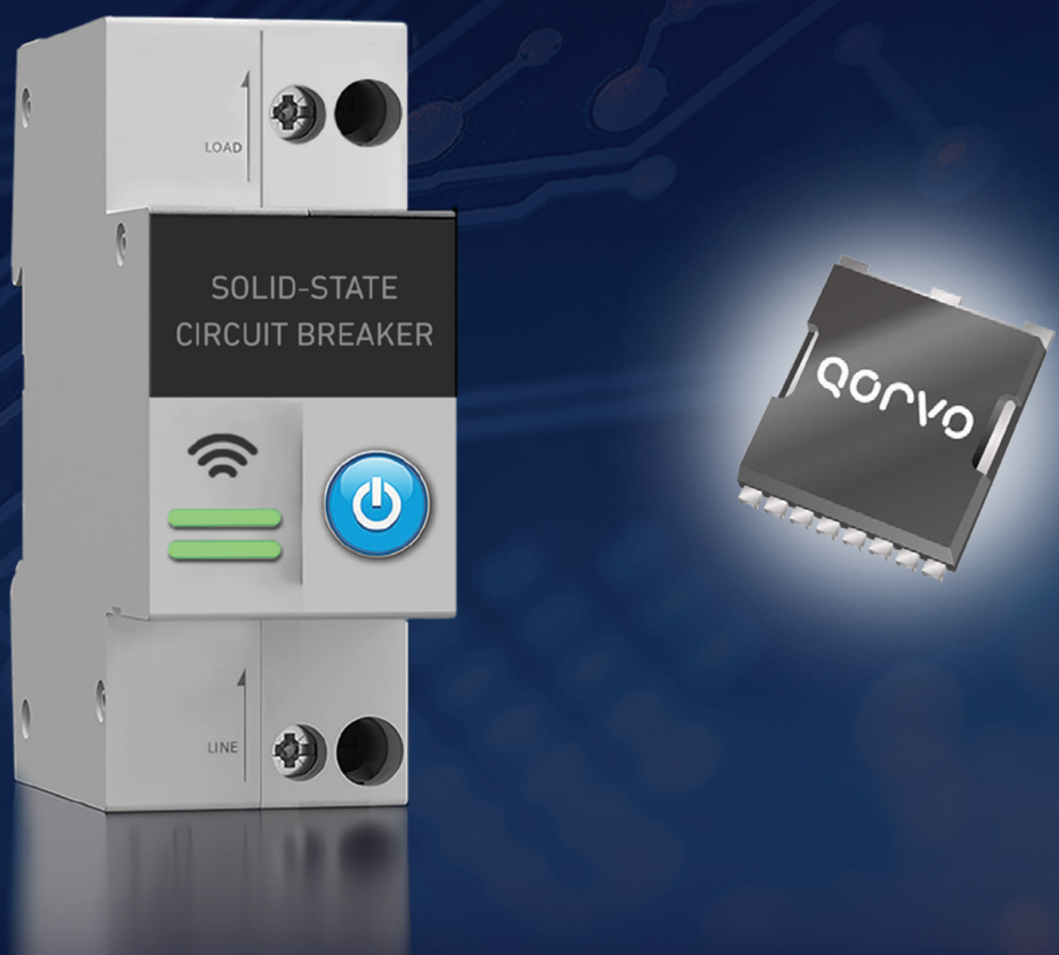
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Addressing Design Challenges with User-programmable Power-management Integrated Circuits

Advancements in processor and field-programmable gate array (FPGA) technology are complicating power requirements. In addition to supplying the correct voltages and currents to power rails, many power solutions need features such as power sequencing (the activation of power rails in a certain order), low-power modes and monitoring elements.

By Louise Yang, Product Marketing Engineer PMIC product line, Texas Instruments

While it is possible to build a solution using discrete parts, power-management integrated circuits (PMICs) can accelerate the design process. PMICs unify many common power-management functions into a single energy-efficient chip, which can simplify designs and shrink power solution sizes.

Advantages of user-programmable PMICs

There are many types of PMICs: factory-programmed, hardware-configurable and software-configurable. But in situations where wide flexibility and easy customization are high priorities, a user-programmable PMIC can be a better fit, giving impressive control over details such as power rail voltages and power sequencing. Linux® drivers developed specifically for these PMICs enable the system to trigger reboots, soft restarts and low-power modes; they also enable dynamic voltage scaling, adapting buck-converter voltages to match the system's current power needs.

It is common for a system's power requirements to change during the design process. You might add or remove peripheral parts, upgrade or swap processors, or want different power modes.

A good example would be the FPGA. The reconfigurability of the FPGA is one of its strongest selling points, but any change to its design and dynamic load requirements will also affect its power-management requirements.

When it comes to customization, the other kinds of PMICs have limitations. For example:

- Factory-programmed PMICs are catalog or custom devices that are pre-programmed to power specific processors or FPGAs, and require a large-volume business case.
- Hardware-configurable PMICs use resistors to change the output voltages, which may lead to power solutions with a larger printed circuit board footprint. Also, adding power sequencing will then require an external sequencer or microcontroller.
- Software-configurable PMICs need an accompanying microcontroller to configure them at startup; these configuration changes are not permanent, and the PMIC must be reconfigured after each power cycle.

Any category of PMIC can offer some level of adjustment to these changing requirements, but the customizability of a user-programmable PMIC is a solid complement to the adaptability of the FPGA; user- programmable PMICs can reduce the amount of time revising FPGA power architectures without compromising the quality of power solutions, giving you more flexibility to experiment with different FPGA designs.

It is possible to reprogram a user-programmable PMIC such as the TPS6521905 multiple times through its electrically erasable programmable read-only memory (EEPROM). The TPS6521905 is initialized with a blank EEPROM, disabling all power rails until configuration and avoiding any potential damage during the production process if you will be powering and placing the PMIC into the prototype board before reprogramming.

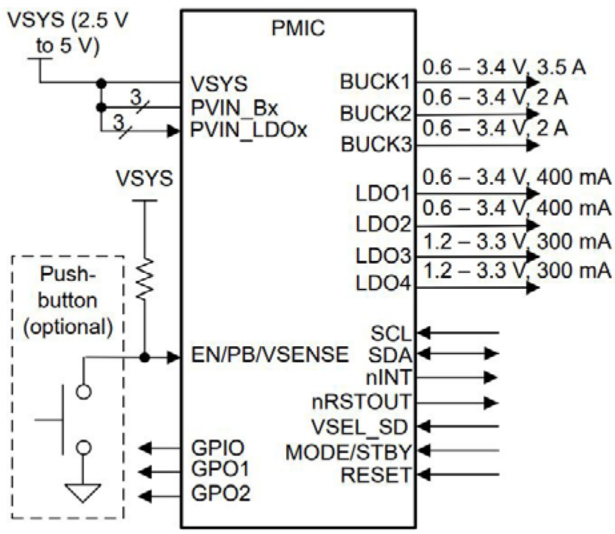

Figure 1: Block diagram of the TPS6521905.

Using I2C communication, you can program the three buck converters and four low-dropout regulators of the TPS6521905 to customize power rail voltages and power sequences and toggle different operating modes. You can set safety features such as undervoltage sensing and temperature thresholds, and configure the three multifunction pins and three digital input/output pins to interface with other devices. If the system needs more power rails, then you can synchronize multiple TPS6521905 devices, as illustrated in Figure 2.

The TPS6521905 comes in a package size as small as 4 mm by 4 mm, and operates at a switching frequency of 2.3 MHz; the compact sizing and high switching frequency allow for smaller input/output inductance and capacitance requirements, which can save space and lower system costs.

Prototyping to production

A user-programmable PMIC is a blank slate with many customization options. It can reduce design cost and time, and is often reusable across different projects. It is possible to reprogram a single part number to substitute several for different part numbers, simplifying the supply chain.

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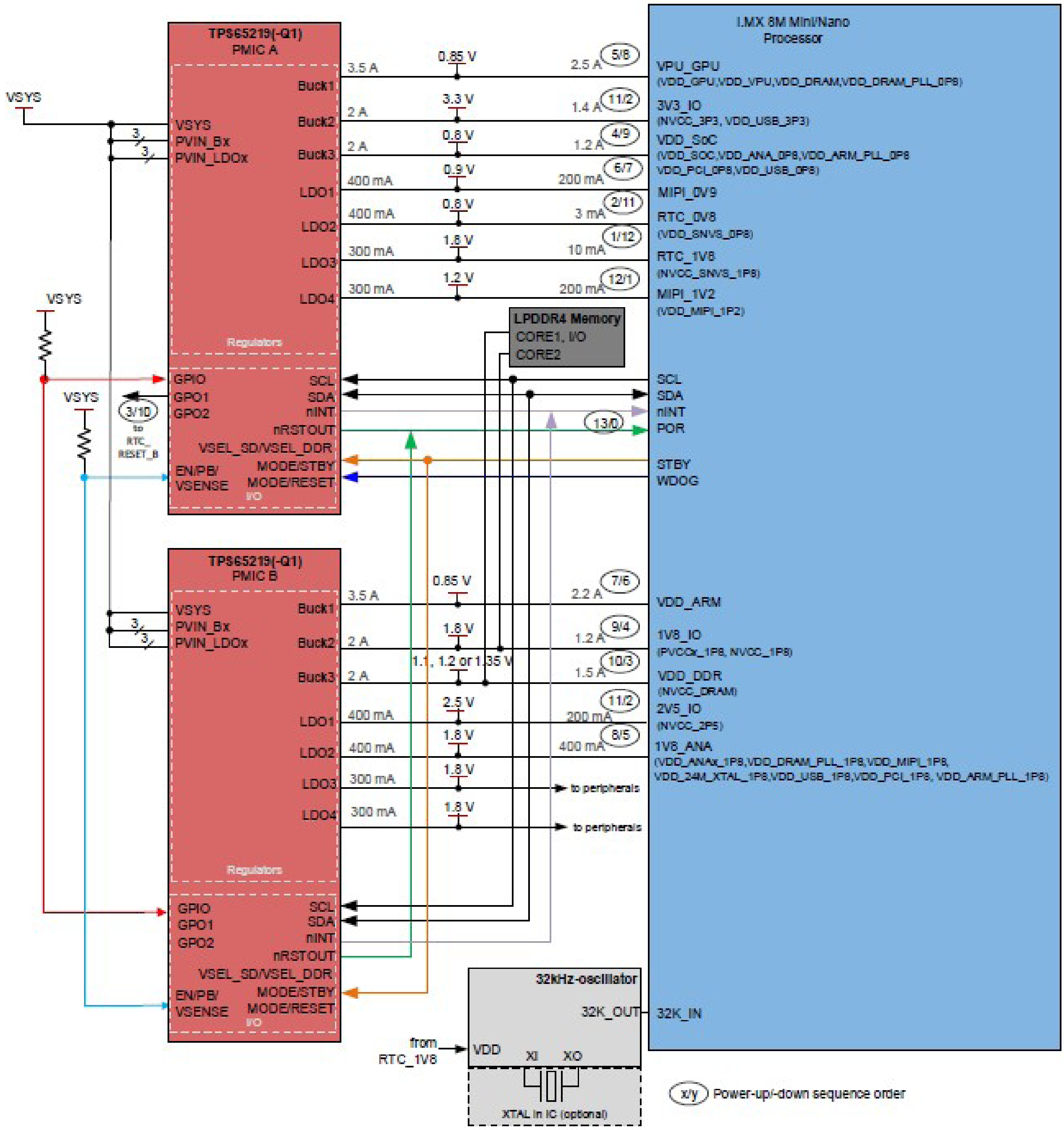

Figure 2: Cascading multiple TPS6521905 devices

Let's go through the steps of the prototyping-to-production process with a user-programmable PMIC such as the TPS6521905:

- Define the specifications of the nonvolatile memory settings according to your power solution requirements.
- Reprogram the TPS6521905 with the TPS65219-GUI and TPS65219EVM-SKT, using the programming guide and tutorial video as references.
- Perform testing and validation on the configured PMIC, reevaluating the design until it satisfies your system requirements.
- Once you have finalized the design, export the custom TPS65219-GUI register settings.
- Your company can mass-program the TPS6521905 registers independently or use a third-party programming service.

Conclusion

A user-programmable PMIC can be a good choice given its many customization options; it can also accelerate design processes and reduce system costs while maintaining power efficiency and compact sizing.

Working with user-programmable PMICs can be a new experience for engineers. TI aims to ease the process and offer technical support at every step of the way through user-programmable PMIC user guides, tutorial videos and application notes, as well as the TI E2E™ design support forums.

About the Author

Louise Yang joined TI in February 2021. Her current role is Product Marketing Manager for the company's PMIC line. She received her Bachelor of Science degree from the Washington University in St. Louis.

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LOW VOLTAGE

	Maximum Ratings (T_A=25°C unless otherwise noted)				Electrical Characteristics: (T_A=25°C unless otherwise noted)						
Central Item No.	V_{DS} (V) MAX	V_{GS} (V) MAX	I_D (A) MAX	I_{DM} (A) MAX	$r_{DS(ON)}$ (mΩ) MAX	$V_{GS(th)}$ (V) MAX	Q_g (nC) TYP	Q_{gd} (nC) TYP	Q_{gs} (nC) TYP	Package	Central Die Item No.
CCSPG0420N*	40	6.0	20	100	4.0	2.4	15.8	8.6	1.9	CSP2X2	CPG005
CCSPG0450N*	40	-4.0 to +6.0	50	200	1.5	2.3	28	4.6	6.2	CSP5X4	CPG006
CCSPG1060N	100	-4.0 to +8.0	60	–	5.5	2.5	9.2	1.9	1.7	CSP3.5X2	CPG001
NEW CCSPG1560N*	150	-4.0 to +6.0	60	–	7.0	2.1	13	2.0	3.0	CSP4X6	CPG008
NEW CCSPG1510N*	150	-4.0 to +6.0	100	–	3.9	2.1	20	3.5	5.0	CSP4X6	CPG009

HIGH VOLTAGE

	Maximum Ratings (T_A=25°C unless otherwise noted)				Electrical Characteristics: (T_A=25°C unless otherwise noted)						
Central Item No.	V_{DS} (V) MAX	V_{GS} (V) MAX	I_D (A) MAX	I_{DM} (A) MAX	$r_{DS(ON)}$ (mΩ) MAX	$V_{GS(th)}$ (V) MAX	Q_g (nC) TYP	Q_{gd} (nC) TYP	Q_{gs} (nC) TYP	Package	Central Die Item No.
CDF56G6511N	650	-1.4 to +7.0	11.5	20.5	190	2.5	2.8	1.1	0.25	DFN5X6A	CPG003
CDF56G6517N	650	-1.4 to +7.0	17	32	140	2.5	3.5	1.2	0.3	DFN5X6A	CPG004
CDFG6511N*	650	-1.4 to +7.0	11.5	20.5	190	2.5	2.8	1.1	0.25	DFN8X8	CPG003
CDFG6517N*	650	-1.4 to +7.0	17	32	140	2.5	3.5	1.2	0.3	DFN8X8	CPG004
NEW CDFG6558N*	650	-6.0 to +7.0	29	58	80	2.5	6.2	2.2	0.5	DFN8X8	CPG010
NEW CDF56G7032N*	700	-6.0 to +7.0	18	32	140	2.5	3.5	1.2	0.3	DFN5X6A	CPG011

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Design Considerations for a High-Voltage SiC-Based Battery Disconnect Switch

Electrical systems with DC bus voltages of 400V or greater, powered by single- or three-phase grid power or an energy storage system (ESS), can enhance their reliability and resilience with the benefits offered from solid-state circuit protection. In designing a high-voltage solid-state battery disconnect switch there are several fundamental design decisions to consider.

By Ehab Tarmoom, Senior Technical Staff Applications Engineer - Silicon Carbide Business Unit, Microchip Technology

Among the key factors are semiconductor technology, device type, thermal packaging, device ruggedness and managing the inductive energy during circuit interruption. This article addresses design considerations in selecting the power semiconductor technology and defining the semiconductor packaging for a high-voltage, high-current battery disconnect switch, as well as the importance of characterizing a system's parasitic inductance and over-current protection limits.

Advantages of Wide-Bandgap Semiconductor Technology

Careful consideration is required to select the optimal semiconductor material to realize a switch with minimal on-state resistance, minimal off-state leakage current, high voltage-blocking capability and high power capability. Figure 1 shows semiconductor material characteristics for Silicon (Si), Silicon Carbide (SiC) and Gallium Nitride (GaN). The electric breakdown field of SiC and GaN is approximately ten times that of silicon. This enables the design of devices with a drift region that is one-tenth the thickness of an equivalent-rated silicon device since its thickness is inversely proportional to the electric breakdown field. Moreover, the resistance of the drift region is inversely proportional to the cube of the breakdown field. This results in nearly 1000 times lower drift region resistance. In a solid-state switch application, where all the losses are conduction losses, the high electric breakdown field is a significant advantage. This decreased resistance also eliminates concerns with dynamic latch-up issues, where high dV/dt transients may trigger the parasitic NPN transistor or thyristor in silicon power MOSFETs and IGBTs, respectively.

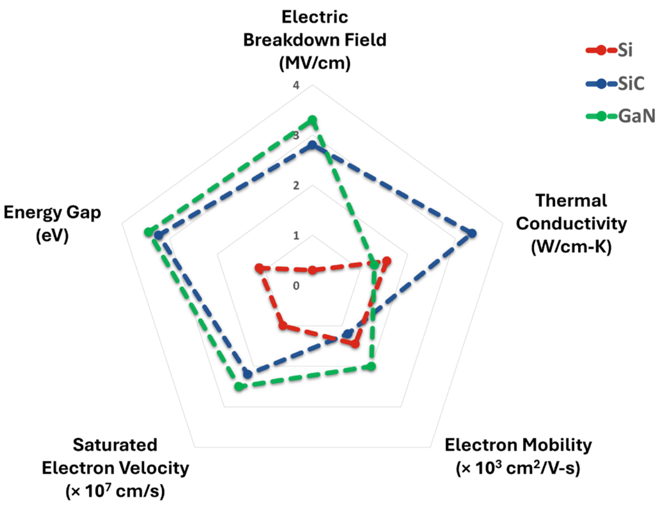


Figure 1: Si, SiC and GaN material properties

Silicon carbide's thermal conductivity, three times that of Si and GaN, significantly improves the ability to draw the heat out of the chip, enabling it to run cooler and simplifying the thermal design. Alternatively, for an equivalent target junction temperature it allows higher current operation. The higher thermal conductivity coupled with the high electric breakdown field, results in a low on-state resistance, further simplifying the thermal design.

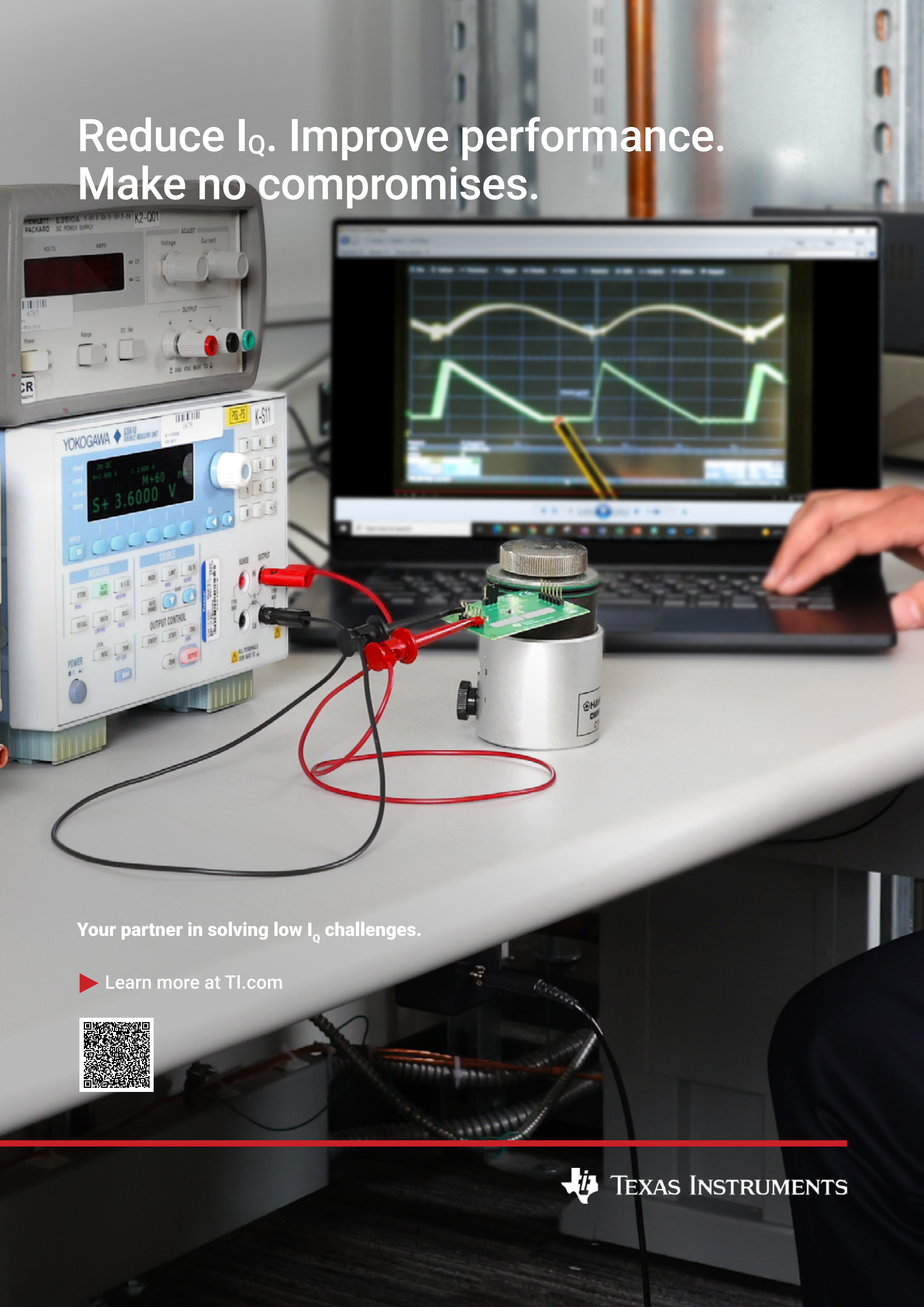
Silicon carbide, a wide-bandgap (WBG) semiconductor material, has an energy gap nearly three times that of silicon, which enables higher temperature operation. A semiconductor ceases to function as a semiconductor at elevated temperatures. The wider energy gap allows silicon carbide to operate several hundred degrees Celsius higher than silicon since the concentration of free charge carriers is lower. However, other factors (e.g., packaging, gate oxide leakage) based on today's technology limit a device's maximum continuous junction temperature to 175°C. Another advantage of WBG technology is it provides a lower off-state leakage current.

Considering these characteristics, silicon carbide is the optimal semiconductor material for this application.

Differences Between Device Types: IGBTs, MOSFETs and JFETs

The type of transistor is the next critical factor. In most cases, the conduction loss presents the greatest design challenge. The conduction loss should be minimized to meet the system's thermal requirements. Liquid cooling is available in some systems, while other systems may use forced-air or rely on natural convection. In addition to minimal conduction loss, the voltage drop must also be kept to a minimum to maximize efficiency across all operating points, including light-load conditions. This is especially important in battery-powered systems. Another important factor in many systems, including DC systems, is bi-directional current flow. A transistor with low conduction loss, low voltage drop and reverse conduction capability is generally desired. Transistors typically considered are IGBTs, MOSFETs and JFETs.

While an IGBT offers comparable conduction loss as a MOSFET at peak load currents, once the load current decreases, the efficiency of an IGBT-based solution decreases. This is because the voltage drop is comprised of two components: a near-constant voltage drop that is independent of collector current and a voltage drop that is proportional to the collector current. With a MOSFET, the voltage drop is proportional to the source current. It does not have the overhead of an IGBT, and this enables high efficiency across all operating points, including light-load conditions. The MOSFET allows channel conduction in the first and third quadrants, meaning current can flow through the device in the forward and reverse direction. An added benefit of a MOSFET's third-quadrant operation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is that it generally has a slightly lower on-state resistance than in the first quadrant. Whereas, an IGBT conducts current only in the first quadrant and an anti-parallel diode is needed for reverse current conduction. The JFET, an older technology but making a resurgence, works in both forward and reverse conduction, and, like the MOSFET, has a voltage drop proportional to the drain current. Where it differs from a MOSFET is it is a depletion-mode device. That is, the JFET is normally on and requires a gate bias to inhibit the flow of current. This presents practical challenges for designers when considering system fault conditions. As a workaround, a cascode configuration which includes a series low-voltage silicon MOSFET can be used to realize a normally-off device. The addition of the series silicon device increases the complexity, which diminishes some of the advantages of the JFET in high-current applications. The SiC MOSFET, a normally-off device, offers the low resistance and controllability needed in many systems.

Thermal Packaging

SiC power modules enable a high level of system optimization that is difficult to realize with paralleling discrete MOSFETs. Microchip's mSiC™ modules are available in a broad range of configurations and voltage and current ratings. Among these is the common-source configuration that connects two SiC MOSFETs in an anti-series configuration to allow bidirectional voltage- and current-blocking. Each of the MOSFETs are composed of multiple chips connected in parallel to achieve the rated current and low on-state resistance. For a unidirectional battery disconnect switch, the two MOSFETs are connected in parallel externally to the power module.

A low on-state resistance and low thermal resistance are needed to keep the chips running cool. The materials used within the module are essential elements that determine the thermal resistance from junction to case, as well as its reliability. Specifically, the die-attach, substrate, and baseplate material properties are the major contributors to a module's thermal resistance. Selecting materials that exhibit high thermal conductivity help minimize the thermal resistance and junction temperature. In addition to thermal performance, selecting materials with closely matched Coefficient of Thermal Expansion (CTE) increases the module's lifetime by reducing the thermal stress at both the interface and the interior of the materials. Table 1 summarizes these thermal characteristics. Aluminum Nitride (AlN) substrates and Copper (Cu) baseplates are standard in mSiC power modules. Options with Silicon Nitride (Si_3N_4) substrates and Aluminum Silicon Carbide (AlSiC) baseplates provide higher reliability. In Figure 2 are common-source power modules in the standard SP3F and SP6C packages and high-reliability baseplate-less BL1 and BL3 packages which are qualified to DO-160.

Device Ruggedness and System Inductance

Along with a module's thermal performance and long-term reliability, another design consideration in a circuit-interruption device is the high inductive energy. Relays and contactors have a limited number of cycles. They are commonly specified with unloaded mechanical switching cycles and significantly fewer electrically-loaded switching cycles. Inductance in the system results in arcing across the contacts causing degradation when breaking a current. As such, the operating conditions of the electrical cycles rating are specifically defined and have a strong influence on its life. Even then, upstream fuses are needed in systems with contactors or relays as the contacts may

	Material	CTE (ppm/K)	Thermal Conductivity (W/cm-K)	Density (g/cm^3)
Die	Si SiC	4 2.6	136 270	
Substrate	Al_2O_3 AlN Si_3N_4	7 5 3	25 170 60	
Baseplate	CuW AlSiC Cu	6.5 7 17	190 170 390	17 2.9 8.9

Table 1: Die, substrate and baseplate thermal properties

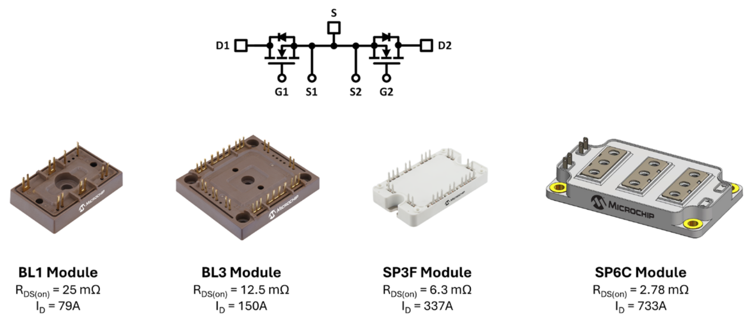

Figure 2: Microchip's mSiC modules in common-source configuration

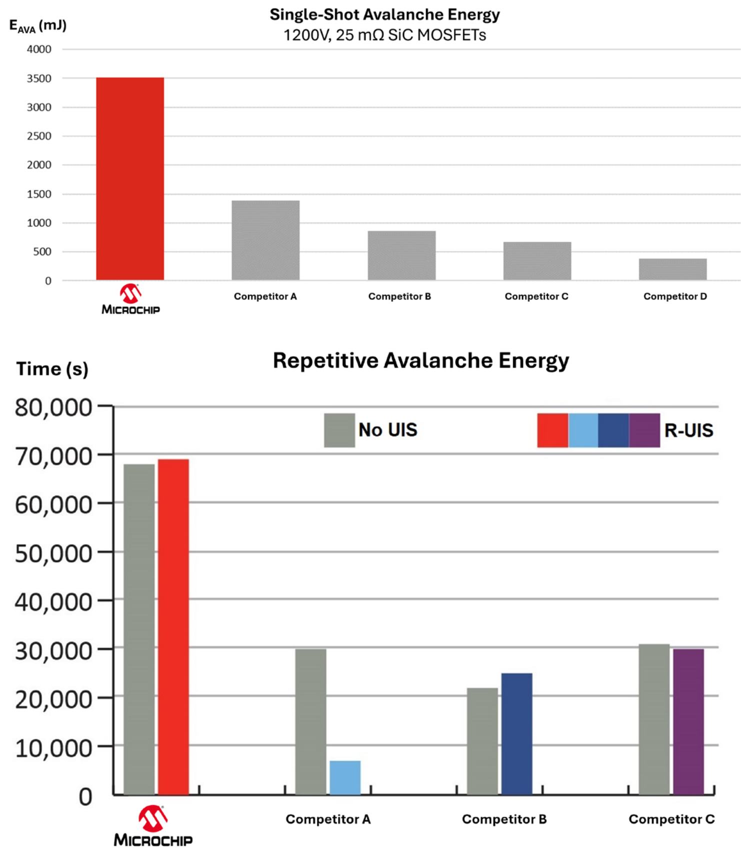

Figure 3: Single-shot (top) and repetitive (bottom) avalanche energy performance

weld shut when subjected to high short-circuit currents. Solid-state battery disconnect switches do not suffer from this degradation, enabling a higher reliability system. Despite that, understanding the parasitic and load inductance and capacitance of a system is also essential in managing the inductive energy present when interrupting high currents.

The inductive energy is proportional to the inductance and to the square of the current in the system at the time of interruption. A short circuit at the output terminals of the switch results in a fast increase in current, rising at a rate of the ratio of the battery voltage to the source inductance. As an example, an 800V bus voltage with 5-microhenry source inductance results in the current increasing at a rate of 160 Amps per microsecond. A 5-microsecond response time to detect and respond will result in an additional current of 800 Amps in the circuit. As it is not recommended to operate a SiC power module in avalanche mode, a snubber or clamp circuit is required to protect the module by absorbing this inductive energy. However, the parasitics introduced to the snubber circuit, when properly designed to meet creepage and clearance requirements, further limits its effectiveness. Therefore, the switch should turn off slowly enough to limit the voltage overstress from the module's internal inductance and the sudden decrease in its current. A module designed with low inductance helps further minimize this voltage stress.

In silicon power devices, a fast interruption of a high current introduces the risk of triggering the parasitic NPN or thyristor which results in an uncontrollable latch-up and eventual failure. On SiC devices a very fast turn-off may result in a low-energy avalanche breakdown in each chip as they turn off until the snubber or clamp absorbs the high energy. Microchip's mSiC MOSFETs are designed and tested for Unclamped Inductive Switching (UIS) ruggedness, providing an additional safety margin as a snubber or clamp begins to degrade. Figure 3 shows the single-shot and repetitive UIS performance compared with other SiC devices in the market.

Although device-level short circuit capability should be understood, and IGBTs do have superior device-level short-circuit performance over MOSFETs, in an actual system it is subjected to different stress conditions. With the inherent current-limiting behavior of the system inductance, a module is unlikely to reach its short-circuit current rating. The limiting factor is the snubber or clamp circuit design. To design a cost-effective and compact snubber, the allowable system-level peak short-circuit current will be limited to a value well below a module's short-circuit current rating. For example, in a 500 Amp battery disconnect switch consisting of nine parallel chips and designed to prevent short-circuit currents from exceeding 1350 Amps, each chip conducts a current of 150 Amps, assuming uniform current distribution. This is much lower current than in a device-level short-circuit test in which the current exceeds several hundred Amps for the duration of the test. Optimization of the voltage clamping device is a key part in the design of a robust solid-state battery disconnect switch.

Other Design Considerations

Beyond the power device, there are design considerations related to the control electronics, including current sensing technology, over-current detection and protection and functional safety. Decisions on whether to use a shunt resistor or magnetic technology for current sensing is important for a design in a system with low parasitic inductance, where a fast response time is essential. Whether to use hardware, software or a combination of two for over-current detection is also an important decision, especially when designing to meet functional safety requirements.

In summary, some crucial aspects in the choice and design of the high-voltage power device in a solid-state battery disconnect switch were discussed. The advantages of silicon carbide and power semiconductor packaging are key enablers to the system-level benefits a solid-state disconnect switch offers over the traditional mechanical disconnect switch. Using silicon carbide technology, devices are now available with low on-state resistance and thermal resistance allowing the low conduction loss needed in many systems, while also using materials that ensure high reliability.

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Slim DIN-rail Mounted Power Supplies

DIN-rail mounting has revolutionized electrical cabinets since the idea was first introduced in the 1920's in an attempt to standardize switchgear mounting and to allow interchangeability between manufacturers. DIN stands for "Deutsche Industrie Norm" or the "German Industrial Standard" and the success of the DIN-rail system rapidly spread outside of Germany, eventually becoming the European standard DIN EN 60715.

By Steve Roberts, Innovation Manager, RECOM Power

The simplicity and versatility of the DIN-rail system, where components can easily click into place or be unclipped for maintenance upgrades or replacement led to a whole range of different electrical components being manufactured for DIN-rail mounting, such as circuit breakers, relays, contactors, terminal blocks, data network components (KNX, DALI, Ethernet), programmable logic controllers (PLCs), and power supplies (Figure 1).

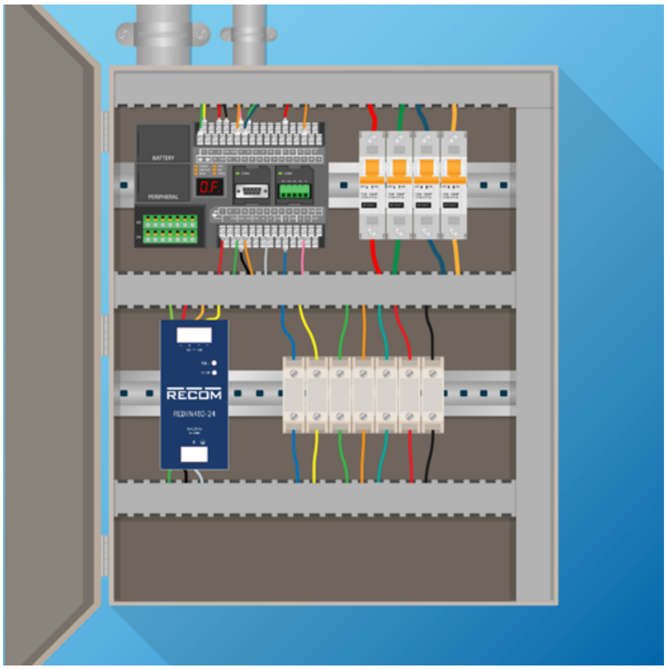

Figure 1: Typical DIN-Rail installation (image partially shutterstock.com)

The reason for the DIN-rail system's success lies in the following advantages:

Firstly, the modular approach allows electrical cabinets and panels to be quickly assembled, moved, or rearranged for optimum use of the available space with only a standard electrician's screwdriver as a tool. There is no drilling, cutting, or threading needed. Electrical cabinets and panels are often available with pre-installed rails so installation can begin immediately.

Secondly, the DIN-rail system allows easy upgrading or repair without disrupting other components – a defective part can be simply unclipped and replaced without affecting the other components. If the new part happens to be slightly larger than the older module, then the existing components can be shifted along the rail to make space.

Thirdly, as the mounting rail dimensions are all standardized, parts from different manufacturers are interchangeable and mounting compatible. On a single rail, different electrical components can be freely mixed, so, for example, connector blocks can be placed next to power supplies to simplify the distribution of power and reduce the amount of cabling required, or actuator relays placed next to PLCs.

Fourthly, as you might expect from a German standard, the ease of mounting allows an organized, neat, and logical layout within the cabinet. This not only speeds up assembly by streamlining the whole construction process but simplifies maintenance and troubleshooting. All electrical contacts are accessible from the front without disconnecting any wiring and many electrical components have status or alarm indicators so that complex installations can be quickly inspected to find the fault.

In some ways, the DIN-rail system has become a victim of its own success. As the DIN-rail mounting system is now ubiquitous for almost all electrical, networking and telecommunication equipment, there is a tendency to try and cram as much as possible onto each rail. Each component should be as thin as possible to minimize the amount of rail space required. However, some electrical equipment generates heat, for example power supplies, contactor coils or relays, so placing these units in very close proximity to each other can adversely affect the natural convection cooling air flow. As every 10°C increase in ambient temperature halves the operational lifetime, this needs to be avoided if possible.

Solutions include adding spacers between equipment to allow free air convection to cool the components, to repositioning heat-generating components so that they are not in close proximity where they could warm each other up, or, in extreme cases, adding fans to force air cool the parts. The vertical separation between rails also needs to be considered so that warm air rising from one component does not adversely affect the component placed immediately above it. Fortunately, software packages are readily available that can be used to both plan the layout of the panel or cabinet in advance and to calculate the expected thermal loading. This software is often offered free by the cabinet manufacturers. More advanced software can also automatically check if the electrical safety, construction, and technical standards, such as EN 61439, are also being complied with.

Figure 2: REDIIN120, REDIIN240, and REDIIN480 DIN-rail Power Supplies

RECOM is an established power supply manufacturer that is well-known for board-mounting or chassis-mounting embedded power, but also offers competitively priced DIN-rail mount power supplies (Figure 2).

Power supplies designed for DIN-rail mounting need to have certain special features which makes them different from standard industrial power supplies:

1: Always-on. Power supplies in panels and electrical cabinets typically operate in "always on" mode. Even if a production line is shut down overnight, the low voltage power supply for the relays and controllers stays on. Operating 24/7 means that DIN-rail power supplies need to have a very long operational lifetime, which is assured both by careful design and also by heavy duty input filtering stages that can withstand severe input voltage fluctuations, supply interruptions, mains transients, and power surges.

2: High efficiency. Both when fully loaded and un-loaded, high efficiency is needed to minimize the internal heat dissipation and to save energy during standby. The REDIIN series feature a flat efficiency curve which remains at around 90-94% for all loads from 20% or less up to 100% full load (Figure 3) independently from supply voltage. Under no-load conditions, the 480W version consumes less than 750mW, while the 120W and 240W versions both consume less than 300mW.

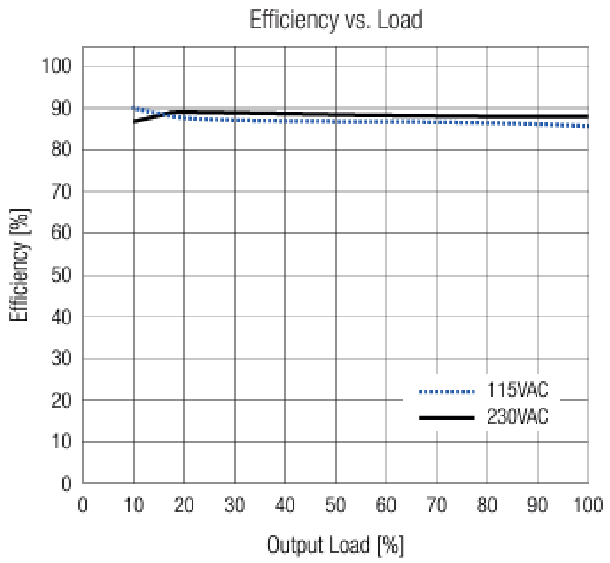

Figure 3: Flat efficiency curve of the REDIIN120-24. No load power consumption is only 150mW.

3: Design. DIN-rail mounted power supplies are designed so that all the electrical connections are at the front and the major heat dissipating components such as switching transistors and power diodes are in good thermal contact with the back of the device (the so-called "book shape"). By using such a thermally efficient layout so that the metal DIN rail can act as an additional heatsink, the REDIIN series can operate at full output power at up to +50°C ambient temperature with only natural convection cooling. Sometimes, the environment may be very cold rather than hot, for example, in an outdoor solar farm PV string controller application or in an unheated warehouse, so low temperature operation is also important. The REDIIN series can operate at full load down to -30°C, with a cold start capability down to -40°C.

4: Protection. All REDIIN power supplies operate from a universal single-phase AC input (90 to 264 VAC), making them suitable for all global mains power supplies including undervoltage and overvoltage variations. Power factor correction is included as standard. The short-circuit, over-voltage and overload protected outputs are the typical industrial supply voltages of 12V (REDIIN 120), 24V or 48V DC, all trimmable over the range of ±10% to adjust for cable losses.

They also have automatic CV/CC operational modes, making them suitable for either highly inductive or highly capacitive loads. An output over-current limit of up to 150% allows high start-up current loads to be driven without needing to over dimension the power supply. If the power supply is continuously overloaded, the built-in over temperature protection will safely turn off the output before the unit becomes damaged. A two-color indicator LED shows if the output voltage is within range or if it is in short-circuit, over-temperature or overload protection mode.

Summary

The cost-sensitive REDIIN power supply series are designed to fulfill the demanding technical requirements needed for many industrial-grade electrical cabinet applications without compromising on quality and reliability. The series are all housed in an extremely slim 'book-shape' case of only 123,6mm high and 116,8mm deep. The REDIIN120 delivers 120W output power with only 30mm width, the REDIIN240 delivers 240W with only 40mm width, while the REDIIN480 delivers an impressive 480W with only 56mm width. The exceptionally slim design frees up valuable space while the low weight avoids overloading the DIN-rail in congested installations.

The products are fully certified according to international safety standards IEC/EN/UL 62368-1, IEC/EN/UL61010-1 and IEC/EN/UL/CSA61010-2-201. Electromagnetic radiated and conducted emissions are compliant with heavy industrial EN 61000-6-4 Class B Emission standard and EN 61000-6-2 Immunity standard.

The REDIIN series are intended for industrial, automation, power distribution and test and measurement environments and will find a wide range of applications in industry, heavy engineering, production, home automation, data and telecom, traffic control and water management - wherever and economical solid, reliable, DC power supply is needed inside of cabinets and other electronic enclosures.

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Dynamic Characterization of a Power Semiconductor Bare Chip

Power semiconductor devices are used in a variety of forms, such as being packaged in Surface Mount Devices (SMDs) or power modules, and they are used in a broad range of applications. These devices also contain power semiconductor bare chips which are loaded into these packages. It is desirable to characterize the bare chip before placing it in a package or a power module to expedite development.

By Yu Watanabe, Application Engineer; Takamasa Arai, Solution Engineer; and Ryo Takeda, Solution Architect, all Keysight Technologies

However, the small size, fragile structure, and parasitic effects caused by probing create multiple challenges for dynamically characterizing these power semiconductor bare chips. This article reviews the challenges of performing dynamic characterization on a bare chip, as well as some new technologies that help address these challenges.

Power semiconductor devices are initially fabricated on a wafer, followed by dicing and packaging before they can be used in actual power electronics circuits. Characterization in the early phases of the manufacturing process helps expedite device development. For power module development engineers, understanding the behavior of power semiconductor bare chips is beneficial for accelerating development and aiding in troubleshooting.

Challenges for dynamic characterization on power semiconductor bare chips

Static characterization of power semiconductor bare chips is not too difficult. The chip is physically fixed tightly on an electrically conductive stage for drain contact, and the source and gate are probed using needles from the top side of the chip. Parasitics associated with the fixturing do not significantly deteriorate measurement performance. Instruments such as curve tracers or impedance analyzers can be used for static characterization.

On the other hand, dynamic characterization of power semiconductor bare chips is extremely difficult. First, parasitics in the test circuit significantly deteriorate dynamic characterization, especially for Wide Band Gap (WBG) power semiconductors due to their fast speed. For instance, probe needles introduce additional parasitics, causing oscillation, ringing, and resulting in distorted measurement waveforms. These probe needles can also pose a risk of arcing due to the high voltage signals used in testing.

Second, SiC MOSFETs, vertical GaN devices, Si MOSFETs, and IGBTs have a vertical device structure where the current flows from the top of the chip to the bottom. Probing a chip from both the top and bottom is extremely challenging. Therefore, one side of the chip must be soldered. However, soldering and unsoldering the chip to a PCA is inconvenient and accelerates board wear, making it less than ideal for testing.

Third, bare chips are physically fragile. Unbalanced forces during fixturing can easily cause cracks or chipping. Additionally, the small size of the chip—often less than 5mm on one side—makes handling even more difficult. In addition, bare chips can break due to voltage surges caused by the fast di/dt (rate of change of current) of the test signal, coupled with surrounding parasitic inductance.

The only method currently used to characterize a bare chip is to create a complete Double Pulse Test (DPT) board for the chip. This board includes an integrated PCA with gate drivers, bank capacitors, isolation components, and other necessary elements. The chip is soldered to the PCA on the drain side, and wire bonding is used to establish connections to the source and gate. Often, the chip is coated with insulating material.

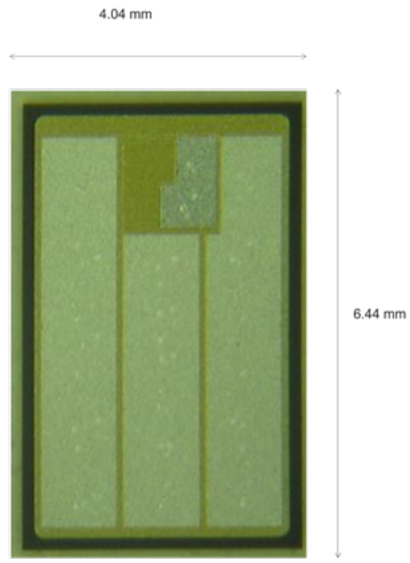

Figure 1: Example bare chip (courtesy of Wolfspeed).

However, this setup is employed only once for chip characterization because the PCB cannot be reused. The associated costs, time, effort, and lack of reusability discourage engineers from using it frequently.

Technologies enabling dynamic characterization of a bare chip

There are a few key technologies and know-how techniques that are necessary to enable dynamic characterization of a bare chip. The creation of a special fixture for a bare die is the most important aspect of the solution. This special fixture must meet the following requirements:

- No probing needle should be used to avoid extra parasitic effects and the risk of arcing
- The fixture must make contact with the vertical structure of the bare chip
- Contact with the bare chip must be tight enough to ensure electrical conductivity but not too tight to avoid physical cracks or chipping
- Solderless contact is desirable
- A mechanism is needed to align a small bare chip with the electrodes on the test fixture.
- Parasitic effects in the test fixture should be minimized (e.g. < a few nH)
- The fixture should have high voltage and high current capabilities (e.g., 600V and 40A)

Additionally, there are several know-how techniques to accomplish this difficult task. For example, handling a bare chip gently is essential to avoid physical damage.

A solution for dynamic characterization of a bare chip

The solution described below utilizes newly developed technologies for chip dynamic testing and is realized for discrete device double pulse tester. The DUT board is rather simple, as shown in Figure 2. The same technology can be leveraged for the power module double pulse testers, allowing power module engineers to use it for characterizing bare chips and power modules with this new solution.

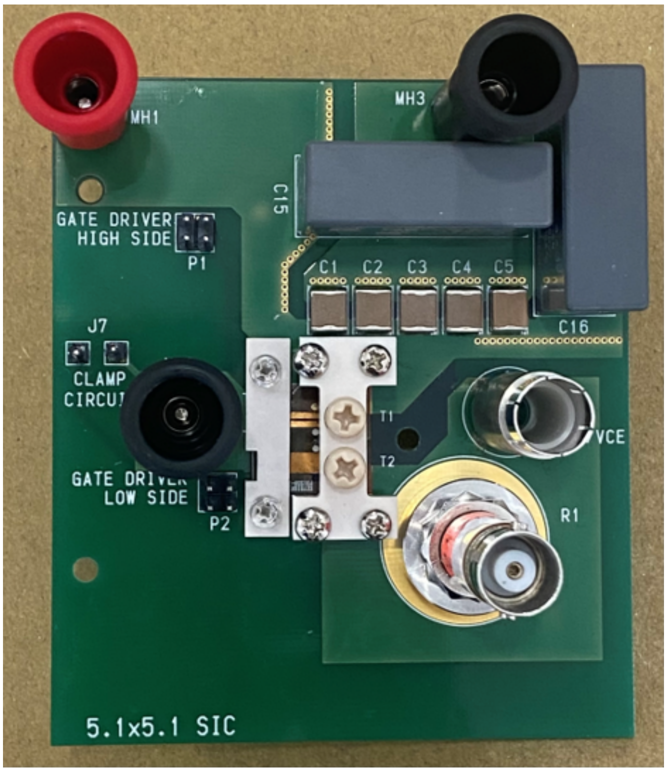

Figure 2: Example PD1500A DUT board for dynamic characterization of a bare chip.

In the DUT board, special treatments are applied to the electrodes on the PCB to allow solderless contact. A flexible PCB with a similar electrode treatment is also used for top-side connections. By placing a chip between the main PCB and the flexible PCB, it becomes possible to flow current from the top of the chip to the bottom, enabling current measurements for vertical structure devices.

The PCB design aims to minimize parasitic inductance in both the power loop and gate loop. The fixture features carefully designed multiple pins protruding from the PCA, which align a bare chip precisely for optimal contact with the electrodes. The absence of probe needles further reduces parasitic inductance in the test circuit.

For Si and SiC devices, a coaxial shunt resistor can be used, even with its several nanohenry (nH) range of extra insertion inductance. In the case of GaN (gallium nitride) bare chips, a patented current sensor [1] provides an additional means to minimize parasitic inductance. Power semiconductor bare chips typically exhibit different form factors. Therefore, our strategy involves creating a customized DUT board for both the Keysight PD1500A and PD1550A, as illustrated in Figure 3.

Figure 3: Tailored bare chip DUT fixture for PD1500A/PD1550A.

Figure 4 shows example measurement results taken for a 1.2 kV-rated SiC MOSFET bare chip. The test is performed at 800 V and 40 A, demonstrating that the fixture provides sufficient voltage and current capability for the 1.2 kV-rated SiC MOSFET. The waveforms are very clean, with a small Vds overshoot at turn-off. The calculated power loop inductance from the turn-on waveform is only 8.3 nH.

Figure 4: Test results (turn-on & turn-off) for a SiC MOSFET.

The fixture for bare chips can also be easily used with curve tracers. It eliminates the need to use a wafer prober for bare chip static measurements, greatly improving productivity.

Summary

Bare chip dynamic characterization, once regarded as very challenging and almost impossible to do, is now available through newly developed solution for Keysight PD1500 series double pulse testers. It is provided as tailor-made solution for a bare chip. There are many know-hows associated with the solution to perform the test safely and with minimized risks.

References

[1] GaN Power Semiconductor Device Characterization, Bodo's Power Systems, October 2020

About the Authors

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Enhancing Reliability and Compatibility with Upgraded E-mode GaNFET

GaNPower International unveils an advanced version of the E-Mode GaNFET (GP65R45T4), featuring a boosted gate turn-on voltage of 4V and an expanded gate driving range of +/-20V. This device incorporates cutting-edge All-GaN-IC technology, enabling a seamless transition from traditional silicon and SiC MOSFETs while ensuring pin-to-pin replacement compatibility.

By Daniel Wan and Simon Li, GaNPower International

Evolution and Reliability of Cascode and E-Mode GaNFETs

Cascode GaN, with a structure depicted in Figure 1 (a), combines a low-voltage normally-off silicon MOSFET and a high-voltage normally-on GaN HEMT in a cascode configuration. The combination effectively results in an enhancement-mode behavior and this technology has been commercially available since the early 2010s. The presence of the silicon MOSFET, with a common gate threshold voltage of 4V, simplifies the gate drive requirements compared to native GaN solutions, as those Cascode GaNs can typically be driven with standard silicon gate drivers. In addition, the hybrid nature of using a silicon MOSFET can enhance reliability. Silicon's known characteristics and behavior can be leveraged to protect the more sensitive gate of GaN HEMT, reducing the risk of failure due to high voltage spikes or improper gate voltage.

However, the extra silicon MOSFET between gate and source of GaN HEMT will considerably increase the effective input capacitance of Cascode GaN device, which largely sacrifice fast-switching characteristics, one of the most outstanding advantages compared to SiC MOSFETs. What's worse, the series connection of silicon MOSFET and D-mode GaN for co-packaging will lead to additional parasitic inductance that cause more ringing and overshoots in the switching waveforms, affecting overall performance and raising concerns on electromagnetic interference (EMI).

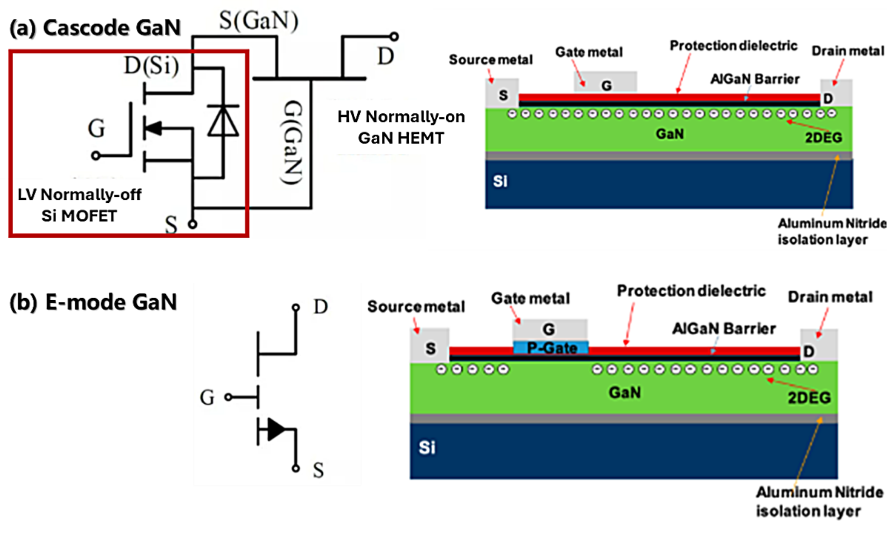
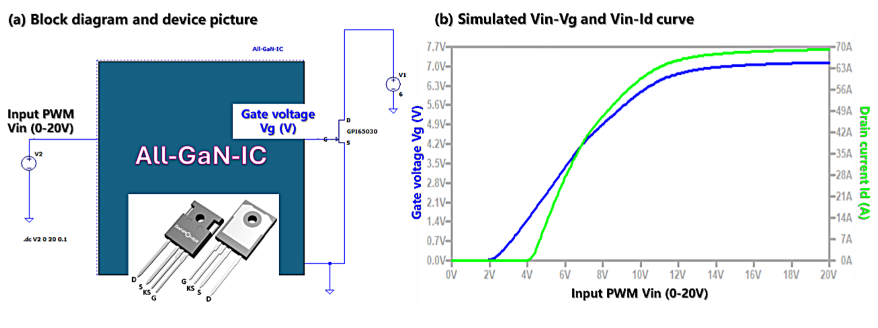


Figure 1: Figure 1. Schematic comparison between (1) Cascode GaN and (2) E-mode P-gate GaN HEMT



FFigure 2: (a) Block diagram and (b) simulated verification of a gate regulator circuit monolithically integrated with a main E-mode p-gate GaNFETs

E-mode GaNFETs, as shown in Figure 1 (b), use a p-type GaN gate structure to provide a positive threshold voltage, making the device normally-off inherently in a single chip solution. This is crucial for power applications where fail-safe operation is necessary. Without any extra components, E-mode GaNFET typically exhibit very low gate charge and capacitances. which results in faster switching speeds and reduced switching losses. They are highly efficient in applications requiring high-frequency operation.

Nevertheless, p-type GaN gate provides a typical lower gate threshold voltage of 1.4V, which would cause accidental device turn-on and system failure due to noise or gate voltage fluctuations. Furthermore, the typical driving range is -10V to 7V that is not compatible with the driving voltages for most of other power devices which requires 12-18V, making it difficult for people switching to GaN HEMTs from other power switches. Last but not least, as p-type GaN gate is not quite mature and more vulnerable, there are concerns about its long-term reliability and threshold voltage stability.

All-GaN-IC Solution: A Leap in Gate Threshold Voltage and Driving Range

GaNPower International has innovated an All-GaN-IC method that boosts the gate threshold voltage from 1.4V to an impressive 3.5-4.0V, with an extended driving range up to ±20V. A proprietary GaN based gate regulating circuit has been monolithically integrated with the power GaNFETs in single chip. This innovation, depicted in Figure 2 (a), aligns the new E-Mode GaN

with the pin-outs, threshold voltage, driving range of silicon and SiC MOSFETs, earning it the nickname 'pin-to-pin' (p2p) for its exceptional compatibility. The P2P technology perfectly combine the advantages of Cascode GaN and E-mode GaN, aims to achieve a more reliable gate driving without largely compromising the fast-switching benefits of GaN power switches.

According to the LTSpice simulated results as shown in Figure 2 (b), the gate threshold voltage of our P2P GaN switch has been increased to around 4V and its gate voltage has also been properly clamped below 7V by All-GaN-IC with 0-20V PWM input. Room temperature experimental static Id-Vg measurement results, presented in Figure 3, also verify the enhancement of gate threshold voltage (3.6V) for our P2P GaN, compared to normal E-mode GaN without the GaN based gate regulating circuit.

Demonstrating Superior Switching Performance

A double pulse testing platform with a customized air-core 128μH load inductor, a freewheeling SiC diode, and a reliable voltage clamp circuit for accurate dynamic Rdson measurement has been built for the burst-mode switching evaluation of our P2P GaN.

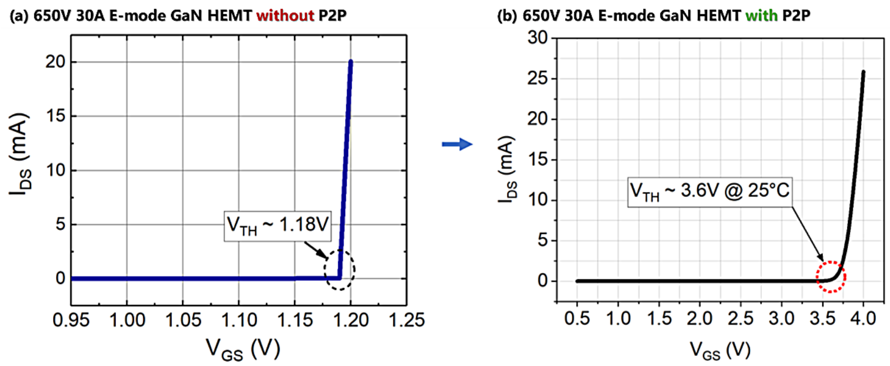


Figure 3: Comparison of Ids-Vgs measurement between 650V 30A E-mode GaN HEMT (a) without and (b) with a monolithically integrated gate regulator circuit (i.e., P2P technology)

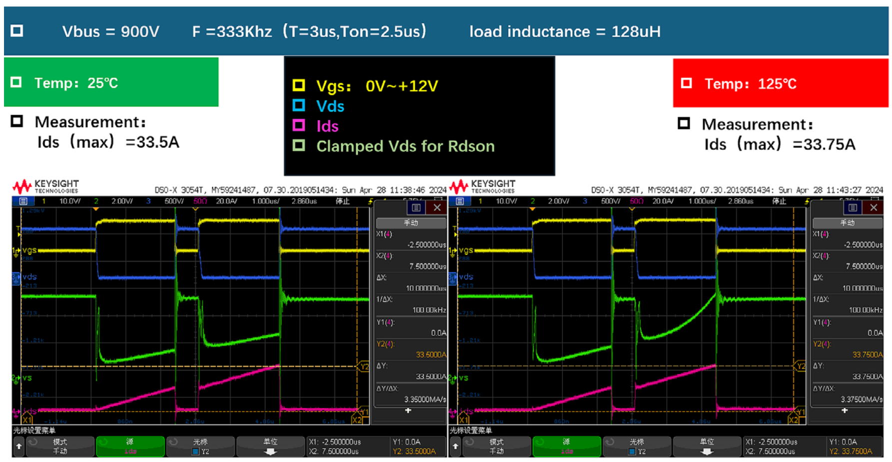


Figure 4: The results of double pulse testing (DPT) at 33A drain current and 900V bus voltage, demonstrating good switching performance at both (a) 25°C and (b) 125°C

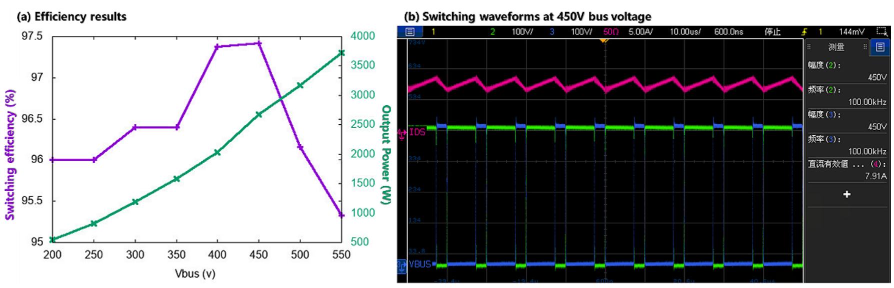


Figure 5: (a) Switching efficiency and (b) switching waveforms of an air-cooled half-bridge Buck converter, where two GaNPower P2P GaN HEMTs (GP65R45T4) were under continuous hard-switched tests

With 12V PWM input and 900V bus voltage, all the switching waveforms (Vgs, Vds and Ids), as shown in Figure 4, are quite clean without considerable ringing or overshoots. In addition, the dynamic Rdson is also within a reasonable range up to 33A (its current ratings) drain current under room temperature, which can be observed from the clamped Vds waveforms. Another double pulse tests conducted at similar loading conditions under 125°C show comparable switching waveforms demonstrated good thermal stability of the GaN based gate regulating circuit.

A 100KHz half-bridge Buck testing platform with a high saturation toroidal power inductor and a constant 40ohm high power resistor load was built for the continuous hard-switched evaluation of our P2P GaN. Two GP65R45T4 devices with suitable heat sinks were installed on the main test board and proper fan cooling was used during the tests.

According to the efficiency reports shown in Figure 5 (a), with 12V PWM input and 200-550V bus voltage, the P2P GaN based Buck converter achieved a peak efficiency of 97.42% and a maximum power output of 3.7kW. Figure 5 (b) demonstrated good continuous switching waveforms without substantial ringing and overshooting at the peak efficiency with 450V bus voltage.

More rigorous reliability testing on a large scale of GP65R45T4 samples are in progress to make sure our P2P GaNs are reliable and optimized in practical industry applications.

In conclusion, the integration of E-Mode GaNFETs with a GaN-based gate regulating circuit (P2P technology) significantly enhances the reliability and compatibility of gate driving for GaN switches, while preserving the fast-switching properties and mitigating ringing caused by co-packaging related parasitic components. This positions GaNPower's P2P technology as a critical innovation in the field of power electronics.

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Impacts of Transients on AI Accelerator Card Power Delivery

AI requires a lot of computational power, especially when it is learning and inferring. This continues to push the boundaries of power delivery networks to new levels never seen previously. These high density workloads have become more sophisticated with higher transient demands pushing every part of the power distribution network to perform at maximum capability. The stringent power requirements of AI accelerator cards are now impacting system performance. In this article, we will review the power distribution network requirements of the AI accelerator card, dissect the impact of the transients, and present a multiphase power delivery solution from Analog Devices that addresses these requirements.

By Hamed Sanogo, End Market Specialist, Analog Devices

AI is revolutionizing computing architectures to replicate neural networks that emulate the human brain. It seems that AI is already everywhere, but in reality, the technology that drives it is still developing. The processor accelerator ICs specialized for AI calculations include GPUs, field-programmable gate arrays (FPGAs), TPUs, and other types of ASICs. This article will collectively refer to all of them as xPUs.

Data centers will continue to buy AI accelerator cards in bulk as deployment of the technology is on a rise. According to Gartner, AI chip revenue totaled more than $34 billion in 2021 and is expected to grow to $86 billion by 2026.[1] x PUs offer a massive leap in AI performance compared to an ordinary CPU by using massively parallel computing implementations. Because of the high number of its small cores, xPUs are well suited for AI workloads, facilitating both neural network training and AI inferencing. However, they typically require relatively large power consumption for the AI computations and data movements. Simply put, xPUs are power hungry ICs. Their stringent power requirements are placing new demands on AI accelerator cards that now affect system performance. In this article, we will review the power delivery network requirements of the AI accelerator card and present a multiphase power delivery solution from ADI that addresses these stringent requirements.

The AI Imposed Power Delivery Challenge

AI is many things, but power efficient is not one of them. When AI is working, especially processing AI workloads such as deep learning and inferencing, it requires extreme computational horsepower. At the system level, AI accelerators play a critical role in delivering the near-instantaneous results that make them valuable. All xPUs have multiple high end cores constructed from billions of transistors and consume many hundreds of amps. The core voltages (V_{CORE}) on these xPUs have been reduced to sub-1.0 V levels. Figure 1 shows a generic block diagram of an AI accelerator card. The article will focus on the multiphase controller and the accompanying power stage ICs proposed for such a system.

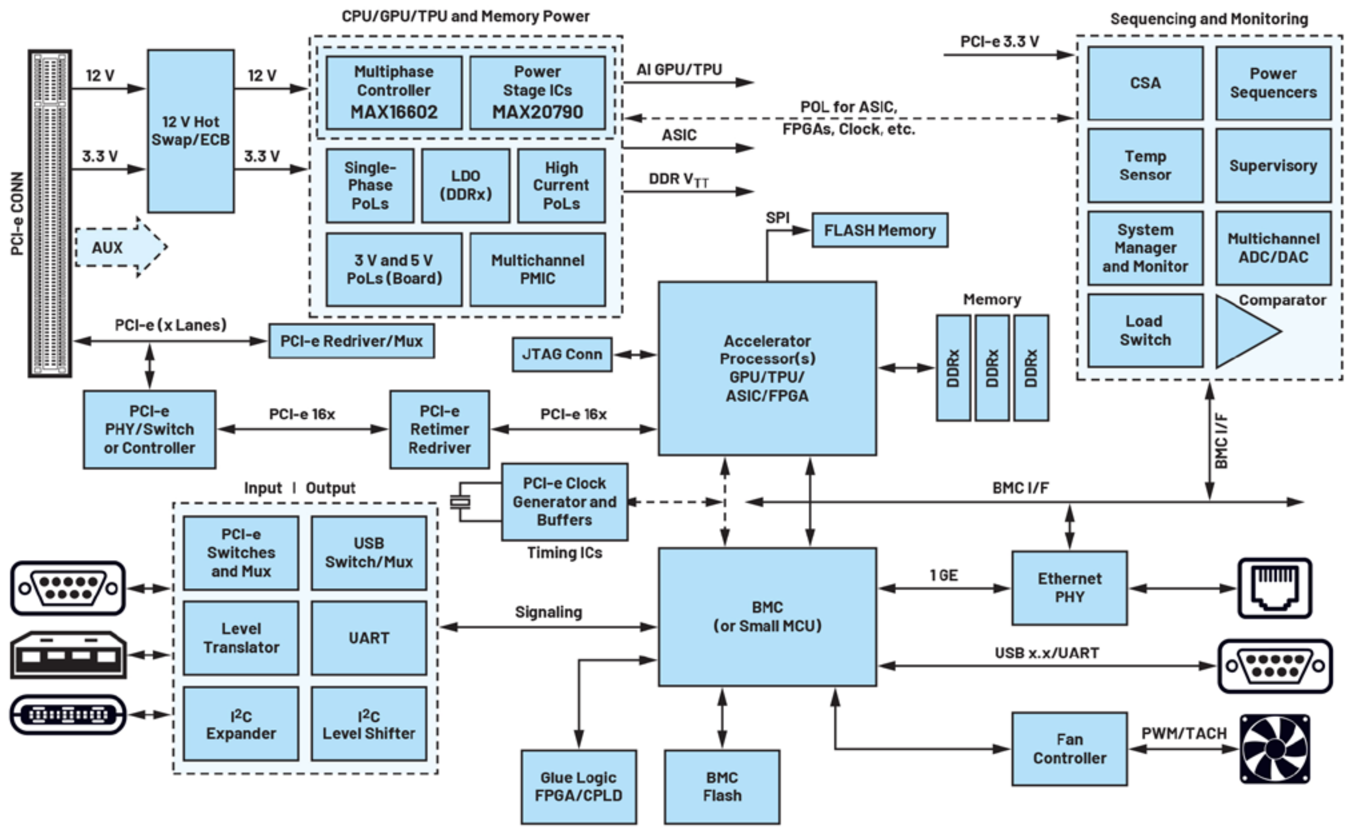

Figure 1: A block diagram of a generic AI accelerator card.

The peak current densities encountered on AI accelerator cards have become extremely heavy for any motherboard to handle. The highly dynamic nature of workloads and extremely high current transients are resulting in very high di/dt and spiking voltage transients lasting for several microseconds that are highly disruptive and can potentially be damaging for the xPU. With the average AI workload lasting that long, the decoupling capacitors are not able to provide the energy to meet the instant demand the entire time. The next section of the article will present an ADI multiphase point of load (PoL) solution proposal that will eliminate the typical AI accelerator's transients that create stress across the power distribution network. But first, let's discuss the power design challenges introduced with AI.

AI Introduces New Power Design Challenges
AI power demands are currently far outpacing traditional power delivery network capabilities. The requirements for the xPU voltage regulators (VRs) are quite different from standard PoL regulators. The industry is seeing greater than 1000 A delivered at <1 V to the xPU in certain applications. It is important that the supply is very stable and produces very little noise while eliminating all possibilities for voltage transients, which can cause false triggering inside the xPU. The design of a high performance AI accelerator VR PoL, with a staggering current demand, must meet certain key requirements.

Voltage Spikes and Transients Management
One of the AI accelerator card's key requirements is to have the VR architected in such a way that it offers superior transients voltage management. Delivering kilowatts of power to any system is always a first order challenge. The output voltage including tolerances, ripple, and load transient dips and peaks must stay above the xPU minimum voltage to avoid system hang and must also stay below the xPU maximum voltage to avoid xPU damage. Transient power spikes from these cards can ask for 2× and more than the maximum thermal power target.

What is important here is that the PoL loop bandwidth is flexibly wide enough to deal with the types of faster transients seen. The higher the bandwidth, the faster the loop responds, and with less voltage deviation. One of the most straightforward methods to achieve fast transient power rails is to select regulators that feature fast transient performance. The ADI AI V_{CORE} family of ICs features exceptionally low frequency output noise, fast transient response, and high efficiency. Adding its load line support to this, the ADI AI power chipsets do an excellent job at helping power designers manage their AI workload induced transients and spikes.

I^2R Losses in the Long Power Path Traces and Thermal Management
As the current of the AI xPU processor continues to increase, the density of the power delivery solution to the PoL has become a critical element. It is becoming extremely hard to deliver power reliably to every part of the xPU without worrying about the dispersed heat impacting the reliability of the chip and leading to thermal runaway. In other words, thermal management is one of the more significant challenges in designing this high wattage power supply. Traditional power delivery methods place the voltage regulator on the side of the xPU such that power is delivered laterally to the processor. Even the smallest resistance in these traces can lead to unacceptable voltage (I^2R) drops. A voltage drop across the PCB power plane resistance is proportionally increased with the xPU current. This represents a few centimeters of PCB power traces between the VR and BGA pins and this is where a significant amount of losses take place. Such losses in the PCB copper power planes have become the most dominant factors in calculating the efficiency and performance of the regulator design. The use of a monolithic power stage IC, with the current and temperature circuit blocks integrated, can greatly reduce the number of high current traces required on the PCB to implement a traditional 3-chip (discrete) power delivery solution.

ADI Value Proposition:
MAX16602 + MAX20790 + Coupled Inductor
The AI voltage regulator accuracy has become even tighter. Efficiency and size are high priorities. Performance and power loss are also under major scrutiny. As was presented in the previous section, solving AI accelerator card VR design problems has become a daunting task. Designers understand too well that generating large steps in demanded current cannot be satisfied without dealing with the unwanted transient effects. Addressing these transient

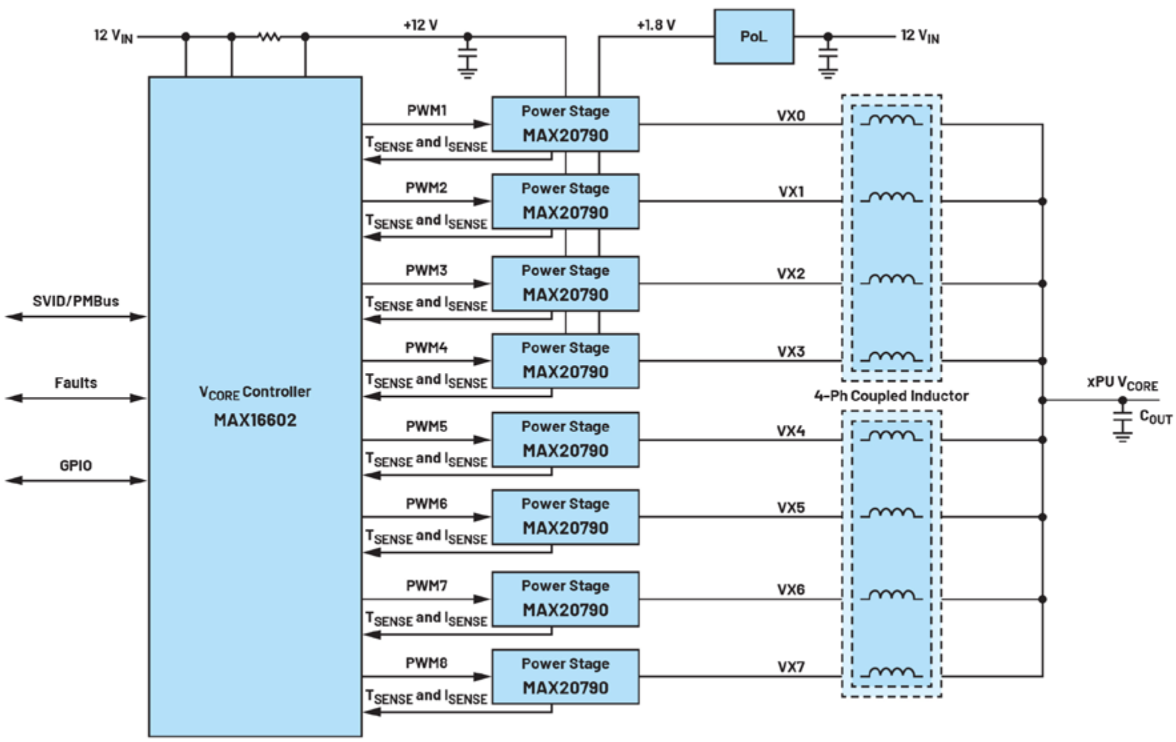

Figure 2: An 8-phase VR design with ADI's high integration power chipsets facilitate a high density design with less external connections.

effects also requires some type of high accuracy dynamic voltage positioning or load line scheme. ADI is heavily invested in the AI market and has a complete portfolio of solutions for both 48 V and 12 V systems. This section of the article proposes the ADI AI multiphase power chipsets, the MAX16602 multiphase controller and MAX20790 power stage, along with our patented coupled inductor (CL) technology to help address these AI PoL design challenges. Figure 2 shows the MAX16602, MAX20790, and CL high level block diagram connection for an 8-phase MAX16602CL8_EV design. This relatively clean design achieves a high current delivery capability of ~88 A_{PK} per phase. The internal compensation and advanced control algorithm, along with the integrated current sensing circuits in the power stage and coupled inductor, make it a small solution with best-in-class efficiency.

Monolithic Smart Power-Stage IC with Higher Level of Integration

The MAX20790 is a feature-rich smart power stage IC designed to work with the MAX16602 (and a few other ADI controllers in the portfolio) to implement a high density multiphase voltage regulator. This is a monolithic integration that nearly eliminates parasitic resistance and inductance between the FETs and driver seen in discrete designs, enabling high switching speeds with significantly lower power losses than traditional implementations. If a switch node (V_X) fault is detected, the power stage immediately shuts down and communicates the fault ID to the controller. This smart power stage IC also includes a current sensor on chip. This current sensing circuit block is far superior to methods that use an inductor's DC resistance. DCR sensing is known to be inaccurate and requires temperature compensation for the current measurement to be trusted.

Controller IC

The MAX16602 is a multiphase controller for xPU V_{CORE} VRs. The IC provides a high density, flexible, and scalable solution to power AI xPUs. The device supports pulse width modulating (PWM) paralleling to control up to 16 phases. The IC's architecture simplifies design, reduces component count, enables advanced power management and telemetry, and increases energy savings over the full load range. Autonomous phase-shedding is implemented to maintain high efficiency across the entire load range. The complete chipset is a highly efficient multiphase buck converter with extensive status and parameter-measurement features. Parameters for protection and shutdown are set and monitored through the serial PMBus® interface, including even faults collected in the power stage ICs.

Here are a couple of other key features supported in the ADI controller that are important for any AI power delivery implementation.

Advanced Modulation Scheme

The MAX16602 includes an advanced modulation scheme (AMS) to provide improved transient response. The modulation scheme allows the turn on and off of phases with minimal delay. Depending on load demand, multiple phases can turn on simultaneously when the load increases or turn off immediately when the load releases. With AMS enabled, the system closed-loop bandwidth can be extended without phase-margin penalty. This allows the PoL a better chance at responding to the type of instant and dynamic current demand experienced with AI VRs.

Load Line Control

The load line allows V_{CORE} to shift between its minimum and maximum based on the output current. It essentially sets V_{CORE} high for light loads and low for heavy loads. The main reason is to allow the control loop to handle higher load current (and this is required to make things work well). The ADI controller provides an accurate output load line control over the entire range of output currents. The output-voltage positioning is performed using the lossless current-sense signals from the power stage IC, which are fed back to the controller. The load line is set in the controller by digitally programming the DC gain of the voltage control-loop-error amplifier. There is a wide range of DC load line profiles presented in the controller's EC table and in Table 6 of the data sheet, from 0.105 mΩ to 0.979 mΩ. Figure 3 shows the transient plot of a 16-phase PoL design for a 40 A to 360 A load step at 800 A/μs slew rate. The result shows minimal overshoot.

Altogether, ADI's multiphase power conversion and PoL products deliver high efficiency and high power density. Figure 5 shows the efficiency plot with bias and inductor losses of our 16-phase MAX16602 + MAX20790 + CLH1110-4 evaluation board. ADI offers voltage regulator and other power conversion solutions for various AI accelerator applications. Our multiphase controller and integrated power stage solutions allow ADI customers to address the most stringent dynamic xPU power requirements and design challenges present with today's AI applications.

Figure 3: Transient plot of a 16-phase VR for 40 A to 360 A step load at 800 A/μs slew rate.

Adding active voltage positioning to the design eases off the requirements on load transient response and makes better use of the total xPU tolerance window. Load line control helps lower peak-to-peak output voltage deviation for a given step load while making it possible to reduce the amount of bulk capacitance on the output rail. The total voltage fluctuation is reduced, lowering the risk of xPU crashing or getting damaged. Note that the load line circuit block can be disabled in the MAX16602.

Benefits of Coupled Inductor

ADI has been investing its patented CL technology for more than a decade. The technology enables higher density, larger bandwidth, faster transient solutions, and as compared to a discrete implementation 50% higher efficiency and 1.82× smaller magnetics. CL effectively works as large inductance in steady state, small inductance in transient, enabling C_{OUT} savings in addition to smaller inductor size.[2] Figure 4 shows a series of coupled inductors commonly used in ADI's multiphase VR designs.

Depending on the design specifications and priorities, the benefit of current ripple cancellation of coupled inductors can be traded for either smaller size or higher efficiency.[1] The big system benefit and ADI's differentiator is that AI PoL designers can use CL to help them achieve a small total VR footprint solution relatively easily. Several well-known and popular magnetics vendors have a free CL license from ADI and can provide us multiple sources for the needed parts.

Top-Side Cooled Packages

Top-side cooling provides an alternative heat dissipation route for surface-mount packages. Both the MAX16602 and the MAX20790 are flip chip quad flat no-lead (FCQFN) packages with exposed top-side thermal pads. FCQFN is an advanced packaging that provides best-in-class thermal performance that designers will appreciate. This leadless package not only reduces parasitic inductances but also allows the heat dissipation directly from the device's junction to the ambient environment. The MAX20790 has a junction-to-case top ($\theta_{JC\text{-}TOP}$) thermal resistance of 0.25°C/W. Taking advantage of top-side cooling configuration with AI power designs, system thermal performance and design flexibility can be improved.

Figure 4: A series of coupled inductors commonly used with ADI's multiphase VR designs.

Vertical Power

The industry has witnessed a dramatic increase in power consumed with the advent of xPUs' processing complex AI functions. VRs with the capability of up to 650 A continuous current and over 1000 A peak current delivery have become common. The challenges of powering AI processors lie in maintaining efficiency. Conventional power architectures are not going to keep pace with these power hungry AI xPUs. VR chip makers and architects are fundamentally looking at different approaches to power delivery. A new trend to powering AI xPUs that the industry is talking about is called vertical power, also known as backside power delivery.

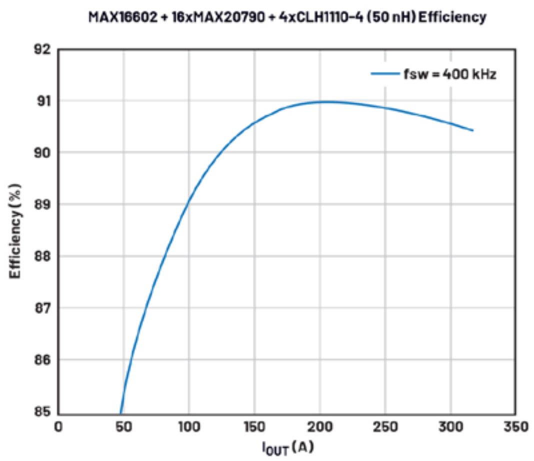

Figure 5: Efficiency plot of a 16-phase AI VR evaluation board design.

VRs must be located as close as possible to the load input xPU power pins for high current power deliveries. We cannot get there with traditional lateral power delivery methods. Vertical power delivery moves and relocates the power regulator directly underneath the processor itself, eliminating all the losses that one would have on the PCB. The structure consists of placing the power converter, power stages, capacitors, and magnetics on the back side of the PCB and delivering power vertically through vias to the xPU. In other words, current delivery takes place vertically from underneath the xPU BGA array. This is a reduced length vertical path that significantly reduces impedance and eliminates losses. Figure 6 shows the vertical power module architecture mounted underneath the xPU on the other side of the PCB. This is for illustration purposes only. ADI has a wide portfolio of AI x PU V_{CORE} solutions to solve these problems today. Our power solutions enable best-in-class efficiency in the smallest form factor. The proposed combination of the multiphase controller MAX16602 and smart monolithic power stage MAX20790 offers the highest power conversion efficiency, fastest transient response, and most accurate telemetry reporting in the industry. For more detailed information about these power chipsets or to purchase the MAX16602CL8 evaluation kit, please visit https://www.analog.com/en/resources/evaluation-hardware-and-software/evaluation-boards-kits/max16602cl8evkit.html.

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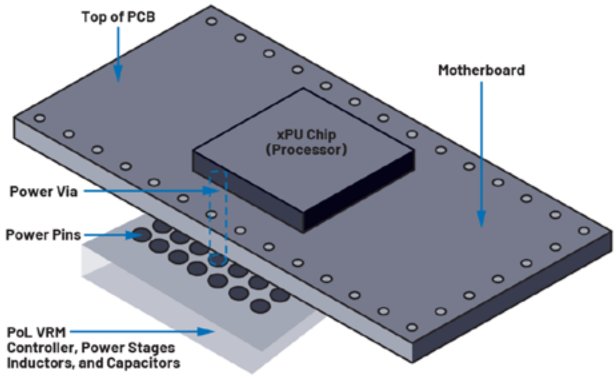

Figure 6: A vertical power module architecture (for illustration purposes only).

Underneath the xPU on the other side of the PCB is also the prime location for the high frequency decoupling capacitors that are required for energy storage to meet instantaneous energy demands. Vertical power delivery paired with ADI's CL technology achieves a higher current density, power density, and faster transient performance. Vertical power gives PoL makers like ADI new opportunities to innovate and continue, in their own way, to support the advancement of Moore's law.

Conclusion

With machine and deep learning, accelerator cards have taken AI from theory to mainstream by enabling the parallel processing power required to speed up both training and inferencing workloads. Designing a VR PoL for a high performance AI accelerator card is a complex task, especially with the ever-increasing power requirements in terms of current levels and voltage accuracy required by the current advanced xPUs.

It has been shown in this article that the requirements for the xPU VR are quite different from standard PoL regulators. xPU rails have extremely fast load changes, require dynamic voltage positioning or load line, and must be small.

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About the Author

Hamed M. Sanogo is an end market specialist for cloud and communications in Analog Devices' Global Applications Group. Hamed graduated with an M.S.E.E. degree from the University of Michigan-Dearborn and later earned an M.B.A. degree at the University of Dallas. Following graduation, Hamed worked as a senior design engineer at General Motors and a senior staff electrical engineer and Node B and RRH baseband card designer at Motorola Solutions before joining ADI. Hamed has spent the past 17 years in different roles, including FAE/FAE manager, product line manager, and currently an end market specialist for communications and cloud

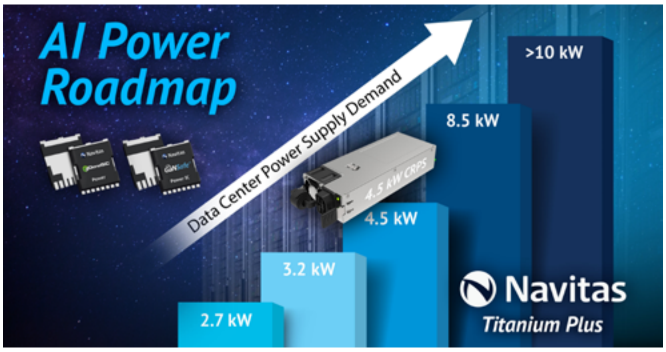
Hyperfast Recovery Rectifiers in ^{2}PAK

Nexperia released 650 V ultra- and hyperfast recovery rectifiers in D^2PAK Real-2-Pin (R2P) packaging for use in various automotive, industrial and consumer applications including charging adapters, photovoltaic, inverters, servers and switched mode power supplies. Combining planar die technology with a state-of-the-art junction termination (JTE) design, these rectifiers offer high power density, fast switching times with soft recovery and excellent reliability. They are encapsulated in a D^2PAK Real-2-Pin Package (SOT8018), which offers the same package outline as the standard D2PAK package but has only two pins instead of three (the middle cathode pin has been removed). This increases the pin-to-pin distance from 1.25 mm to over 4 mm, which allows to meet the creepage and clearance requirements stated in the IEC 60664 standard.

www.nexperia.com

4.5 kW Power Supply for AI GPU Racks

Navitas Semiconductor released its 4.5 kW AI data center power supply reference design, with GaNSafe™ and Gen-3 'Fast' (G3F) SiC power components. The design is claimed to "enable the world's highest power density with 137 W/in^3 and over 97% efficiency". Next-generation AI GPUs like NVIDIA's Blackwell B100 and B200 each demand over 1 kW of power for high-power computation, 3x higher than traditional CPUs. These new demands are driving power-per-rack specifications from 30 - 40 kW up to 100 kW. The latest 4.5 kW CRPS185 design demonstrates how GaNSafe power ICs and GeneSiC™ Gen-3 'Fast' (G3F) MOSFETs enables highest power density and efficiency solution. At the heart of the design is an interleaved CCM totem-pole PFC using SiC with full-bridge LLC topology with GaN, where the fundamental strengths of each semiconductor technology are exploited for the highest frequency, coolest operation, optimized reliability and robustness, and highest power density and efficiency. The 650 V G3F SiC MOSFETs feature 'trench-assisted planar' technology which delivers "world-leading performance over temperature for the highest system efficiency and reliability in real-world applications". With a 3.2 kW power supply on the market Navitas plans to introduce an 8.5 kW design in September.



www.navitassemi.com

Multi-Channel Modular Power System

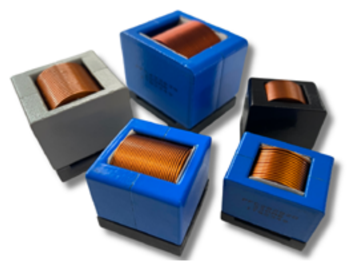
The instrument measurement world is about to get another power supply test solution: the ultra-high power density IT2700 multi-channel modular power system from ITECH. The system integrates

several test functions, the 1U main frame can include up to eight modules (200 W each) or four modules (50 0W each), including bi-directional DC power supply, DC power supply, and regenerative load module. This will allow users to flexibly combine according to specific test needs. The IT2700 multi-channel modular power system can be widely used in ATE integration in R&D, design verification and manufacturing of DC/DC converter, communication power semiconductors, 3C products, like smartphone, PCBA, battery simulation and test, chips BMS chips etc.

www.itechate.com

Power Factor Correction: Chokes with High-Current Offering

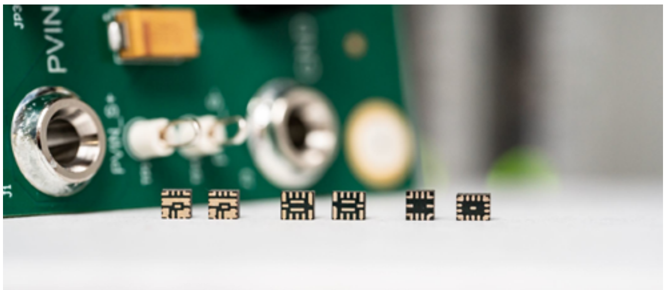
ITG Electronics has expanded its portfolio of power factor correction chokes (PFCs) with a set of solutions designed for comparatively high-wattage applications. The company's PFC383637B Series solutions can handle up to 3,300 W and include CCM PFC boost converters with switching frequencies from 60 to 200 kHz. An extension of ITG Electronics' Cubic Design set of power factor correction chokes, PFC383637B Series solutions are suitable for Inductance ranges from 180 – 360 µH at footprints up to 37.5 mm x 36.5 mm with maximum heights of 36 mm. Compared with traditional toroidal-shaped PFC chokes, the PFC383637B Series features a flat wire and square core construction to save space and increase power density. The solutions are up to 50% smaller compared to toroidal-shaped PFC chokes with similar power ratings, and their flat wire technology can reduce DC resistance by as much as 40%, leading to substantially lower copper losses. The PFC383637B Series of PFC chokes is applicable for AC to DC conversion in industrial, equipment and automotive applications. Notably, the high-current output chokes can handle up to 32.4 A with approximately 50% roll off.



www.itg-electronics.com

Magnetic Packaging Technology for Power Modules: Cutting Size in half

Texas Instruments (TI) introduced six power modules designed to improve power density, enhance efficiency and reduce EMI. These modules leverage TI's proprietary MagPack™ integrated magnetic packaging technology, "shrinking their size by up to 23% compared



to competing modules", enabling designers of industrial, enterprise and communications applications to achieve previously impossible performance levels. In fact, three of the six devices, the TPSM82866A, TPSM82866C and TPSM82816, are claimed to be "the industry's smallest 6 A power modules, supplying a power density of nearly 1A per 1 mm^2 of area". The magnetic packaging technology includes an integrated power inductor with proprietary, newly engineered material. As a result, engineers can now reduce temperature and radiated emissions while reducing both board space and system power losses. This is especially important in applications such as data centers, where electricity is the biggest cost factor, with some analysts predicting a 100% increase in demand for power by the end of the decade.

www.ti.com

Analog-Digital Fusion Control Power Supply Solution

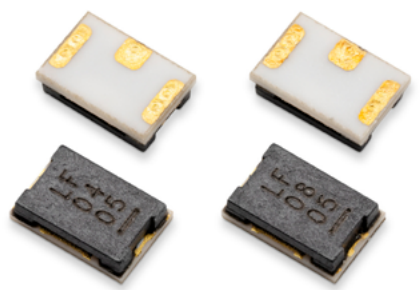
Rohm has established LogiCoA™, a power supply solution for small to medium power industrial and consumer equipment (30 W to 1 kW class). It provides the same functionality as fully digital control power supplies at low power consumption and cost equivalent to analog power types. The LogiCoA power solution leverages the strengths of both analog and digital technologies. Low power LogiCoA MCUs are utilized to facilitate control of a variety of power supply topologies. The LogiCoA brand embodies a design philosophy of fusing digital elements to maximize the performance of analog circuits. Rohm claims that its LogiCoA power solution is "the industry's first

analog-digital fusion control power supply that combines a digital control block" centered around the LogiCoA MCU with analog circuitry comprised of silicon MOSFETs and other power devices. The evaluation reference design REF66009 allows users to experience the LogiCoA power supply solution in a non-isolated buck converter circuit. Various tools necessary for evaluation are also offered, including circuit diagrams, PCB layouts, parts lists, sample software, and support documents, while actual device evaluation is possible using the optional EVK-001 evaluation board.

www.rohm.com

Protector Series to Prevent Li-ion Battery Pack Damage

Littelfuse announced the extension of its ITV2718 surface-mountable Li-ion battery protector series. These fuses safeguard Li-ion battery packs against overcurrent and overcharging (overvoltage) conditions - even when fast charging. The latest addition, the ITV2718, provides a five-amp, three-terminal fuse in a 2.7 mm x 1.8 mm footprint. The design utilizes an embedded fuse and heater element combination to respond quickly, interrupting the battery pack's charging or discharging circuit

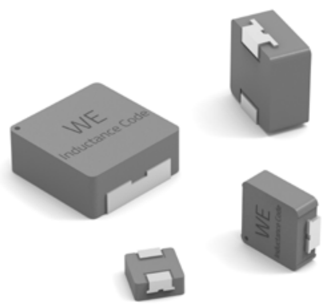


before overcharging or overheating conditions occur. The ITV2718 Battery Protector is suited for a wide range of consumer electronics applications, including game consoles, E-call, portable routers and modems, smartphones, notebooks and tablets. It meets industry safety requirements via UL and TÜV certifications for faster compliance approval while being halogen-free and RoHS compliant environmentally friendly components.

www.littelfuse.com

High-Current Inductor for Automotive Applications

Würth Elektronik offers WE-LHCA (Low Profile High Current Automotive Inductor) – a particularly flat and temperature-tough inductor in four sizes with different inductance values. The power inductors are designed for an extended temperature range of -55 to +155 °C and are constructed to avoid thermal degradation. The AEC-Q200-certified inductor is suitable for applications such as high-current power supplies,



start-stop systems, power distribution modules, on-board chargers, infotainment or HVAC systems. The members of this inductor family are available in the following sizes: 7030 (L = 0.47 - 22 µH), 1040 (L = 1 - 68 µH), 1365 (L = 1 - 47 µH) and 1770 (L = 4.7 - 82 µH). These components feature a low-profile shielded construction with a distributed air gap in iron alloy powder.

www.we-online.com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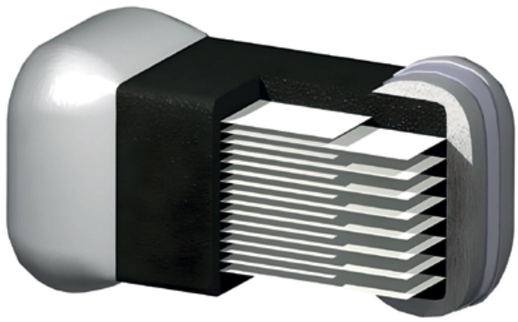
Varistor Series Offers Surge Current Protection up to 6,000

KOA Speer Electronics introduces the NV73S series multilayer type metal oxide varistor that handles a surge current of up to 6,000 A, which is five times higher than existing products. The multilayer construction can absorb a large surge. The two-way symmetries can absorb positive and negative surges. The NV73S replaces the NV732E (1210) through 2L (2220) due to its improved surge protection. Maximum peak current and sizes for the new NV73S are 400 to 800 A (1210), 500 to 1,200 A (1812), and 1,500 to 6,000 A (2220) with a working voltage range of 6 to 95 V (AC) and 9 to 127 V (DC). The varistor voltage range for the NV73S series is 12 to 150 V. The NV73S series metal oxide varistor offers protection from ESD and EMI. It also provides surge protection for motors, relays, and solenoid valves. It meets EU-RoHS requirements.



www.koaspeer.com

1200V *e* SiC MOSFET for High Performance Applications

Power Master Semiconductor has released the 2nd generation of the 1200V *e* SiC MOSFET, which is intended for applications such as DC EV charging stations, solar inverters, energy storage systems, motor drives and industrial power supplies. The 1200 V devices are claimed to "offer e. g. higher power density, efficiency and less cooling effort due to its much lower power losses". FOM characteristics such as gate charge (Q_G), stored energy in output capacitance (E_{OSS}), reverse recovery charger (Q_{RR}) and output charge (Q_{OSS}) are improved by up to 30 % compared to previous generation. All devices are 100 % tested in terms of avalanche capability. Due to its lower miller capacitance (Q_{GD}) it achieved 44 % lower switching losses than the previous generation.

www.powermastersemi.com

Thermal Pads Protect EV Battery Packs

The Chomerics Division of Parker Hannifin has introduced its THERM-A-GAP™ PAD 30 thermally conductive gap filler pads for EV battery packs that fits seamlessly into robotic assembly processes. THERM-A-GAP PAD 30 thermally conductive gap filler pads for EV battery pack applications are claimed to "provide exceptional performance and conformability". During assembly, vision sensors can see THERM-A-GAP pads which enables effective quality control and fast production. The pads release directly from their liner for pick-and-place robots, making them well-suited for high-volume applications, and come in specially designed packaging to ensure safe shipment. The pads provide a soft (34 Shore 00) solution with 3.2 W/m-K of thermal conductivity and are claimed to offer low outgassing, ensuring an effective thermal interface between heat sinks and electronic devices where there are uneven surfaces, air gaps and rough surface textures. The supporting electrical properties of this RoHS-compliant thermal gap filler pad include: 5.9 kVAC/mm dielectric strength (ASTM D149 test method), 10^{13} Ωcm volume resistivity (ASTM D257), 7.7 dielectric constant at 1,000 kHz (ASTM D150) and 0.001 dissipation factor at 1,000 kHz (Chomerics CHO-TM-TP13).

www.parker.com

Advertising Index