ISSN: 1863-5598

ZKZ 64717
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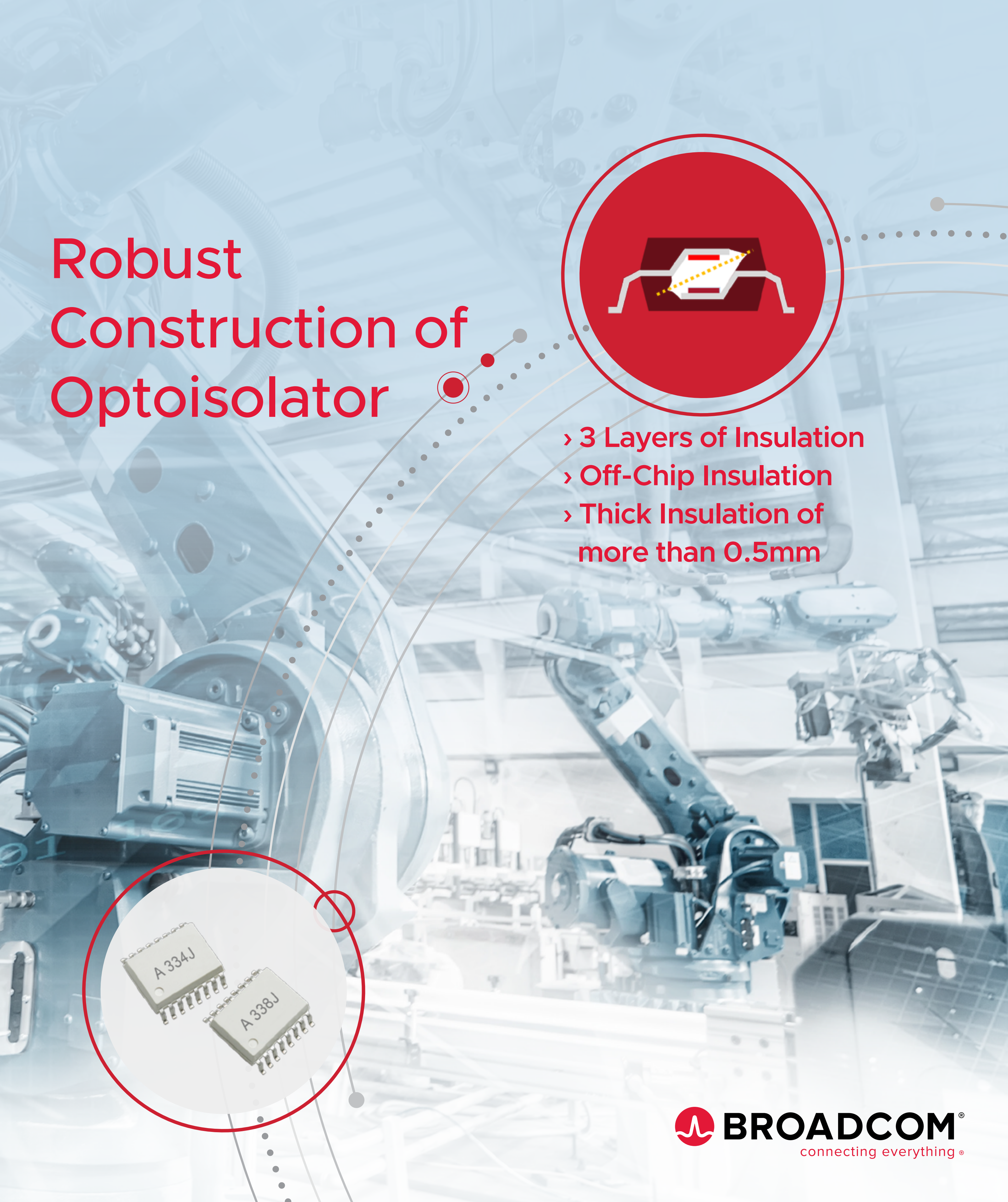
Bodo´s Power Systems®

Electronics in Motion and Conversion

August 2024



PULSED INDUCTANCE MEASUREMENT

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KEY FEATURES

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

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Content


Bodo's Wide Bandgap
EVENT 2024
December 3-4
Hilton Munich Airport
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bodoswbg.com
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for SiC and GaN!"

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A Media
Katzbek 17a
24235 Laboe, Germany
Phone: +49 4343 42 17 90
Fax: +49 4343 42 17 89
info@bodospower.com
www.bodospower.com

Founder
Bodo Arlt, Dipl.-Ing.
bodo@bodospower.com

Editor in Chief
Alfred Vollmer, Dipl.-Ing.
alfred@bodospower.com

Correspondent Editor Bavaria
Roland R. Ackermann
roland@bodospower.com

Editor China
Min Xu – xumin@i2imedia.net

US Support
Rusty Dodge
rusty@eetech.com

Creative Direction & Production
Bianka Gehlert
b.gehlert@t-online.de

Publisher
Holger Moscheik
holger@bodospower.com

Free Subscription to qualified readers
Bodo´s Power Systems is available for the following subscription charges:
Annual charge (12 issues) is
150 € world wide · Single issue is 18 €
subscription@bodospower.com

Printing by:
Westdeutsche Verlags- und Druckerei GmbH; 64546 Mörfelden-Walldorf Germany

Urban Wafer Fab

A few weeks ago, I had the honor to attend Nexperia's 100th birthday celebration in downtown Hamburg. Historically, it all started with the Valvo electronic tubes and, since the facility is in our neighborhood, I took the car and trusted the GPS to get me there quickly and easily. What I didn't expect is that we would literally be going almost to the middle of the city!

Given the many products that are manufactured here, I wondered why the company would choose this location over an industrial area outside of the city, with direct access to the highway maybe? But, I was soon to learn later that day that this was due to the history of the site and this district in particular. Also, Hamburg in general, over the following decades has developed into the metropolis it is today. I also learned that the location is a great advantage for the company's HR department as it attracts talent, especially the younger generation. Part of the program was a tour of the clean room and wafer production. This was a very interesting experience, and you could see how state-of-the-art technology and modern equipment has been integrated into these historic buildings. On the same day, Nexperia announced that it will be making a further investment in the site, specifically tailored to WBG technology. "Only the fence is the limit," as their COO explained in a press briefing.

The airport in Munich is not really an urban location for obvious reasons. But it is easy to reach by public transport, which is very important for our audience at the WBG event in Munich in December. Preparations have started and we have recently sent out the invitations. Bodo's panel at PCIM was a good appetizer for what to expect, but of course we can go into much more detail during our conference. We will keep the successful format from last year, with an opening day and the conference on the second day. The program on www.bodoswbg.com will grow steadily over the next few months and tickets will go on sale in October, exclusively on this website. The response last year was overwhelming, and we look forward to this gathering of industry experts. If you work with SiC or GaN, you can't miss it, so mark your calendar!

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 www.bodospowerchina.com. An archive of our magazine with every single issue is available for free at our website www.bodospower.com.

Green tip of the month:
Don't let the traffic steal your time. The bigger the city, the greater the chaos. Every alternative to the car is worth trying out, which is what I discovered following my recent visit to Hamburg!

Kind regards,

Holger Moscheik

Events

CIGRE 2024
Paris, France August 25 - 30
https://session.cigre.org

Smarter E South America 2024
Sao Paulo, Brazil August 27 - 29
www.thesmartere.com.br

PCIM Asia 2024
Shenzhen, China August 28 – 30
www.pcimasia-expo.com

ECCE Europe 2024
Darmstadt, Germany September 2 – 6
www.ecce-europe.org

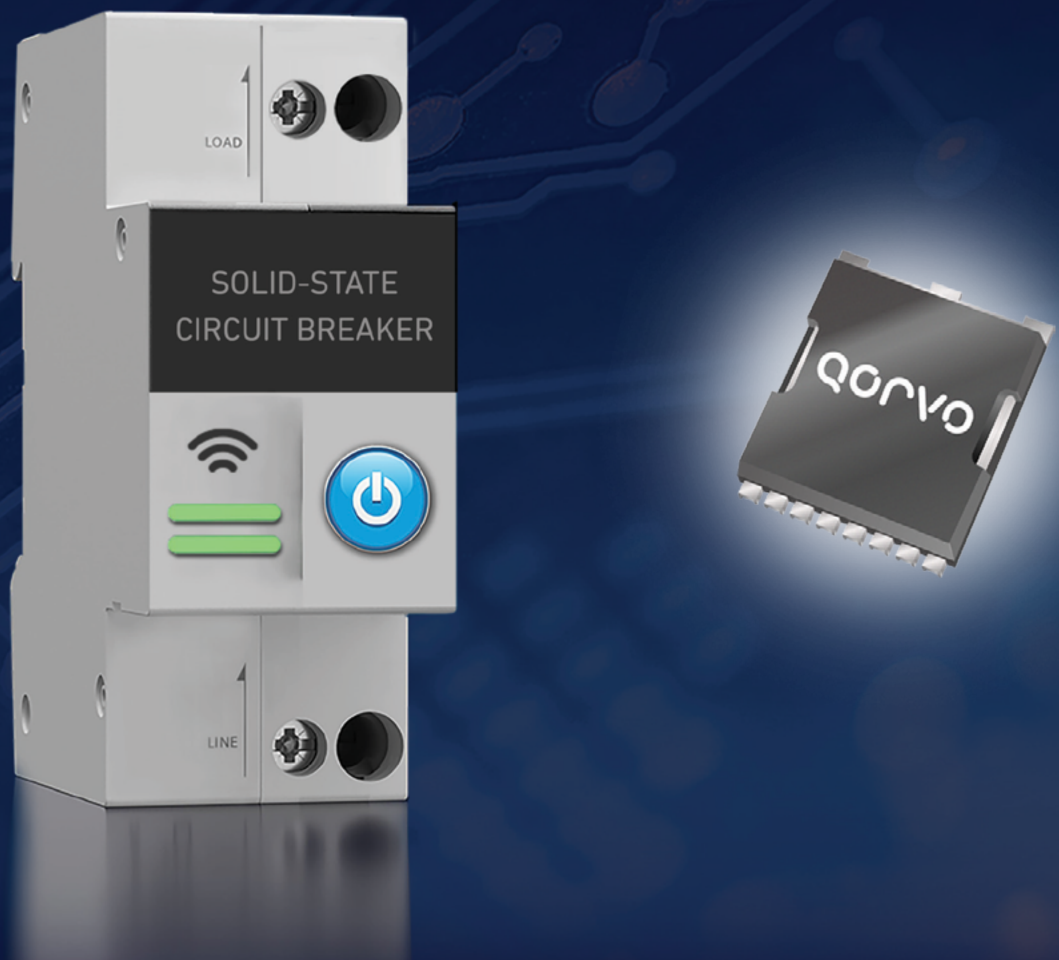
ESREF 2024
Parma, Italy September 23 – 26
www.esref2024.org

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

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

WiPDA 2024
Dayton, OH, USA November 4 – 6
https://wipda.org

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

High-density Power Modules for Deep-Sea ROVs

Historically, commercial divers have taken great risks to inspect oil and gas pipelines, high-voltage electrical cables, wind turbines and other critical infrastructure deep undersea. Saab has eliminated that risk bringing deep-sea exploration expertise to commercial underwater applications. With a mission to keep people and society safe, the Seaeye range of ROVs has been developed with more agile and modular systems designs. Saab UK's Seaeye systems are capable of performing a wide range of tasks from observation and inspection to more complex functions like underwater maintenance. This evolution has culminated in the development of a system which is claimed to be "the world's most advanced all-electric work-class ROV (eWROV)", which combines versatility and maneuverability. Unlike traditional hydraulic ROVs, the eWROV eliminates the need for large amounts of hydraulic fluid, thereby mitigating environmental risks. Critical specifications for the eWROV's power converter are size, mass and thermal dissipation, given that the electronic systems are housed in sealed enclosures where space is at a premium and conventional convection cooling is not possible. To meet these requirements, Saab chose Vicor power modules for their high density and efficiency. These modules enable efficient power distribution to various eWROV subsystems such as thrusters, manipulators and onboard electronics. The use of Vicor power modules allows Saab to customize Seaeye subsystems according to specific industry-standard 24V and 48V levels required by onboard computers, sensors, video cameras, lights and navigation equipment.

www.vicorpower.com

SiC Manufacturing Facility planned to be built in Czech Republic

onsemi announced plans to establish a vertically integrated silicon carbide (SiC) manufacturing facility in the Czech Republic. The site would produce the company's intelligent power semiconductors that are essential for improving the energy efficiency of applications in electric vehicles, renewable energy and AI data centers. onsemi's plan to expand SiC manufacturing with a multi-year brownfield investment of up to $2 billion (44 billion CZK) is part of the company's previously disclosed long-term capital expenditure target. This investment would build on the company's current operations in the Czech Republic, which include silicon crystal growth, silicon and silicon carbide wafer manufacturing (polished and EPI) and a silicon wafer fab. Today, the site can produce more than three million wafers annually, including more than one billion power devices. Upon completion, the operation would contribute annually more than $270 million USD (6 billion CZK) to the country's GDP. Pending all final regulatory and incentive approvals, this would be one of the largest private sector investments in the Czech Republic's history and would further contribute to the prosperity and economic dynamism of the Zlín region.

www.onsemi.com

Collaboration between Semiconductor Manufacturer and Power Supply Provider

Texas Instruments announced a long-term collaboration with Delta Electronics, a global power and energy management manufacturer, to create next-generation electric vehicle (EV) onboard charging and power solutions. This work will leverage both companies' research and development capabilities in power management and power delivery in a joint innovation laboratory in Pingzhen, Taiwan. Together, TI and Delta aim to optimize power density, performance and size to accelerate the realization of safer, faster-charging and more affordable EVs. Phase one for the collaboration focuses on Delta's development of a lighter-weight, cost-effective 11 kW onboard charger, using TI's latest C2000TM real-time microcontrollers and TI's active EMI filter products. The companies are working together using TI's products to reduce the charger's size by 30% while achieving up to 95% power conversion efficiency. In phase two, TI and Delta will leverage the latest C2000 real-time MCUs for automotive applications to enable automakers to achieve automotive safety integrity levels (ASILs) up to ASIL D, which represents the strictest automotive safety requirements. Highly integrated automotive isolated gate drivers will further enhance the power density of onboard chargers, while also minimizing overall solution size.

In phase three, the two companies will collaborate to develop the next generation of automotive power solutions by using GaN technology.

www.ti.com

Long-Term SiC Supply Agreement and Joint Lab

STMicroelectronics and Geely Auto have signed a long-term Silicon Carbide supply agreement to accelerate their existing cooperation on SiC devices. Under the terms of this multi-year contract, ST will

provide multiple Geely Auto brands with SiC power devices for mid-to-high-end battery electric vehicles (BEVs). In addition, building on their longstanding cooperation across multiple automotive applications, Geely and ST have established a joint lab to exchange information and explore solutions related to automotive Electronics/Electrical (E/E) architectures (i.e. in-vehicle infotainment, smart cockpit systems), ADAS, and NEVs. Geely Auto Group has adopted ST's third generation SiC MOSFET devices in electric traction inverters. Geely Auto sold a total of 1.68 million vehicles in 2023, with NEV sales reaching 480,000 units, accounting for 28% of the company's total sales for the year. This NEV sales volume represents a year-over-year increase of 48%.

www.st.com

Charity Benefit from PCIM Booth for Education in Ecuador

Vincotech staged a charity benefit at the PCIM Europe trade fair to raise funds for the NGO Plan International Germany. Visitors rose to this virtual reality (VR) challenge. Vincotech and its partners rewarded their efforts by donating €15,000 to a project to support young Ecuadorians. Vincotech has a history of hosting char-

ity events at PCIM Europe. Ranging from wall climbing to Sudoku, these activities have been a big hit with fairgoers. This year's event – a VR flight over mountainous terrain – was yet another audience magnet. Hundreds of PCIM Europe visitors (including a Bodo's Power Systems editor) took up the challenge, with Vincotech matching all pledges to raise €15,000 for a Plan International Germany project in Ecuador. The money goes to support youngsters, especially girls, in ten communities each in the Cotopaxi and Santa Elena regions. It funds projects to convey entrepreneurial, digital, and soft skills that will help them get off to a better start in professional life, as well as health services for mothers and children. This project, which involves 2,000 individuals directly and indirectly benefits nearly 6,000 community members, is a certainly a winning proposition young Ecuadorians in the region. Plan International is an independent organization, with no religious, political or governmental affiliations, standing up for children's rights worldwide and striving to be open, accountable and honest in what the NGO does.

www.vincotech.com

IWIPP 2025 Call for Papers

The organizing committee is pleased to announce that the Call for Papers for IWIPP 2025 is now available. The online portal for abstract submission will open September 1, 2024, and the deadline for submission is November 1, 2024. IWIPP 2025 technical abstracts are submitted in a compact format consisting of a single-page technical description and a second page of figures.

IWIPP 2025 will be held April 8-10, 2025, on the beautiful campus of University of Alabama, Tuscaloosa, USA. The content of IWIPP 2025 will include a set of keynote addresses from leading power technology experts, a broad range of technical sessions, as well as extensive networking opportunities. All of this is included in the workshop registration fee.

www.iwipp.org

APEC 2025 Announces Call for Industry Session Proposals

APEC 2025, to be held next year in Atlanta, Georgia, March 16-20, announces the call for submission of proposals for the conference's popular Industry Session series. The Industry Session component of the conference is intended to encourage content from industry practitioners. Industry Session (IS) speakers are invited to make a presentation only, avoiding the formality of writing the papers for IEEE Xplore publication. IS tracks run in parallel with APEC Technical Sessions and the presentations are included for download by paid APEC attendees. The deadline for submission of proposals is August 23rd. Industry Session proposals may be submitted for an individual speaker presentation or for an overall session proposal.

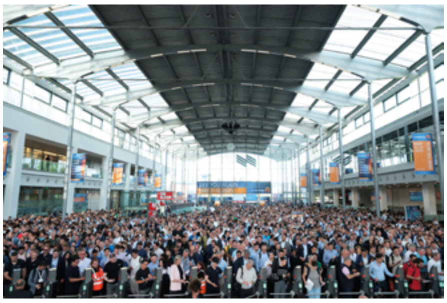
The total time allowed for each presentation is 25 minutes, including 5 minutes for Q and A. To submit a proposal for an Industry Session at APEC, presenters should prepare a 2-3-page proposal that provides a summary of the presentation content and a description of the target audience. Also, a short professional biography of the speaker should be included. If proposing for a full session, a proposal for each of the individual presentations must be submitted. Presentations should have strong technical content and commercial references should be limited and only in support of the core content.

www.apec-conf.org

The Smarter E Europe 2024 in Munich – Largest Energy Industry Event Again Presented Records

After three eventful days at the trade fair and inspiring conferences and forums, Europe's largest trade fair alliance for the energy industry once again achieved record results: 3,008 exhibitors from 55 countries – with, for the first time and undeniably, China at the forefront – showcased their latest products, applications and solutions for a 24/7 renewable energy supply in all of the 19 exhibition halls plus an outdoor area, covering a total area of 206,000 square meters.

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



The fair alliance, taking place from 19 to 21 June and uniting the four trade fairs Intersolar Europe, ees Europe, Power2Drive Europe and EM-Power Europe, attracted the interest of around 110,000 trade visitors from 176 countries who came to Munich to find out about the state of the art, current trends and developments as well as new business models in the fields of solar energy, energy storage, e-mobility, smart grids and prosuming at the trade fairs. New records were also set for the conferences and side events: over 2,500 participants attended this year. The smarter E Europe has thus once again succeeded in demonstrating the full potential of renewable energies.

"The fact that we've once again broken our own records in terms of exhibitor and visitor numbers is a clear sign that the energy transition has gathered considerable momentum in recent years, and is continuing to do so. This year has shown us that the vision of a renewable 24/7 energy supply is taking shape and becoming a reality," said Markus Elsässer, CEO of Solar Promotion GmbH, which organizes The smarter E Europe alongside FWTM. "The decarbonization of industry, and of life in general, is a global challenge that can only be met if we all work together," added FWTM's CEO Hanna Böhme. "Once again, The smarter E Europe in Munich has created a significant platform for bringing together talent, innovators and entrepreneurs from around the world."

Intersolar Europe: Focussing on European PV production

The Munich fairgrounds were dominated by Intersolar Europe in 10 halls, focussing on photovoltaics, solar thermal technologies and solar power plants. Since its founding, it has become the most important meeting point for manufacturers, suppliers, distributors, and service providers in the solar industry.

Most important topic of discussion: Photovoltaic production must return to Europe - with strong political backing. After all, in order to achieve energy sovereignty and the resilience of the European energy system in the long term, technological dependencies and supply chain difficulties must be minimised.

ees (electrical energy storage) Europe 2024

In five exhibition halls, the ees exhibition area offered a broad supporting programme to provide orientation for growth. ees Europe is celebrating its tenth anniversary this year, and the general conditions for the dynamic development of storage markets are now very favourable in more and more countries. Florian Mayr, Committee Chair of the ees Europe Conference, put it in a nutshell: "The industry is in the middle of the "energy storage decade". The possible development direction of the storage industry was the subject of exchange and discussion in the supporting programme of Europe's largest and most international trade fair for batteries and energy storage systems. Mayr explained: "As always, the ees Europe supporting programme covers the hottest and most interesting topics for the industry."

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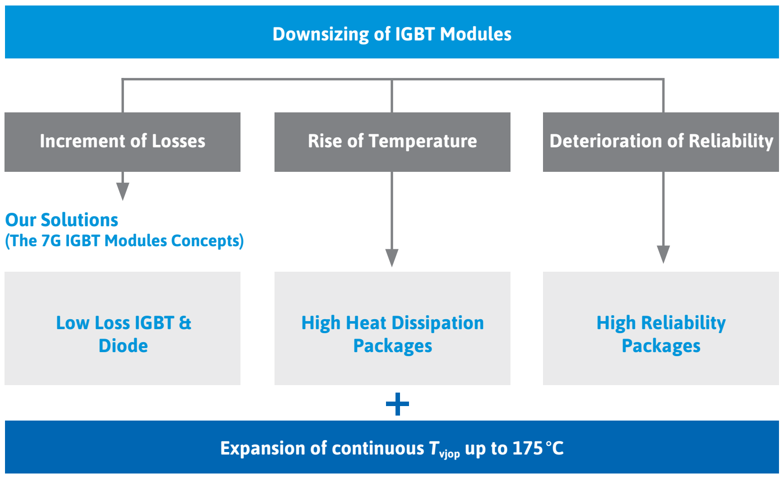

www.fujielectric-europe.com

Fuji Electric
Innovating Energy Technology

Battery storage is seeing exponential growth around the world. Experts predict that the global production capacity will reach 500 GWh per year by 2025. For years, tenders for new wind or solar generation capacity in markets such as Australia, the USA or India have been combined with storage systems, for example by defining time-based requirements for guaranteed capacity or the ability of solar power generators to supply power at night. The markets in these countries are skyrocketing. China plans to expand its current capacity of 3 GW to 100 GW by 2030.

According to a study by Frontier Economics, the volume of on-grid storage systems in Germany alone could grow to 60 GW/271 GWh by 2050 under ideal regulatory framework conditions. That is the current storage capacity multiplied by forty. Their price is expected to fall and their deployment speed to increase, similar to what photovoltaics (PV) has experienced in recent years. Battery storage systems will soon completely change our energy supply. This growth brings enormous benefits to the energy system and to the economy of the entire country. In Germany, the deployment of large-scale storage systems may drastically reduce the need to invest in new gas-fired power plants by up to 9 GW. This is another way in which storage systems contribute to reducing carbon emissions.

Power2Drive Europe 2024: Number of exhibitors doubled

E-mobility is in the fast lane worldwide. This was also reflected in the number of exhibitors and the activities surrounding the international trade fair Power2Drive Europe in two exhibition halls: over 400 exhibitors represent an increase of more than 50 per cent compared to the previous year. This means that one in five of the approximately 3,000 exhibitors at the overall event presented innovations from the mobility sector. In addition to the latest technical developments in the field of electric vehicle charging, visitors enjoyed a comprehensive supporting programme - from the compact Morning Briefing at the trade fair forum and the Women in Mobility Breakfast for networking to the trade fair workshop for fleet managers and e-mobility advice at the Test Drive.

EM(Energy Management)-Power Europe 2024: Start-ups digitalise the energy world

The ongoing expansion of volatile renewable energies is making the flexibilization of electricity consumption an important topic in the energy transition. Digitally controlled intelligent consumption management can make a significant contribution. It helps to stabilise the electricity system and at the same time enables flexible end consumers to save money. In addition to numerous established players, innovative young companies were also presenting their applications and solutions for an increasingly digitalised energy world in two halls at EM-Power Europe, the international trade fair for energy management and networked energy solutions.

The smarter E AWARD 2024: Five Categories

1 award, 5 categories, 15 winners: on the eve of the exhibition, the winners of this year's The smarter E AWARD were honored at an official ceremony: Winners in the Photovoltaics category were ArcelorMittal Construction (France) with Helioroof, up to 50 percent lighter and 40 percent faster to install, and NexWafe (Germany) with their EpiNex wafers aiming to revolutionize solar cell production and with Sunny Central FLEX, the German company SMA Solar Technology offers a key interface between large-scale PV plants, the power grid and battery storage systems. Winners in the Energy Storage category were ESS Inc. (USA) with Energy Center, a containerized iron flow battery system designed to reduce the cost and the ecological footprint of commercial energy storage, Pfannenberg Europe GmbH with Compact Chiller VLV 12, an intelligent thermal solution for liquid-cooled battery systems, and sonnen GmbH with their with its sonnenPro FlexStack, a modular outdoor energy storage system

In the E-Mobility category were awarded: (Swiss) Designwerk Technologies´s Megawatt Battery Charging System, EcoG (Germany) with their EcoG Connect, an intelligent, resource-efficient charging solution reducing capex by 25%, and Apollo Power (Israel) and their flexible solar modules SolarPaint. Winners of the Smart Integrated Energy category: CyberGrid (Austria) and their SaaS platform CyberNoc, Dvlp.energy (Germany) dvlp.energy which helps developers quickly identify and analyze potential locations, saving time and resources in project planning, and The Mobility House, founded in Germany in 2009, with a software and technology platform for monetizing battery storage systems on an industrial scale. And, last but not least, winners in the Outstanding Projects category were IO-Dynamics (Germany) and their Last-Mile Electrification, MaxSolar's innovation project in Bundorf, Bavaria, a prime example of energy transition in action, and Red Sea Global`s Red Sea Destination Renewable Utilities Infrastructure, a project in Saudi-Arabia setting new standards for sustainable tourism.

The Smarter E Europe 2025:

The race will continue: The smarter E Europe 2025 and its four individual trade fairs (Intersolar Europe, ees Europe, Power2Drive Europe and EM-Power Europe) will again take place next year at Messe München from 7 to 9 May 2025.

www.thesmartere.com

Design Higher Power Density USB-C PD Applications with 50 V GaN FET in Tiny 1.8 mm² Footprint

EPC introduces the 50 V, 8.5 mOhm EPC2057 GaN FET in a 1.5 mm x 1.2 mm footprint, offering higher power density for USB-C PD applications

Efficient Power Conversion (EPC) has launched the 50 V, 8.5 mΩ EPC2057. This GaN FET is specifically designed to meet the evolving needs of high-power USB-C devices including those used in consumer electronics, in-car charging, and eMobility.

Key Features and Benefits:

- High Efficiency: The 50 V GaN FET boasts an ultra-low on-resistance of just 8.5 mΩ, significantly reducing power losses and enhancing overall efficiency.
- Compact Design: Its tiny footprint makes it ideal for space-constrained applications, allowing for smaller, more efficient power adapters and chargers.
- Fast Switching: The GaN technology enables faster switching speeds, improving power density and reducing the size of passive components, leading to more compact and lightweight designs.

"As USB-C PD continues to gain traction, efficient, compact, high-performance power solutions are vital. Our new GaN FET meets these needs with a reliable, efficient solution that enhances performance," said Alex Lidow, EPC CEO and co-founder.

Industry Impact

With the increasing adoption of USB-C PD, there is a growing demand for power components that can deliver higher efficiency and performance while minimizing size and heat generation. EPC's GaN FET is designed to meet this demand, offering a superior alternative to traditional silicon-based FETs.

Development Board

The EPC90155 development board is a half bridge featuring the EPC2057 GaN FET. It is designed for 40 V maximum operating voltage and 10 A maximum output current. The purpose of this board is to simplify the evaluation process of power systems designers to speed their product's time to market. This 2" x 2" (50.8 mm x 50.8 mm) board is designed for optimal switching performance and contains all critical components for easy evaluation.

Designers interested in replacing their silicon MOSFETs with a GaN solution can use the EPC GaN Power Bench's cross-reference tool to find a suggested replacement based on their unique operating conditions.

www.epc-co.com

Robust Construction of Optoisolator

The concept of functional safety revolves around the assurance that a system will behave in a predictable and safe manner, even when faced with internal faults or external disturbances. In the context of motor drives, this entails implementing measures to mitigate risks associated with electrical, mechanical, and software failures, ensuring that the system operates reliably under all foreseeable circumstances and prevent injury, damage, or even loss of life.

By Chun Keong Tee, Product Manager of Isolation Products Division, Broadcom

In this article, I will be discussing how a single point failure of the power supply can lead to uncontrolled movements. The other aspect of such failure is the damage of the galvanic insulation barrier, which can lead to electric shock as motor drive deliver high power, operating off AC line high voltages in the range of hundreds to thousands of volts. To minimizing the likelihood of accidents and optimizing operational efficiency, we will look at how the robust construction in high voltage optoisolator can help to mitigate such disastrous consequences from power supply failure.

Isolator Construction

Before dwelling into the single point failure of the power supply, we will look at the construction of an optical and capacitive galvanic isolated gate driver. The reason for focusing on gate drivers is that they are used to drive power semiconductors like IGBTs in motor drives extensively. They provide reinforced galvanic insulation between high voltage IGBTs and control circuits. Their ability to reject high common mode noise is important to prevent erroneous driving of the IGBTs. Therefore, the robust construction of the isolated gate driver is critical to drive the motor in a fail-safe manner during fault.

Optoisolator provides reinforced insulation by wide distance through insulation (DTI) between the LED and detector with three layers of insulation barriers. The three layers of insulation are made up of silicone, polyimide film and silicone as shown in figure 1. Polyimide film is developed specifically to withstand the damaging effects of partial discharge, which can cause ionization and breakdown of insulation material. Polyimide's unique properties of high dielectric strength and wide temperature range allow it to be used extensively in electrical insulation applications, from locomotives to aerospace. The polyimide film used in ACPL-334J gate drive optocoupler has a typical dielectric strength of 300 kV/mm and can withstand temperatures as low as -200 °C and as high as 400 °C. The DTI of ACPL-334J is 0.5 mm.

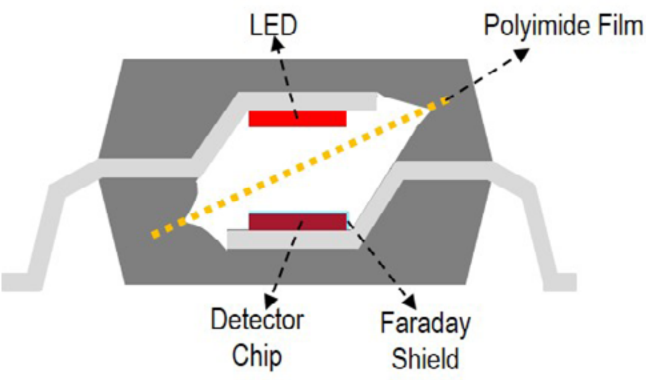

Figure 1: Optoisolator structure with three layers of insulation barrier

IEC defines a SELV (separated extra-low voltage) circuit as an electrical circuit in which the voltage cannot exceed ELV (extra-low voltage) under normal and single-fault conditions. A SELV circuit must have electrical protective separation from all other circuits. In motor drives, the power supply circuit at the input should be separated from the PWM (Pulse Width Modulation) control circuit. The lead frame at the input of ACPL-334J is designed with a protective separation distance of more than 0.8 mm as shown in figure 2.

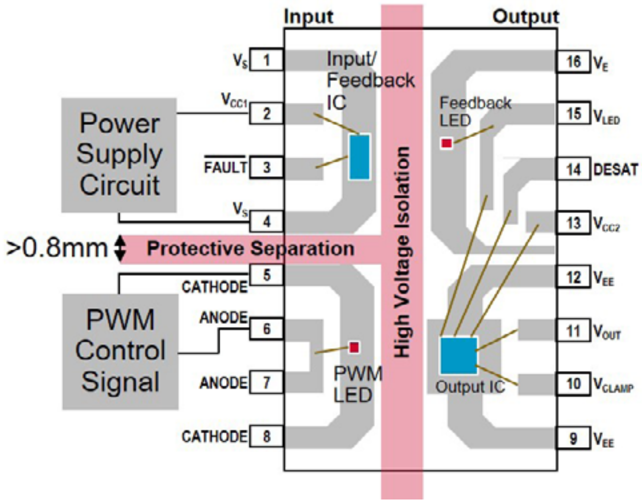

Figure 2: ACPL-334J's lead frame structure with protective separation

Capacitive isolator uses silicon dioxide (SiO_2) as dielectric for the on-chip insulation. The isolation circuit is integrated on the same chip along with other circuitry in a monolithic process. High voltage isolation is achieved using two thick SiO_2 capacitors in series, one on input side and the other on the output side. The high voltage capacitors use the same process as the CMOS production. The thickness of the SiO_2 or DTI of a capacitive isolator is between 0.014 to 0.028 mm.

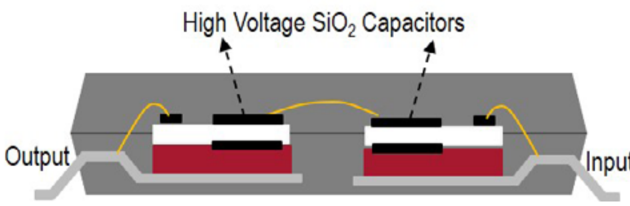

Figure 3: Capacitive isolator structure with two series SiO2 capacitors

The x-ray of a gate driver using capacitive isolation in a two-chip module is shown in figure 4. The input and output ICs have isolation capacitors to increase the high voltage capability. As this is a monolithic process, the input IC of the gate driver consists of the power supply circuit, PWM control circuit and SiO_2 capacitor in a single chip.

Erik Rehmann, GVA expert for Quality Management

gva-power.de

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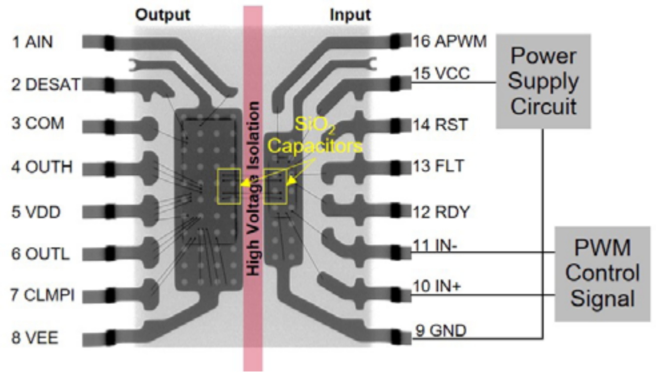

Figure 4: X-ray of a gate driver using capacitive isolation in a two-chip module

A Single Point Failure - Power Supply Fault

One of the primary reasons why functional safety is of utmost importance in motor drives is the catastrophic consequences during fault. A single point power supply fault can lead to uncontrolled movements and compromise the isolation barrier. The PWM controller, on its own cannot be considered safe off. The reason for this is that if there is a malfunction on the power supply and damage the input IC, the ability to switch off the motor must be guaranteed.

However, in the single chip architecture of the capacitor isolation, the power supply malfunction can cause input logic (IN+/IN-) to be in the wrong state signaling wrong motor movements. On the other hand, lead frame at the input of ACPL-334J provides a protective separation from the malfunctioned power supply. This redundancy in architecture provides a fail-safe condition in which the PWM LED will not transmit wrong signal to the motor.

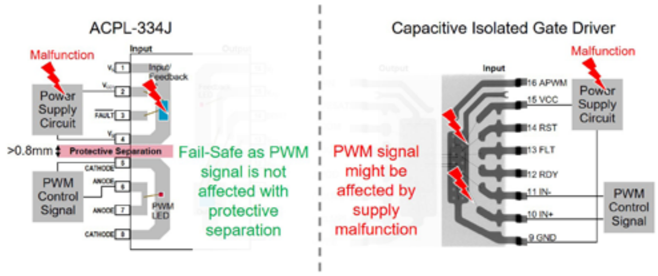

Figure 5: Protective separation provides fail-safe condition during power supply fault

The other aspect is to study the impact of the power supply fault on the galvanic insulation barrier. A power supply destructive test was conducted by increasing the bias of the supply pins of the optical and capacitive isolated gate drivers until the input IC broke down. This is to simulate the power supply fault with uncontrolled current surge into the input IC. In accordance to UL 1577, the gate drivers were proof tested by applying insulation test voltage of 5 kVRMS to detect leakage current, I_{I-O} not exceeding 5 µA. Table 1 shows the test conditions and results of the power supply destructive test.

The high voltage leakage current was applied to a control unit accompanying the device under test (DUT) to see if there is any degradation of the insulation barrier. The ACPL-334J gate driver using

Power Supply Destructive Test	Input Biasing Conditions before IC Broke Down	I_{I-O}, 5kV$_{RMS}$ Per UL 1577
ACPL-334J Control Unit		3.2µA
ACPL-334J DUT	Anode/Cathode>6V, I_{LEDI}>1A(S/C)	**3.2µA (PASS)**
Capacitive Isolated Gate Driver Control Unit		1.6µA
Capacitive Isolated Gate Driver DUT	V_{CC}>15V, I_{CC}>13mA	**>99.9µA (FAIL tester limit)**

Table 1: High voltage leakage current test after power supply destructive test

optical insulation shows there is no change in leakage current after the power supply destructive test. This is attributed to the robust insulation construction with wide DTI and the three layers of insulation made up of silicone, polyimide film and silicone as shown in cross-sectional x-ray of ACPL-334J. Although it is obvious that the power supply has damaged the PWM LED and the input IC, the polyimide film or the insulation tape remain unscathed due to its distance from them.

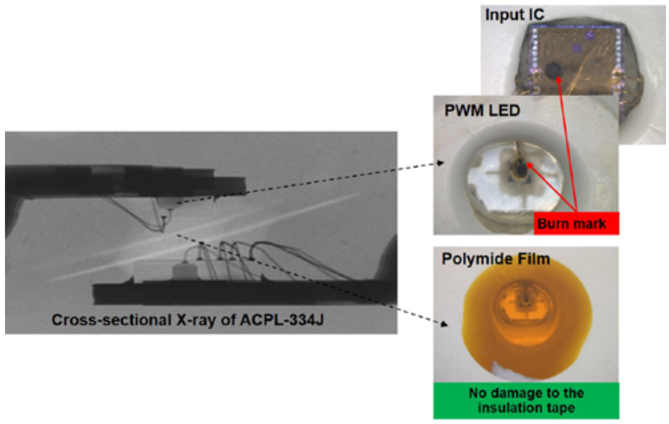

Figure 6: Failure analysis of ACPL-334J after power supply destructive test

The gate driver using capacitive insulation however shows very high leakage current that exceeds the limit of the high voltage tester. A failure analysis was conducted to see the extent of the damage that caused the high leakage current.

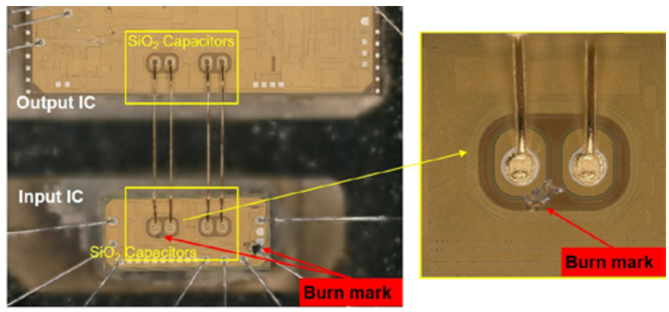

Figure 7: Failure analysis of the capacitive isolated gate driver after power supply destructive test

Figure 7 shows that the SiO_2 capacitor at the input IC is damaged and compromised the insulation capability of the isolator. As the insulation circuit is integrated on the same chip along with input circuitry in a monolithic process, their close proximity and thin DTI are obvious reason for the failure of the insulation. This shows that the single point failure of the power supply failure can damage the capacitive insulation barrier, which can lead to electric shock and compromise safety.

Conclusion

Both optical and capacitive isolator can do a very good job insulating high voltage, protecting the low voltage circuit and ensure the users' safety. However, fault events at peripheral circuit, like the power supply fault discussed in this paper can damage the insulation barrier, compromising the functional and electrical safety. The fundamental construction of the isolation barrier is crucial to determine how easily the fault can reach and damage the insulation barrier. The protective separation in the lead frame and three layers of insulation of the ACPL-334J create a gap impossible for the fault energy to reach. On the other hand, capacitive isolation construction uses a monolithic process, integrating electrical circuits and the SiO_2 capacitor in a single chip, creating close proximity for the fault to reach the insulation barrier.

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Automotive USB-C solutions: Enabling high-power charging and seamless connectivity

SPR and EPR solutions from Infineon for in-cabin USB-C charging provide higher charging speeds and data transfer rates. EZ-PD™ CCG7xxx USB Power Delivery (PD) controllers and EZ-USB™ HX3 USB hub controllers combined with firmware can implement dynamic load sharing, output power throttling, and moisture detection for most automobiles.

By Subu Sankaran, Director of Product Marketing for Automotive USB controllers, Infineon

In May 2021, the USB promoter group announced the Standard Power Range (SPR) and Extended Power Range (EPR) standards of power delivery enabling USB devices to deliver up to 100 W and 240 W of power, respectively [1]. Consequently, mobile devices such as phones, tablets, gaming consoles, and PCs are now increasing their charging capabilities to around 100 W. As these devices go truly mobile, the demand for charging them while on the move is increasing as well. Automotive OEMs can now meet these high-power charging demands with USB hub and Power Delivery (PD) controllers from Infineon for all three types of applications:

- Head unit (HU) applications or breakout boxes
- Rear seat charger (RSC) applications
- Rear seat entertainment (RSE) applications

Head unit (HU) applications

For the driver and the front passenger, the HU application or breakout box module provides two or more USB Type-C ports, with USB connectivity from the plugged-in mobile device to the automotive infotainment system for Apple CarPlay, Android Auto, or media/data transfer functionality. Along with USB data connectivity, the module can also provide USB power (USD PD) up to 100 W per port.

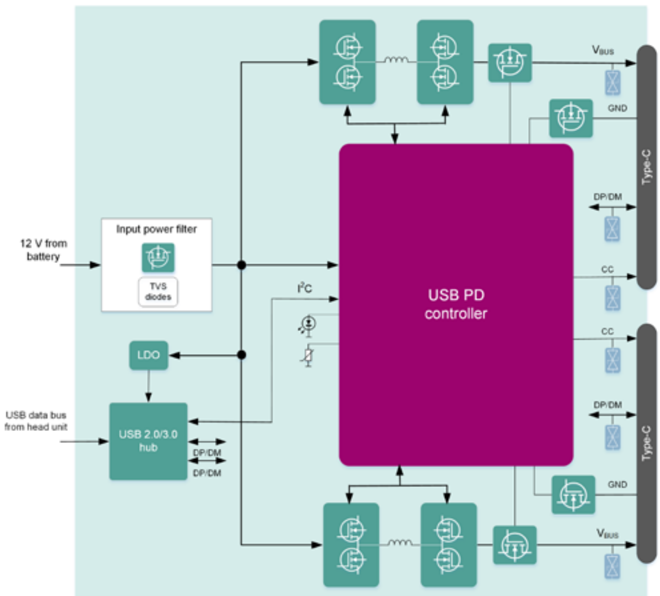

Figure 1: Schematic of a HU solution using Infineon's CCG7D, an automotive USB PD controller

As shown in figure 1, the USB hub is connected to the PD controllers through an I2C interface for control and status. This helps the PD controllers share status information about the PD ports to the infotainment system on the Host Protocol Interface (HPI) layer of the firmware. Using this information, the controller can simultaneously manage commands to change the characteristics of the PD ports. In this era of EVs and software-defined vehicle architectures where saving and controlling the power is essential, such a two-way control is essential.

Rear seat charger (RSC) applications

Passengers at the rear also get high-power charging of up to 100 W per port with the RSC solution for vehicles with regular offerings. This solution also supports legacy charging protocols such as Apple Charging, Samsung's AFC, and Qualcomm's QC. See figure 2.

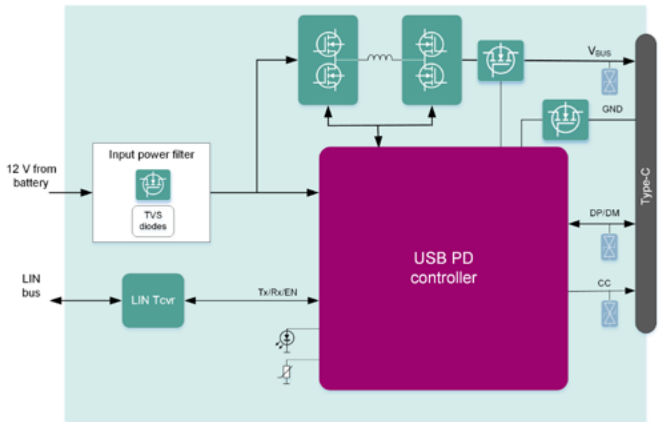

Figure 2: Schematic of an RSC solution using Infineon's CCG7S/CCG-7SAF, an automotive USB PD controller

Rear seat entertainment (RSE) applications

Vehicles with premium offerings for rear passengers can use the RSE module that provides a USB PD port for charging along with DisplayPort (DP) support. This concept allows streaming videos from a connected mobile device to a monitor behind the front seats using the Alternate (Alt) mode functionality, by implementing the Billboard feature through the I2C interface. See figure 3.

The PD controller implements additional functionality to support DP Alt mode called "Hot Plug Detect" (HPD), which detects the DP display and converts the display signals into USB PD data packets over CC lines of the USB Type-C connector.

A good example of the solution's robustness is seen when the RSE module cannot successfully connect to the host mobile device. In such a situation, the Billboard device enumerates and reports the error condition to the host.

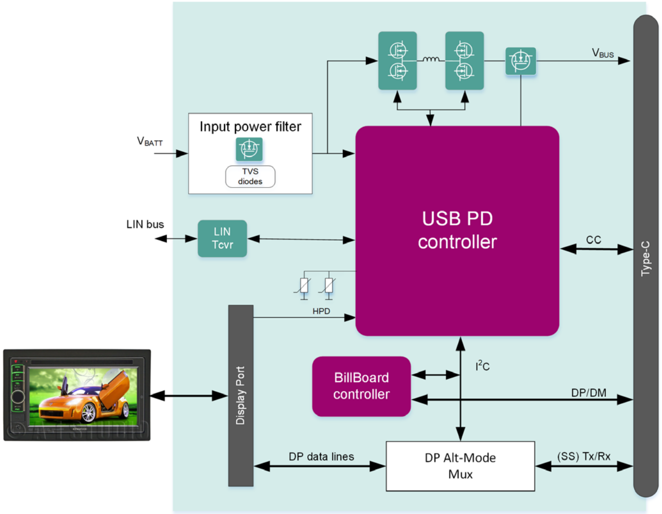

Figure 3: Schematic of an RSE solution using Infineon's CCG7S/CCG7SAF an automotive USB PD controller

Options for OEM customization

The PD controllers of the RSC and RSE solutions can use the LIN interface to communicate with the automobile's control unit for control and status, similar to the HU application.

The GPIOs in the PD controllers can drive LEDs to illuminate various points in the module and contain NTC thermistors to measure temperatures at various points on the PCB. These features can be modified by OEMs to their specific safe operation limits.

Along with the hardware, Infineon also provides a firmware stack to implement value-add features such as dynamic load sharing, output power throttling (based on temperature and battery voltage), and moisture detection in the USB Type-C connector.

Dynamic load sharing

In a USB PD module with two or more ports, a limited input power budget is dynamically distributed across the ports based on demand or the power can be split 50:50. For example, consider a two-port module with a total input power capacity of 90 W. When a device, like a laptop is connected to one of the ports of the module and requests 60 W, the module splits the 90 W of power to provide 60 W to port 1 and the rest 30 W to port 2. Similarly, if the connected device requests 45 W, the 90 W of power is evenly split between the two ports, providing 45 W per port.

The dynamic load sharing algorithm ensures that the connected devices get the maximum amount of power to charge efficiently.

Output power throttling

The module's output power can be throttled based on the module's temperature or the input voltage of the battery. The granularity of the steps to throttle the output power can be configured depending on the OEM's requirements.

The module's temperature can be measured using one or more thermistors connected to the PD controller. Based on the measured temperature and the power throttling algorithm, the output power is regulated to reduce the thermal dissipation loss. At extreme temperatures, the output power is reduced to a minimum of 15 W (5 V and 3 A), as defined by the USB specification.

Automotive OEMs limit the module's operating voltage based on the maximum current carrying capacity of the cable harness. The PD controller continuously measures the input voltage and regulates the output power to keep the input current under limits. When the input voltage reaches the cut-off limit, the output power is limited to 15 W (5 V and 3 A).

Moisture detection in the USB Type-C connector

Some of us must have had the experience of having some liquid in the USB Type-C connector of our phones, with a warning message that says "Do not connect a charger to the phone". Similarly for automobiles, power should not be provided if moisture is present in the USB Type-C connector as it is a power source. The software algorithm in PD controllers can detect the change in resistance between the pins of the USB Type-C connector due to a liquid and disable power to the connected device as a safety measure. The I2C/LIN interface in the PD controllers enable connectivity to automotive systems to relay and show an error message on the infotainment display to inform the user why their devices are not being charged.

Conclusion

So, as is now evident, Infineon provides robust yet convenient solutions for in-cabin USB-C solutions, even for high-power charging. Infineon is also a one-stop solution for most of the components for the application schematics shown in figure 1, figure 2, and figure 3:

- EZ-PD™ CCG7D, CCG7S, and CCG7SAF families of USB PD controllers [2]
- EZ-USB™ HX3 family of USB hub controllers [3]
- OptiMOS™ 5, 6, and 7 families of switching MOSFETs [4]

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About the Author:

Subu Sankaran is the Director of Product Marketing for Automotive USB controllers at Infineon, working with global Automotive OEMs and Tier 1s. He has over 20 years of experience working with USB standards and products. He has a bachelor's degree in Electronics and Communication from Bangalore University and an MBA from University of Phoenix.


DANISENSE

Powering the Future: 8th Generation Si IGBT Chips in Innovative LV100 Packages

In power electronics, Insulated Gate Bipolar Transistor (IGBT) technology is crucial for high-efficiency in high-power applications especially where the blocking voltages are above 600 V. Mitsubishi Electric's 8th generation IGBT chips in the innovative LV100 package promise superior performance and reliability, making them essential for renewable applications.

By Narender Lakshmanan, Eugen Stumpf, Mitsubishi Electric Europe B.V., Ratingen, Germany
Daichi Otori, Mitsubishi Electric Corporation, Fukuoka, Japan

Introduction

The renewable energy sectors, such as photovoltaic (PV) and energy storage systems (ESS), have grown significantly to combat global warming, driving up the demand for power semiconductors. The demand for inverters with high power ratings are increasing. Engineers must design high-power systems within a limited space, necessitating IGBT modules that deliver higher output power while maintaining established package sizes. The Low Voltage Directive 2014/35/EU allows a voltage level of up to 1500 V DC for "low voltage" applications. The 1200V-class IGBT power modules are vital in these systems as it is possible to develop a 3L-ANPC (three-level Active Neutral Point Clamped) topology to address the requirement of DC-Link voltages of up to 1500V.

Increasing the power density per power module is considered as an important target for achieving higher output currents while using the 1200V IGBT modules especially for high power solar or energy storage converters requiring the 3L-ANPC topology where there are certain cost implications for the efforts needed for cooling. This requires reducing electrical losses to optimize efficiency and improving heat dissipation to operate at higher power levels without overheating, ensuring reliability and performance.

Performance Estimation and Design Targets:

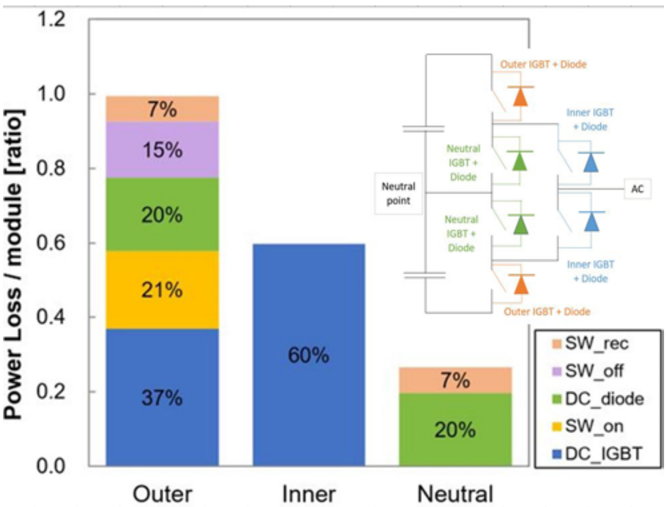

Figure 1: The power loss distribution by using of conventional 1200V-class module. Conditions: T_{vj}=150 °C, V_{cc}=750 V, M=0.75, PF=1, f_c=3 kHz, f_o=50 Hz, 3-level A-NPC topology

Figure 1 illustrates the normalized ratio of calculated conduction and switching losses for the 7th generation 1200A/ 1200V rated IGBT product in an LV100 package consider the 3L-ANPC topology. In the figure, conduction losses and switching losses are referred to as "DC" and "SW" respectively.

It can be observed that the losses are dominated by the DC power losses. This is true for both, IGBT and diode, and for all devices: outer, inner, and neutral. Additionally, the turn-on switching power loss ratio is particularly pronounced in the outer devices. Therefore, targeted reductions in IGBT DC power losses, diode DC power losses, and turn-on switching power losses are critical for minimizing total power losses within the system.

Reducing these specific power losses can substantially enhance the overall system efficiency. The high DC power loss rates in the IGBT and diode suggest that optimization in these components could yield significant performance improvements. Similarly, addressing the elevated turn-on switching power losses at the outer devices can further contribute to a decrease in total power dissipation, thereby enhancing the module's operational efficiency and reliability.

The 8th Generation Chip Technology – Key Features:

The 8th generation chips primarily utilize the Split-Dummy-Active (SDA) gate structure and the Controlling-Charge-Carrier-Plasma -Layer (CPL) structure. These advanced technologies are described in this article in detail.

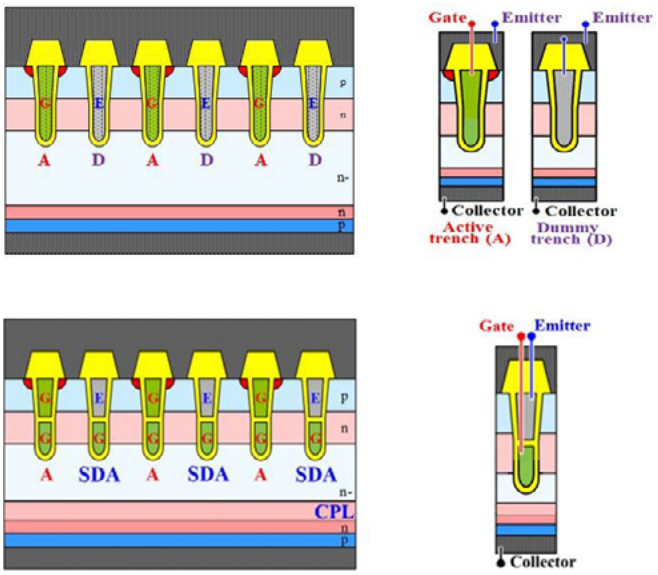

Figure 2: Chip cross section of 7th generation CSTBT™ (top) vs. 8th generation CSTBT™ (bottom)

In Figures 2, schematic cross-sectional views of the 7th generation and the 8th generation involving SDA and CPL is presented.

Turn-on switching power loss in IGBT modules can be reduced through high-speed switching, but this results in high reverse recovery dv/dt, which generates EMI and stresses motor insulation.

To manage this, gate resistance (RG) is typically increased, but this also increases switching power losses. Therefore, reducing reverse recovery dv/dt without increasing RG is crucial.

The 8th generation uses SDA trenches instead of dummy trenches. In SDA trenches, the upper electrode connects to the emitter and the lower electrode to the gate. Additionally, a CPL structure is applied to the backside buffer.

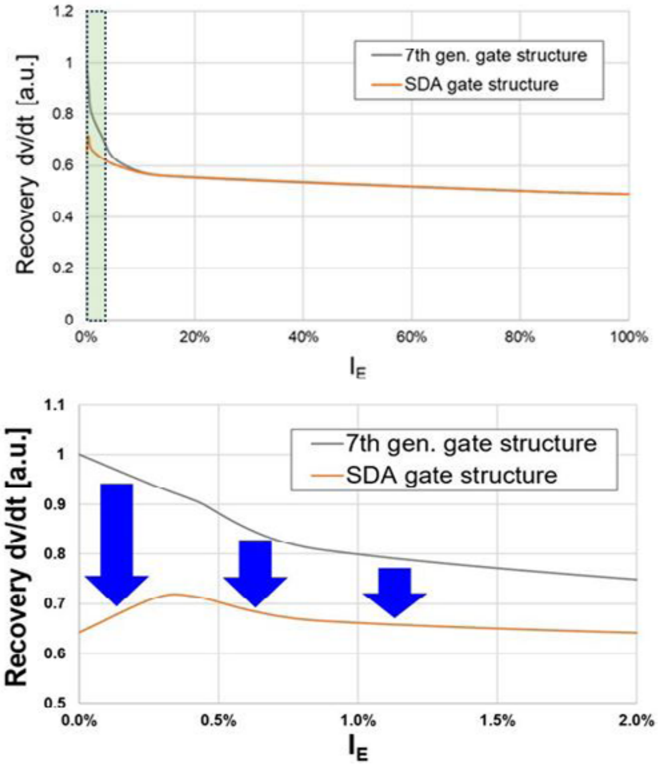

Figure 3: Chip characteristics. Emitter current dependence of recovery dv/dt. 0-100% area on top; 0-2% area on bottom

Figure 3 depict the emitter current (I_E) dependence of reverse recovery dv/dt for both generations. The SDA structure increases gate-collector capacitance (C_{GC}) without affecting gate-emitter capacitance (C_{GE}), effectively reducing recovery dv/dt at low currents without impacting high currents. This is critical as reverse recovery dv/dt is typically highest at low collector currents.

DC and switching power losses can be reduced by decreasing chip thickness, but this must be balanced with breakdown voltage considerations. During high di/dt turn-off operations, excessive V_{CE} surge voltage can destroy the IGBT. Suppressing the turn-off V_{CE} surge voltage is essential for reducing chip thickness and enabling high di/dt operation.

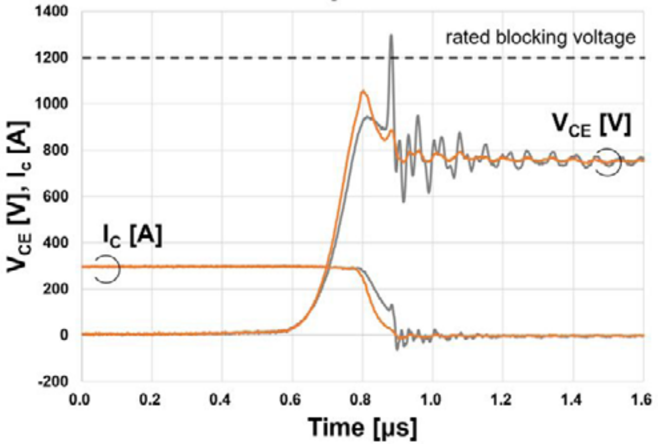

Figure 4: Turn-off waveforms of the IGBTs with and without CPL. Condition : T_{vj}=150 °C, V_{cc}=750 V, V_{GE}=15 V, R_G=1.6 Ω, I_C=rated current

The 8th generation IGBT uses an optimized backside buffer with a Controlling Charge Carrier Plasma Layer CPL structure. The CPL structure enhances turn-off softness by managing the distribution of charge carriers during turn-off, thereby reducing peak V_{CE} surge voltage and oscillations. Figure 4 illustrates that the IGBT with CPL suppresses turn-off V_{CE} surge voltage below the 1200V rating, unlike the sharp surge observed in IGBTs without CPL.

This improved design allows for higher di/dt turn-off operations, reduced chip thickness, and consequently lower power losses, making the 8th generation IGBT more efficient and reliable.

In the following a benchmark is performed to quantify the advantages of the 8th generation chips and its advanced technologies, including the SDA gate structure and the CPL.

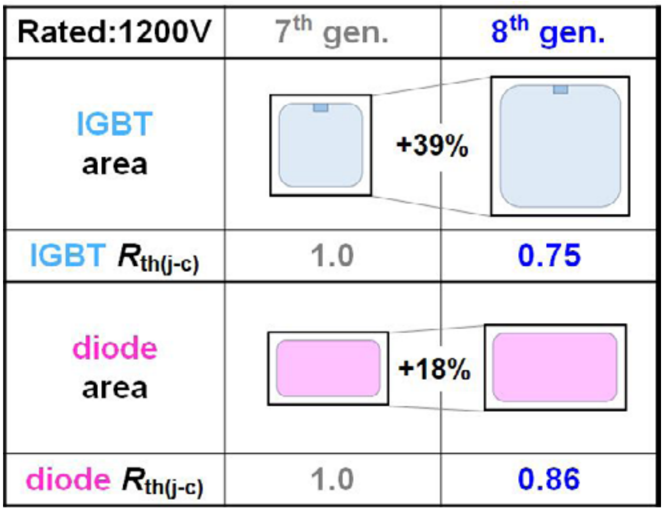

Figure 5: 1200V-class chip area and $R_{th(j-c)}$

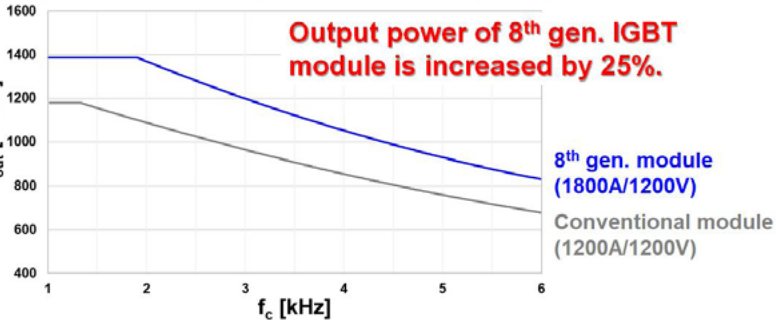

Figure 6: Output power comparison. Condition : T_{vj}=150 °C, V_{cc}=750 V, M=0.75, PF=1, fo=50 Hz, forced air cooling, T_a=40 °C, 3-level A-NPC topology

The 8th Generation Chip Technology – Performance Benchmarking: Figure 5 illustrates the chip areas and a normalized comparison of junction-case thermal resistance ($R_{th(j-c)}$). The 8th generation 1200V-class chips are optimized for the LV100-package chip mounting areas. By increasing the IGBT chip area by 39% compared to the 7th generation, the 8th generation IGBT significantly reduces $R_{th(j-c)}$ and DC power loss.

The 8th generation diode, optimized for loss trade-offs and chip thickness, also benefits from an 18% larger chip area compared to its predecessor. This expansion reduces both, $R_{th(j-c)}$ and DC power loss. Additionally, the internal design of the LV100-package has been optimized to maximize the chip mounting area for the 8th generation IGBT modules.

As result of above innovative steps, Figure 6 illustrates the relationship between carrier frequency (f_c) and output current (I_{out}) of the IGBT modules. The horizontal axis represents f_c, while the vertical axis shows the running value of I_{out}. The results indicate that the 8th generation IGBT module can achieve approximately 25% more output power compared to conventional modules. Alternatively, carrier frequency could be increased from 2.7 kHz to 4.4 kHz for same output power.

Summary

The 8th generation IGBT chips, utilizing advanced technologies such as the Split-Dummy-Active (SDA) gate structure and Controlling Charge Carrier Plasma Layer (CPL) structure, represent a significant leap in Si IGBT chip technology. These innovations enhance power density, reduce switching and DC power losses, and improve thermal performance.

The renewable energy sectors, particularly photovoltaic (PV) and energy storage systems (ESS), have driven increased demand for high-efficiency power semiconductors. The 1200V-class IGBT modules, crucial in these applications, benefit from higher output power capabilities while maintaining conventional package sizes. The 8th generation chips achieve this by optimizing chip thickness, enhancing the backside buffer design, and expanding chip areas within the LV100 package.

Testing has demonstrated that the 8th generation IGBT modules significantly reduce switching losses and improve thermal performance compared to previous generations. Figures show a 39% increase in IGBT chip area and an 18% increase in diode chip area, leading to reduced junction-case thermal resistance ($R_{th(j-c)}$) and DC power losses. Additionally, these modules achieve approximately 25% more output power, with further potential improvements through optimized cooling and system design.

In summary, the 8th generation IGBT modules offer substantial advancements in efficiency, reliability, and power density, making them ideal for high-power applications in rapidly growing renewable energy markets.

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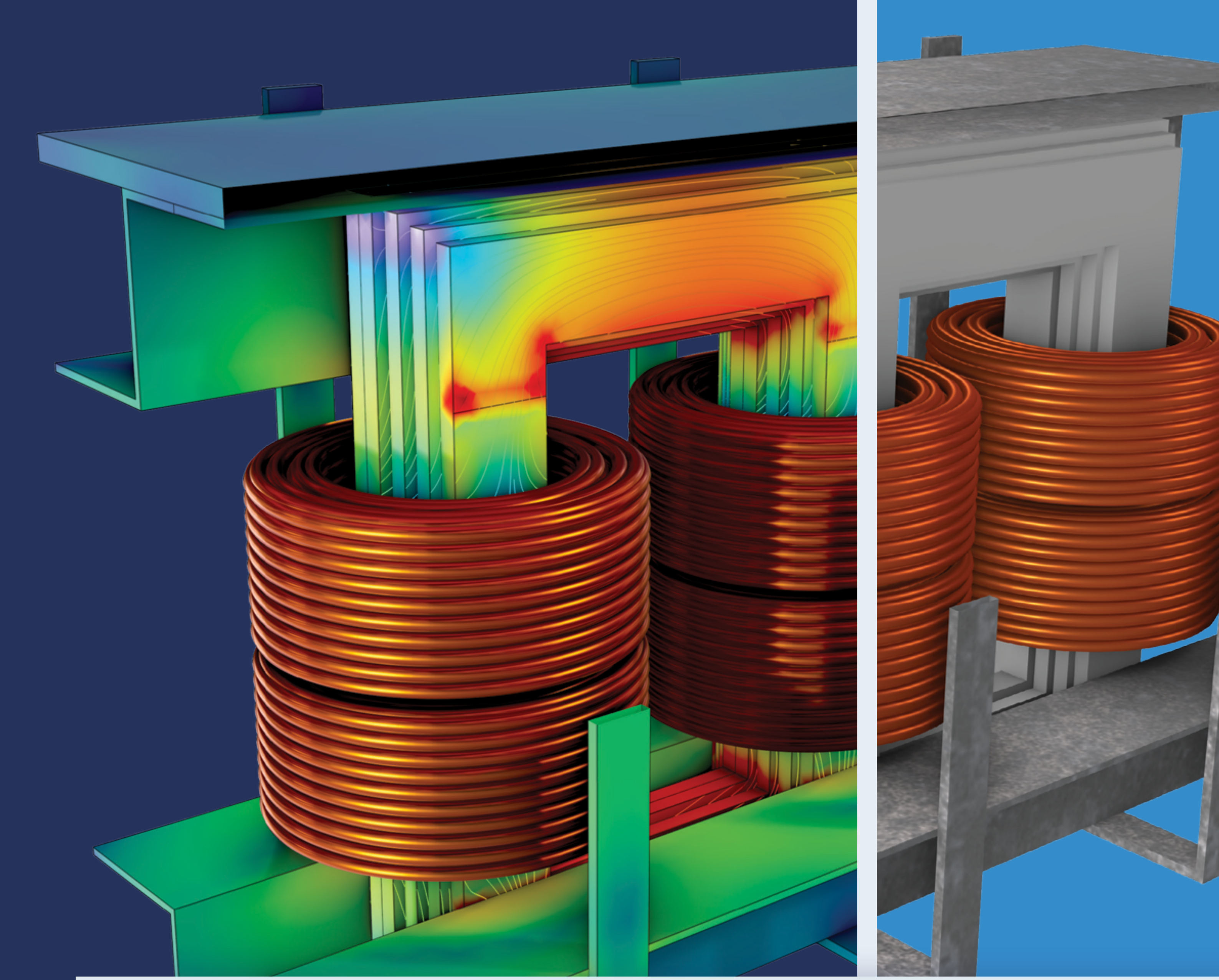

An Advanced Isolated Discrete Package to Keep SiC MOSFET Chip up to 60°C Cooler

Isolation of conventional discrete SiC MOSFETs from heatsinks relies on an external, thermally conductive, electrically isolating material. This not only increases thermal resistance junction-to-heatsink, but also complicates thermal management and creates obstacles in both automated and manual assembly processes. Furthermore, poor thermal conductivity reduces power and current handling capabilities, significantly limiting optimal SiC chip utilization. The ISO247 package from Littelfuse, featuring high performance silicon nitride (Si_3N_4) ceramic, addresses these challenges, improving SiC chip utilization and enhancing SiC MOSFET based applications.

By Sachin Shridhar Paradkar and Francois Perraud, Product Marketing, Littelfuse Germany

ISO247 – High Performance Ceramic based Discrete Isolated Package

The ISO247 belongs to the ISOPLUS™ family of internally isolated discrete power semiconductor device packages. The ISOPLUS™ family features direct copper bonding (DCB) substrates with aluminum oxide (Al_2O_3) ceramic, which was first pioneered by IXYS Semiconductor (now a part of Littelfuse) in 2003. The ISO247 adheres to the JEDEC TO-247AD outline, ensuring pin compatibility with the standard TO-247 package. The ISO247 spans a variety of semiconductor technologies including Si/SiC MOSFETs, IGBTs and Diodes with voltage classes ranging from 70 V to 1600 V. The ISO247 package, with advanced high performance silicon nitride ceramic, as detailed in reference [1], is specifically tailored to meet the demanding requirements of SiC MOSFET-based applications and offers the following key advantages compared to standard TO-247:

- High performance ceramic-based active metal brazing (AMB) substrate offers inherent isolation, higher thermal conductivity and reduced thermal resistance junction-to-heatsink [1].
- Isolation voltage rating of 2.5 kV AC, 1 minute or 3 kV AC, 1 second.
- Higher temperature and power cycling in seconds (PCsec) withstand capability ascribed to the matched co-efficient of thermal expansion (CTE) for SiC chip and AMB substrate [1].
- Increased power density and simplified thermal management.
- Reduced EMI attributed to the small chip-to-heatsink stray capacitance.

Although ISO247 and TO247 packages share identical outer dimensions and pinout configurations, their internal structures and mounting approach exhibit notable distinctions as depicted in Figure 1. While the TO-247 device necessitates external isolation during its attachment to the heatsink, the ISO247 device employs only thermal interface material for its mounting to the heatsink [2]. Note: The thermal interface material provides no electrical isolation, its function is only to improve thermal conductivity.

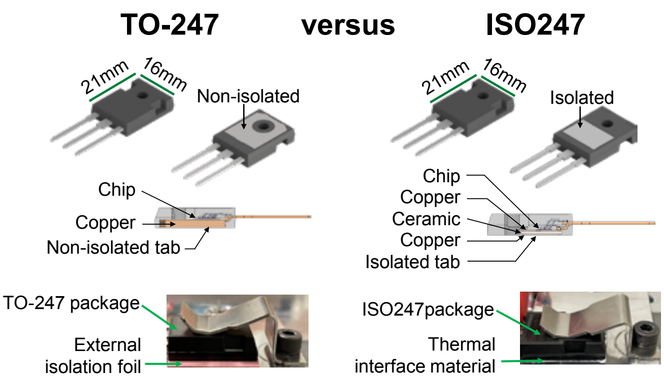

Figure 1: Internal construction and mounting difference between TO-247 vs ISO247 packages.

Thermal Performance Comparison between ISO247 and TO-247 based SiC MOSFETs

The standard TO-247 package has an electrically conductive mounting tab, which is typically at the drain potential. It is generally desirable to electrically isolate the device mounting tab from the heat sink due to safety concerns and the desire to mount multiple discrete devices on the same heat sink frame. The utilization of an external, thermally conductive, electrically isolating foil between the semiconductor package and the heatsink has become a widely adopted approach in the industry for this purpose. Nonetheless, employing external isolation entails significant drawbacks. Increased thermal resistance, diminished power and current handling capacity, complex thermal management, and substantial assembly efforts are each either direct or indirect consequences of external isolation tactics. The mentioned penalties, particularly the issue of reduced power handling capabilities, become unacceptable, especially in cases where wide-bandgap (WBG) semiconductors like SiC MOSFETs are utilized.

To evaluate the performance advantages of the advanced ISO247 package, thermal measurements were conducted using a 1200 V, 25 mΩ SiC MOSFET chip in various packaging and thermal interface configurations summarized in Table 1. Thermal measurements were executed using the cooling curve method in accordance with IEC 60747-8 [3], with measurement set-up detailed in reference [4, 5].

Device	Device 1	Device 2	Device 3
Chip	1200 V, 25 mΩ SiC MOSFET		
Package	TO-247	TO-247	ISO247
Device-to-Heatsink Isolation	External isolation foil with thermal conductivity 1.8 W/mK	External isolation foil with thermal conductivity 6.5 W/mK	Internal isolation with high performance Si_3N_4 ceramic*

*DOWSIL 340 thermal grease was used.

Table 1: ISO247 and TO-247 devices for thermal performance comparison featuring SiC MOSFETs.

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Benefits

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- Reduced system components
- Significantly increased power density
- Peak power pulse capabilities
- Optimized for the PCB layout

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Thermal measurement results for a heating current I_H=40 A are illustrated in Figure 2. As evident from Figure 2a, the ISO247 with high performance ceramic improves the steady state thermal resistance R_{thJH}, by up to 64% when compared to the TO-247 devices. Likewise, as depicted in Figure 2b, the SiC chip in the advanced ISO247 package stays up to 60°C cooler when compared to the TO-247 devices with external isolation. This results in a lower temperature swing between the junction and heatsink, ΔT_{JH}, at the given heating current. The advanced ISO247 has nearly a 53% reduction in temperature swing ΔT_{JH} compared to the standard discrete, significantly improving the device's lifetime and in turn the reliability of the system.

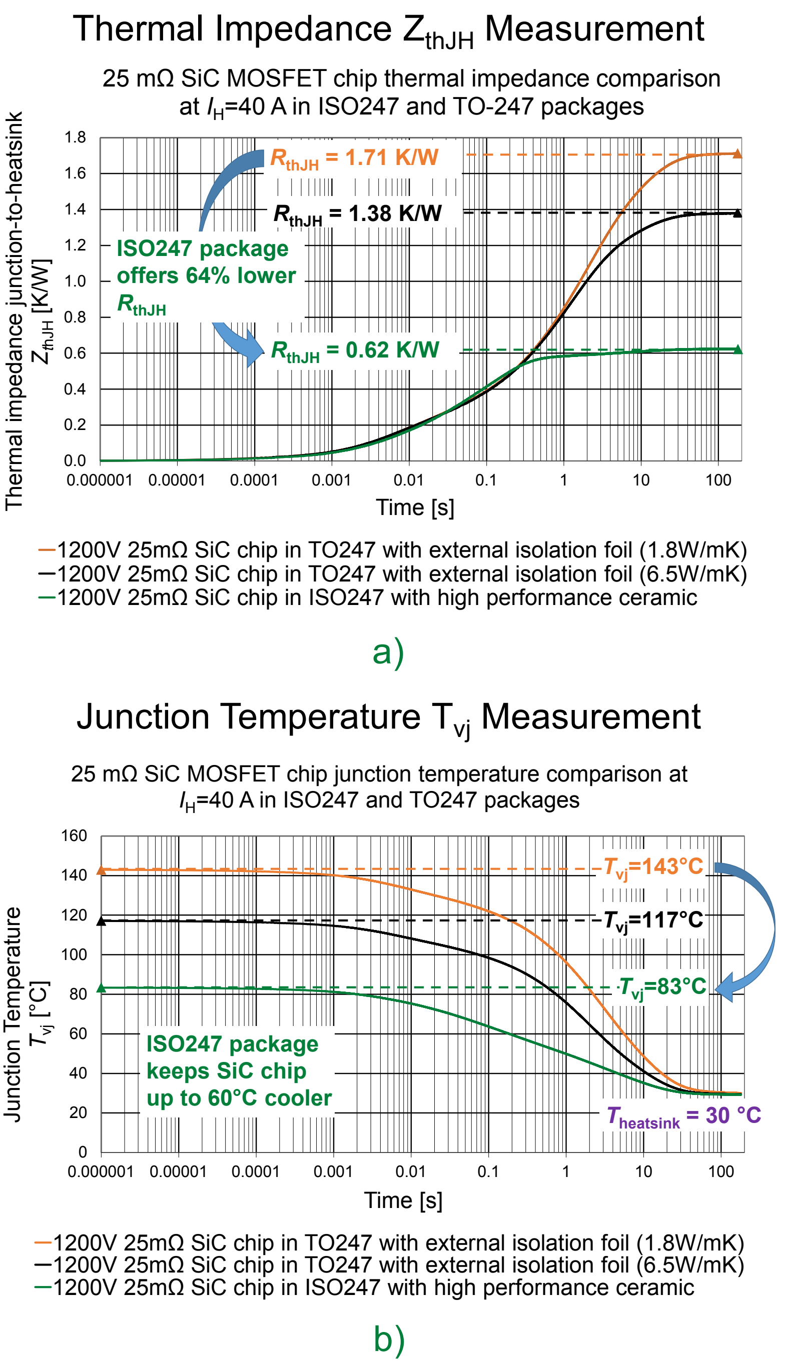

Figure 2: Comparison of a) thermal impedance and b) junction temperature measurement between ISO247 and TO-247 based SiC MOSFETs.

Enhancing Application Power Output and Reducing System-Level Costs by using ISO247

To demonstrate the improvement in application power output using the ISO247, thermal measurements with a heating current I_H resulting in a chip temperature T_{vj} of 130°C were applied to different packages, all containing the same 25 mΩ, SiC MOSFET chip. A junction temperature, T_{vj} of 130°C was selected, as most real-world applications are designed to operate with chip temperatures T_{vj}≤130°C. The results from the thermal measurements have been summarized in Figure 3a. It is apparent that the ISO247 package demonstrates a remarkable 170% improvement in power handling capacity and 30% improvement in current handling capacity compared to the TO-247 packages at a junction temperature of 130°C.

The exceptional thermal performance exhibited by the advanced ISO247 package unleashes the potential for enhancing power density and output power in the end application. Upgrading an active front end converter with a DC-link voltage of 800 V originally designed for 20 kW from 1200 V, 25 mΩ, SiC MOSFETs in TO-247 package with external isolation foil to the same SiC MOSFETs in advanced ISO247 packaging solution could potentially increase the DC power output of this system to ~30 kW. This represents a substantial increase in DC power output—up to 48% —as depicted in Figure 3b.

The ISO247 solution additionally offers a considerable opportunity for cost savings. An example scenario is shown in Table 2.

- Direct cost savings attributed to the enhancement in current and power handling capability, improved power density, savings in PCB area, and SiC chip cost.
- Indirect cost savings due to reduction in potential warranty claims by eliminating isolation foil.

Device and isolation type	T_{vj} [°C]	I_H [A]	R_{thJH} [K/W]	P_{DJH} [W]
TO-247 with 1.8 W/mK isolation foil	130	38.8	1.71	59
TO-247 with 6.5 W/mK isolation foil	130	42.2	1.38	73
ISO247 with High performance ceramic	130	50.8	0.62	160

30% and 170% increase in current and power handling resp.

a)

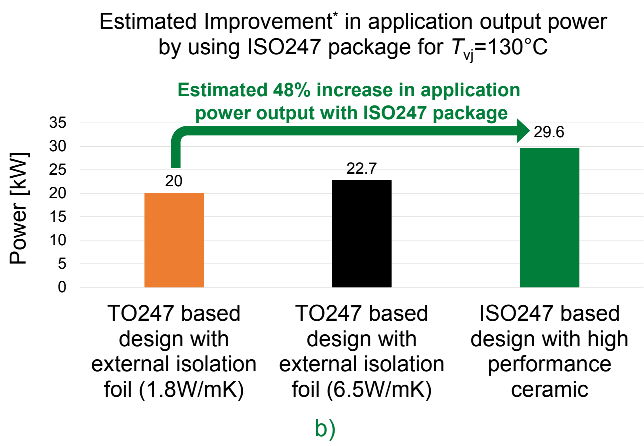

Figure 3: a) Thermal measurement results at T_{vj}=130°C and b) estimated increase in application power output by using ISO247.

Parameter	*ISO247 solution	TO-247 solution
No. of devices	6	12
No. of isolation pads	Not Required	12
Ease of assembly	Simple	Complex
PCB area	Up to 50% less area for ISO247 solution	
SiC chip cost	Up to 50% savings for ISO247 solution due to the elimination of SiC device paralleling	
Dollar per Ampere ($/A)	Up to 50% savings with ISO247 solution	

*Indicates potential for savings

Table 2: System-level cost savings opportunity using the ISO247.

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Summary

The growing prevalence of WBG devices demands innovative advancements in packaging technology to fully harness the advantages offered by WBG semiconductors. The ISO247 from Littelfuse is a unique isolated package specifically designed to address the rigorous requirements of SiC-based applications while remaining compatible with the standard TO-247 footprint. From the thermal measurement comparison, between the ISO247 and TO-247 packages, it has been established that the Littelfuse ISO247 with high performance Si_3N_4 ceramic offers a remarkable 64% reduction in thermal resistance, R_{thJH} and 53% reduction in temperature swing, ΔT_{JH}. Consequently, the SiC MOSFET chip in the ISO247 package remains up to 60°C cooler at the same DC current. This significantly improves overall device lifetime and application reliability. In simpler terms, due to the improved thermal resistance, R_{thJH} and power dissipation, P_{DJH} of the ISO247 package with high performance ceramic, engineers can choose higher $R_{DS(on)}$ chips for a given application power rating. This presents a significant cost-saving opportunity at the system level. Additionally, employing the ISO247 in power-electronic applications reduces mounting efforts, enables space-saving, decreases overall thermal resistance, and increases power density, all while simplifying thermal design.

Smart Energy Management for Buildings

A new smart fuse switch-disconnector by Mersen measures power flows in local low-voltage grids. This makes building switchgear fit for the age of renewable energy sources.

By Simon Landrivon, Marketing Communications Manager, Mersen

The electrical power grid is changing fundamentally as a result of the energy transition: instead of a few large power plants, electricity will come from numerous small renewable energy sources in the future; in parallel, more and more new type of electric loads such as EV charging stations and heatpumps are pulling energy from the low voltage network.

The operating companies therefore face the enormous challenge of ensuring the smoothest possible grid operation, avoiding power outages and maintaining high power quality. A new smart NH fuse switch disconnector allows monitoring and control of these ever more complex energy flows, while simultaneously protecting switchgear against surge currents.

Figure 1: Mersen-ProGrid-building-distribution-Adobe-Stock_491977888.jpg: Smart fuse switch disconnectors from Mersen monitor the current flow in building distribution systems (Image: ©stock.adobe.com/Kadmy)

The smart solution is from Mersen, a French company, world leader in power management applications, among others. ProGrid is the name of the innovative product, which Mersen developed especially for use in grid and transformer stations, cable distribution cabinets and low-voltage distributors. It represents a new modular generation of fuse switch disconnectors, which not only protect local low-voltage grids against surge currents, but also measure energy flows and other parameters.

Several versions available

The new ProGrid offer is available in three versions: Mersen ProGrid, Mersen ProGrid Smart and Mersen ProGrid SmartStation. Mersen ProGrid standalone fuse switch disconnectors protect substations, transformer stations or switchgear in buildings against surge currents and short circuits. This version embeds a new safer and patented switching mechanism and can be upgraded for monitoring with a smart module if required. The module and the sensors are already included in the second offer variant, Mersen ProGrid Smart. The latter features extended functionality and can enable to measure efficiently the energy flow at the low-voltage outlets of the switchgear, transformation station or substation.

Figure 2: The new ProGrid Smart fuse switch disconnectors from Mersen monitor the energy flow from PV systems to transformer stations (Image: ©stock.adobe.com/Mike Mareen)

Protection and monitoring of complete switchgear systems

Mersen ProGrid SmartStation makes it possible to combine ProGrid Smart with additional modular measuring instruments and sensors. The result is a complete energy and environment monitoring system for medium-voltage/low-voltage substations. ProGrid SmartStation allows the combination of the ProGrid fuse switch disconnector with additional modular measuring instruments, such as sensors for smoke detection, indoor and outdoor temperature, relative humidity or the status of the switchgear doors. Flood detectors or ozone sensors can likewise be integrated in the ProGrid SmartStation monitoring system.

ProGrid is an advancement of time-proven products

The ProGrid solutions are based on conventional NH fuse switch disconnectors from Mersen, which have been protecting power distribution systems in buildings and power grids for decades. In 2022 already, Mersen presented a new smart module for its current fuse switch disconnectors to enable real-time monitoring of the energy flow in low-voltage applications.

ProGrid is an advancement of these smart modules. The modular fuse switch disconnectors of the latest generation protect the low-voltage grid against surge currents and also enable digitalization of the grid. This is the main requirement for intelligent and flexible distribution of electricity generated by renewable energy sources. The ProGrid solutions offer numerous advantages for building automation and electrical installation specialists, as well as switchgear manufacturers. They not only protect the in-house power grid against surge currents due to fluctuations in the general power grid, the smart ProGrid fuse switch disconnectors can also measure the energy flow of PV systems, which are either supported on the roof or integrated directly in the building – for example, as an element of the roof or facade.

Energy flows in local grids have to be measured

The Renewable Energy Act (EnWG §14a) expressly requires the measurement of these energy flows by the so-called distribution management system. The purpose of the distribution management system is to prevent overloads to the public power grid. If capacities are insufficient to accommodate the power generated by the PV system, the grid operator can limit various stages of the system. However, this requires exact measurement of the energy flow from the PV systems to the public grid. This is where ProGrid solutions from Mersen are very useful, since real-time measurement of the energy flow allows efficient adaptation of the distribution networks.

ProGrid was created in cooperation with grid operators

Mersen developed the ProGrid fuse switch disconnectors in close cooperation with leading grid operators in Germany and other European countries. The development was pursued in agile mode with early user tests for the main functionalities and at each stage of the project. This immediate and direct feedback allowed the development team to integrate improvements early in the process. Valuable user experiences were taken into account to deliver this final product. As a result, the fuse switch disconnectors are optimally adapted to the requirements in the substation or in building automation switchgear. The degree to which Mersen tailored the ProGrid solutions to the requirements of power companies and electricians is already obvious in the patented switching/opening mechanism. It ensures highest safety level for the user, and fast installation and ergonomic servicing and replacement of the modules.

Opening mechanism facilitates installation

The mechanism executes two-step motions: parallel and rotating. The first parallel step is safer than other solutions, as it ensures IP20 protection against electric shock for the operator. IP20 protection lasts during the complete operation of the device, with no finger access to the electrical contacts. The second rotary motion allows easy access to the fuse.

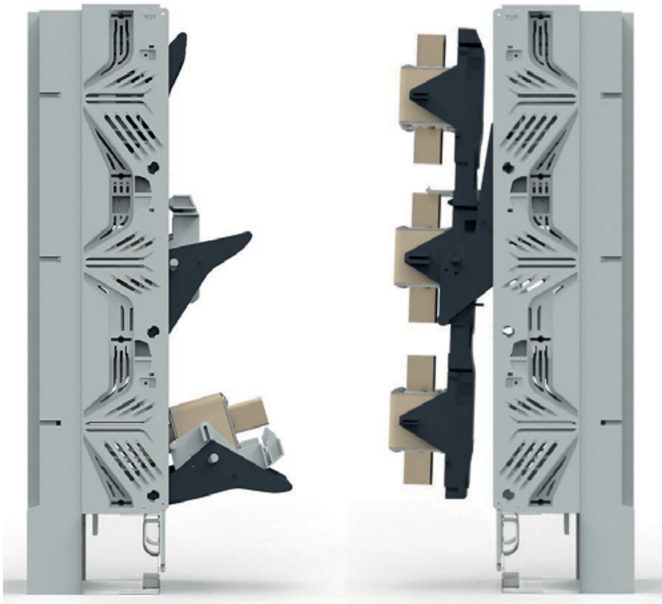

Figure 3: The patented opening and switching mechanism allows fast and safe handling of the fuse switch disconnectors

With a suitable tool, the fuse switch disconnectors can be mounted securely on current-carrying bus bars. They can also be installed on non-threaded bus bars using hook elements – even with current transformers.

Designed for easy retrofitting on switchgear

Mersen offers the ProGrid fuse switch disconnectors as a stand-alone version and as ProGrid Smart with factory-integrated sensors and smart module on the top or on the bottom of the device. The Top version is especially suitable for installation in new switch panels or transformer stations/substations. To retroffit an existing cabinet, the Bottom smart solution is ideal, as it enables one-to-one replacement of the already installed standard fuse switch disconnectors with ProGrid Smart Bottom. This is currently the most compact smart version of a fuse switch disconnector on the market and the footprint of the device matches exactly the standard from the market, limiting the impact on existing installation.

Up to 24 ProGrid smart modules can be connected per master in sequence through daisy-chaining. Mounting involves only minimal wiring: the sensors' cables are inside the fuse switch disconnector and are not in contact with the bus bar system. With only 1 Modbus cable distributing the communication between the modules and the gateway, the ProGrid Smart module offers direct access to the real-time energy and status data.

In addition, the design of the ProGrid fuse switch disconnectors enable the upgrade from standard to smart, thanks to pre-wired accessory kits and easy to install sensors cabling through the inside of the device. This product concept even convinced the jury of the renowned "German Design Council", which honoured ProGrid with the German Innovation Award 2024.

Worldwide access to all sensor data
ProGrid Smart modules are compatible with all devices that communicate using the Modbus RTU and ProGrid SmartStation measuring modules can also communicate in Modbus TCP/IP and MQTT protocol. Grid operators can use these interfaces for real-time access via the internet to all data measured by the sensors in the switchgear and its environment (via light control system provided by Mersen or other partners). The Modbus RTU cable in the Mersen ProGrid Smart fuse switch disconnectors is not only used for data transfer, but also supplies the modules with power. This eliminates cables and reduces installation space.

Figure 4: ProGrid fuse switch disconnectors from Mersen are available with a smart module mounted on the top or bottom. The smart modules can also be retrofitted on existing fuse switch disconnectors

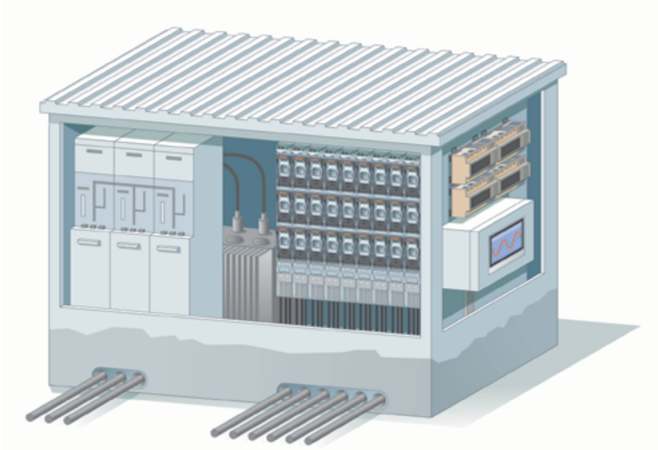

Figure 5: The ProGrid SmartStation solution not only protects transformer stations against surge currents, but also monitors the current flow and measures other important parameters

With high compatibility to any Modbus RTU or TCP/IP gateway and controllers, the ProGrid solution allows LV network data collection and analysis through all market-renown software solutions for improved and efficient maintenance by DSOs with the ultimate goal of high service availability and lower operation costs for the end-consumer.

Ready for the power grids' transformation
The new smart ProGrid NH fuse switch disconnectors from Mersen offer a tool for complete monitoring and control of medium/low -voltage switchgear. The smart ProGrid solutions allow switchgear manufacturers, electrical installation and building automation specialists to prepare the low-voltage grids of their customers for the challenges of the energy transition.

www.mersen.com

Addressing Next-Generation System Power Demands

Modular, configurable power for industrial systems and data centers

Global electricity consumption will grow by 3.5% over the next few years[1] driven by increased demand across all sectors, not least energy-intensive industrial applications and data centers addressing demand requiring processing capacity for artificial intelligence (AI) and machine learning (ML). At the same time, legislative, environmental and operational cost challenges put pressure on designers and system architects to deliver optimized power supply and conversion technologies that support ultra-efficient and scalable power delivery in the smallest possible form factors. Here, Advanced Energy looks at how highly efficient and configurable power supplies can address this need with sustainable, high-density power architectures for the future.

By Nate Mandelko, Senior Product Marketing Manager – Industrial Power Conversion, Advanced Energy

Power Demands of Next-Generation Applications

Motors are a key element of many industrial systems, consuming significant amounts of electricity. In fact, estimates[2] suggest that motor-driven systems are the largest consumer of energy, at around 40% of all electricity use. Industrial applications are growing rapidly, with factories being upgraded to meet the needs of Industry 4.0, bringing in industrial internet of things (IIoT) with its diverse power needs.

Figure 1: Powering a factory is becoming increasingly challenging

Due to the need for a diversity of power levels, powering an industrial facility can be a challenge. Motors can require anything from a few tens of watts to multiple kilowatts. Many control systems have standard requirements to power logic levels, while sensors and other application-specific devices can require non-standard voltages, many of which may not be available from a standard power supply.

As technology in industrial applications becomes more mobile (for example, automated guided vehicles in logistics operations) there is an increasing need for power solutions with a constant current output to recharge batteries.

The data center sector also uses huge amounts of power, which supports the cloud-based services relied on by many aspects of people's daily lives. Demands for these services are growing exponentially, especially with the staggering growth of artificial intelligence (AI) and machine learning (ML) applications and the increased virtualization of telecommunications. A recent report[3] estimated that data centers consumed 460 TWh in 2022 and estimate between 650 TWh and >1,000 TWh for 2026, meaning that there will be a minimum of 40% growth in consumption, with a (more than) doubling possible.

Figure 2: Modern data centers require huge amounts of power

Many AI servers now consume >100 kW and this is leading to some refining of the power architecture within data centers. It is becoming more common to use 48 V as the bus voltage, with 48 V standardization being driven by the Open Compute Project's Open Rack initiative (to which Advanced Energy has been a key contributor). Moving to 48 V from 12 V lowers current and the associated power losses in cables and drives down heat generation, leading to energy savings in both power supply operation, cooling and ventilation.

Modular, Configurable Power

Power density is heavily linked to the efficiency of the power supply (PSU). If the supply is more efficient, then less waste heat is generated. This means that less space is needed for thermal mitigation measures such as fans or heatsinking. As less forced air is required to pass through the PSU, components can be placed closer together, reducing overall space consumption. Of course, increasing efficiency is not trivial and requires selection of high-performance components, use of efficient topologies, good design

practices throughout the PSU and experience in designing for efficiency. At the same time, delivering optimized power – i.e. exactly what an application needs - ensures no more power than necessary is consumed.

All these factors are driving the growth in configurable, modular power supplies.

In general, power supplies contain a front end that rectifies the AC mains, provides power factor correction (PFC) and safety isolation followed by a second stage to produce the voltages for the load(s). A modular, configurable power supply retains this electrical architecture. However, while the front end (PFC) is fixed in the chassis, each output is usually a discrete module that plugs into a backplane at the primary/secondary boundary.

Figure 4: Advanced Energy's 18 kW Open Rack power solution

Most manufacturers offer a range of output modules, many of which are adjustable. This, along with the ability to connect multiple modules in parallel or series, allows an unlimited number of output configurations to be realized with little more than a screwdriver. Modules normally contain protection features (OVP, OCP, short-circuit, etc.) and a remote sense for use with distant loads.

As the primary difference between a standard and a modular configurable PSU is mechanical (the physical split between primary and secondary), a configurable PSU is just as efficient as any similar standard PSU. In addition, the modular approach supports the concept of optimized power thanks to the flexibility it delivers. System engineers can rapidly configure a single PSU solution that delivers standard logic voltages alongside non-standard voltages for more unusual system components, without buying an 'over-specified' off-the-shelf solution.

Figure 3: NeoPower NP08 offers up to 4 kW of power in a compact eight-slot chassis

Modular solutions are no longer limited to low- and medium-power designs. For higher power industrial and medical applications, for example, Advanced Energy recently launched the NeoPower™ configurable power solution that can supply up to 4 kW of power in a 2.5" high, 8-slot chasses with an input voltage range of 90 - 264 VAC.

Units are configured via a proprietary graphical user interface (GUI) and five different galvanically isolated output modules are available, with fixed and adjustable output voltages up to 300 VDC. Modules can be connected in series and parallel to achieve many voltage and current options. Both voltage source and current source operation are possible.

Modular power for the rack-mounted architectures of data centers takes a slightly different approach that is driven by standards such as the OCP's ORv3 specification that provides a base frame for large-scale deployment of racks. Advanced Energy, for example, offers an ORv3-compliant rack power shelf in its Artesyn® product line into which six 3 kW power modules can be fitted to deliver up to 50 V/18 kW capability.

The 3 kW rectifier modules, which feature best-in-class 97.8% efficiency and accept an AC input in the range 200 to 277 VAC, are fully OCP-compliant and hot-pluggable to support redundancy within the rack.

The 1OU rack can be used with one or two power cords giving the option for N+1 redundancy (15 kW) or N+N redundancy (9 kW) with dual cords. Input configurations can be 3P Delta 4 W, 3P Wye 5 W, 3 x of 1P.

Connectivity, Communication and Monitoring

Finally, it is worth noting that modern PSUs are increasingly 'connected'. NeoPower NP08 has a communication bus that supports MODBUS RS-485 and various other protocols such as PMBus and CANOPEN using a dongle. NeoPower will support multiple industry standard protocols while not adding unnecessary cost and complexity to the base model. The 3 kW Open rack has DTMF Redfish® compatible Ethernet via a hot-pluggable shelf controller.

Digital communication busses allow system designers access to key PSU operating parameters such as voltage, current and temperature. Monitoring this information for unexpected changes (such as additional power being drawn) can give warning of impending failure, preventing a simple maintenance task from becoming a fully-fledged breakdown.

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Credit: Figure 1 & 2 Adobe Stock, Figure 3 & 4 Advanced Energy

www.advancedenergy.com

Modular 100kA Surge Current Source with Programmable Current Shape

The often cited I^2t value describes a power semiconductor's ability to withstand surge current events. However, the dependency on current shape is usually overlooked. This article gives a short introduction to a surge current tester with arbitrary output current waveform and exceptionally low output current ripple, which enables a wide range of surge current tests.

By Stefan Wettengel, Andreas Hoffmann, Jonas Kienast, Lars Lindenmüller and Steffen Bernet, Technische Universität Dresden, Chair of Power Electronics

Introduction

Surge current withstand capability is an important ability for power semiconductors, e.g. in case of a fault event. The overcurrent capability of power semiconductors is quantified by the maximum surge current I_{TSM} and the I^2t-value. Both parameters are defined for a half-sinusoidal current pulse with a pulse duration T_P = 10 ms [2]. This definition does not, however, take different current waveforms or multi-pulse surges into account.

To perform experiments for a wide range of applications, a wide range of amplitudes, pulse durations and waveforms is required. Well-known standard solutions using passive components (e.g. resonant or capacitor discharge circuits) do not meet these requirements, as they can only realize fixed current waveforms with frequencies and time constants depending on the passive components used.

Alternatives utilizing active switches do exist, but come with their own drawbacks. An example is presented in [3]: A massive parallelization of MOSFETs used as analog amplifiers enables a programmable current waveform, but causes very high losses, which limits pulse duration and repetition rate.

Design of the surge current source

Requirements for the surge current source presented in this article include a freely programmable current waveform with a maximum amplitude beyond typical thyristor maximum peak currents, which can exceed 90 kA, see e.g. [4]. To potentially realize pulse-trains corresponding to multiple grid-frequency periods, pulse widths of several tens of ms are required. Further requirements include high accuracy and a low device under test (DUT) current ripple.

Table 1 lists key parameters of the surge current source. To meet the requirements a modular approach has been chosen: the current source is comprised of 16 cells, each consisting of two IGBT half-bridges, a dc-link capacitor C_{DC} = 9 mF and one output inductor L_{out} = 50 µH per half-bridge. The structure of a cell is depicted in Figure 1, together with its possible output configurations: The cells can be used as two independent half-bridges in high current mode (HCM) or as one full-bridge in dynamic current mode (DCM).

In Figure 2 a photograph of the setup can be seen. Mechanically, the current source is divided in two halves, with 8 cells each. To limit the magnetic forces, the full current is only flowing through the DUT itself. The copper bars connecting eight cells per side to the DUT only carry half the current, reducing the occurring magnetic forces by a factor of four. The copper bars on each side are clamped together with insulating clamps, to withstand the remaining magnetic forces.

Parameter	Range	Notes
maximum DC-link voltage	1200 V	low voltage, (<1500 V DC)
max. IGBT voltage	1700 V	low voltage IGBTs
max. stored energy ΣW_C	104 kJ	-
max. current I_{pk}	100 kA	-
max. current ripple	60 A	equals 0.06 % (at 100 kA)
min. current rise time t_r	380 µs	controller-limit
maximum di_{DUT}/dt	768 A/µs	hardware-limit
	263 A/µs	resulting from t_r (at 100 kA)
pulse width T_p	≈ 1 ms … ≈ 100 ms	min/max width, dependent on waveform, peak current and DUT

Table 1: Key parameters of the surge current source

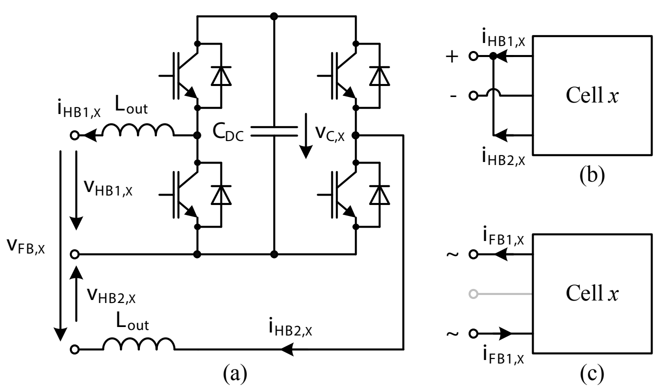

Figure 1: Electrical structure of one of the cells in the surge current tester (a). The cells can be configured in HCM (b) or DCM (c) [1]

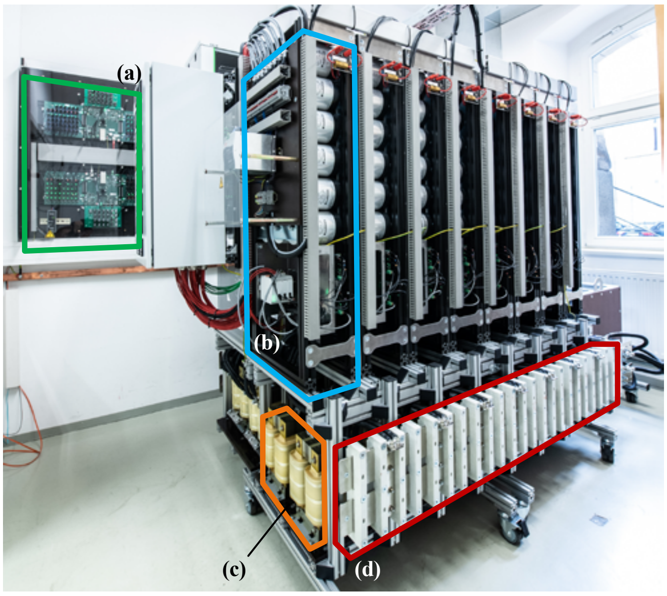

Figure 2: Photograph of the high current source [1]. Highlighted parts are (a) control platform, (b) one of 16 cells, (c) inductors L_{out} and (d) high current bus bars

The control platform, see Figure 2(a), is responsible for communication with the operator's computer and runs the control algorithms. It handles a multitude of signals. This includes measurements: 32x current and 16x dc-link voltage, control signals: 32x enable, 32x PWM, 32x GDU feedback as well as auxiliary signals: 2x arc detection, 4x discharge relays, 16x delta-sigma clock. The half-bridges are switched interleaved with an effective switching and control cycle frequency of 96 kHz. All signals are transmitted using fiber-optics.

Experimental Test Results

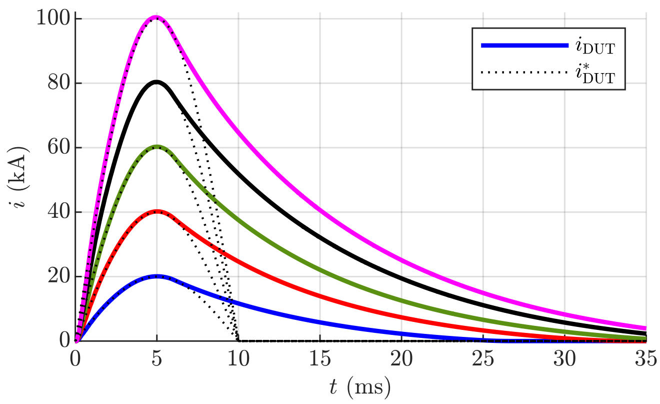

Figure 3: Comparison of current i_{DUT} measured by the control platform and target current trajectory i^*_{DUT}. Short circuit load. HCM

The performance of the surge current tester has been evaluated by a multitude of practical experiments, both in HCM and DCM. Two examples are shown here. In Figure 3 a comparison of half-sine current pulses with different amplitudes can be seen, realized in HCM. Since the cells are configured as half-bridges in HCM, the falling current slope is only determined by the losses in the system. In DCM on the other hand, the cells are configured as full-bridges, which enables negative output voltages and thus a controlled negative di_{DUT}/d_t. As an example Figure 4 shows a waveform resembling the outline of the Frauenkirche in Dresden.

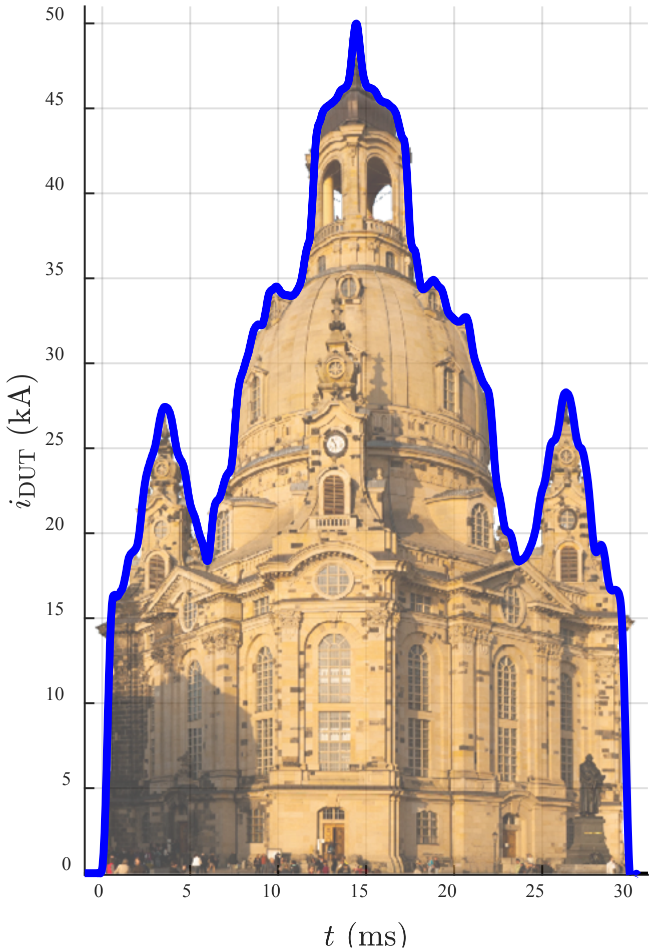

Figure 4: Example of a dynamic current waveform: DUT-current tracing a profile of the Frauenkirche in Dresden [1]. Source of photograph: [5]. Thyristor as load. DCM

Conclusions

This article is a short introduction to the authors' recently built programmable, modular surge current tester. The basic principles and abilities of the current source are described and shown with experimental test results. For further reading see the open access publication "Topology, Design and Characteristics of a Modular, Dynamic 100 kA Surge Current Source with Adjustable Current Shape" [1]. It describes many aspects of the current source's design in more detail.

Sources

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www.tu-dresden.de/et/le

Simplified Calculation of DC-Link Capacitors for Automotive High-Performance xEV power train architecture

A capacitor in the intermediate circuit of the automotive inverter for storing and buffering energy is called DC Link capacitor (outlined in green in Figure 1). The main target of the DC Link capacitor with his capacitance is to absorb sufficiently current ripple generated by the fast switching 3 phase inverter power stage, which is connected to the motor through short cabling or bus bars.

By Dipl.-Ing. Wolfgang Rambow, Rambow-Technology, and Katharina Mankel, R&D, Mankel Engineering

The capacitance is therefore chosen in order to keep the maximum DC-Link voltage ripple under control and at the same time to improve system energy density. These capacitors typically operate at high voltages extending from 400 V_{DC} to 800 V_{DC}. The automotive industry is well known for stipulating components that guarantee outstanding reliability when operating under influence of heavy stress, e.g. at extremely high temperatures, vibration and humidity. It is true, for all inverters, that the DC-Link capacitor, as an A-Component, is key to the design, reliability and, hence, its success. There is a large number of more or less complicated calculation formulas for DC-Link capacitance in PWM (Pulse Width Modulation - Figure 2) modulated inverters of electric cars available. Here we will show a simplified way to quickly find a pragmatic solution.

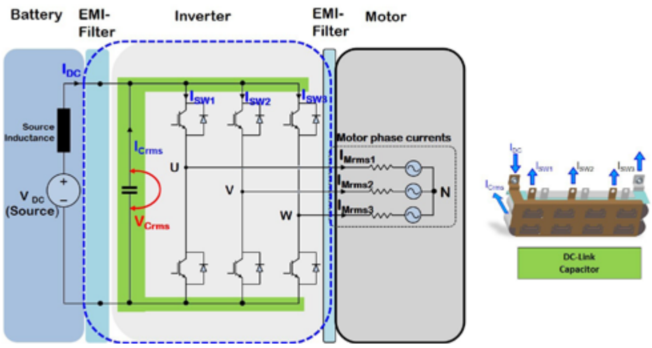


Figure 1: Simplified Power Train Circuit Diagram schematic and a Capacitors currents flow example [Source: Rambow Technology]

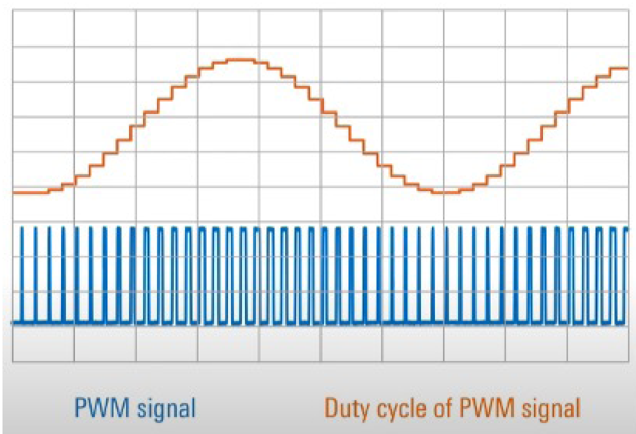


Figure 2: PWM - the duty cycle is being varied in a sinusoidal manner [3 source: Rohde&Schwarz]

In automotive power trains, the DC-Link film capacitor is mounted directly to single switches or semiconductor power module(s) (if B6 or half bridges are used) with very low ESL and ESR values (green colored in Figure 1). The vicinity of the capacitor to the power module is one essential target to minimize stray inductance between the power stage and the capacitor itself.

Applying an overlapping busbar concept keeps the ESL as low as possible while the ESR is determined by the inner construction of the capacitor itself. Even a few nanohenries of stray inductance in the capacitor current path raises the impedance at the switching frequency to levels that negate their effectiveness. Large ripple voltage indicate large ripple current flowing in bulk capacitors and can cause excessive power dissipation in the ESR. Before becoming thermally limiting, the proper selection of a capacitor and its location can have positive effects on the car's EMC robustness. If ripple voltages and corresponding currents kept low, the potential influence to safety relevant systems in the car is drastically reduced too, so that no interference occurs in the vehicle electrical system that could affect other functional modules.

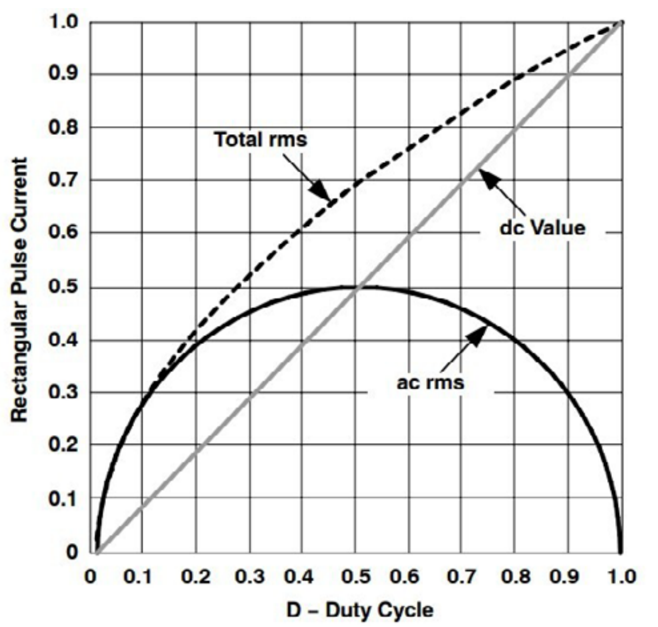


Figure 3: Magnitude drops on either side of 50% [1 Source: Texas Instruments]

As frequency goes up, the battery and cable parasitic source Inductance cause the impedance to increase. The DC-link capacitor impedance goes down so it becomes the preferable path for high frequency AC to circulate - capacitor ripple current (I_{Crms}).

Load current (I_{Mrms}) magnitude and the resulting capacitor ripple current (I_{Crms}), duty cycle (dc or m; in worst-case m=0.5), switching frequency (f) and temperature ($T_{(C)}$) are typical factors which determine the magnitude of the ripple voltage across the capacitors terminals. Since the ripple voltage amplitude is directly proportional to the output load current, the maximum current ripple amplitude occurs at maximum output load, which is not really surprising. The solid curve in figure 3 shows the calculated AC rms ripple amplitude that generates the considered loss in the capacitor. It reaches a maximum at 50% duty cycle. The chart [[1] Source: TI] shows how this magnitude falls off on either side of 50%.

Various types of capacitor constructions can impact the considered capacitance. While classical high capacitive electrolytic capacitors do not play a major role in this application segment, the technology of power film capacitors come into focus – for good reason. Indeed Power film capacitor technology brings certain valuable advantages into designs, including:

- low DF (Dissipation Factor) = low ESR = low losses
- high current ripple current capability
- dry construction = no concern for evaporation
- selfhealing within limits

Some Key Design Considerations for Power Film DCLink Capacitors

Temperature robustness

The maximum hot spot temperature inside of each film capacitor elements is limited to 105°C (for polypropylene film, which is widely used). While the maximum self-heating temperature of the capacitor is 20°C, the heatsink temperature should not exceed 85°C. There are already film materials for 125°C available but cost as well as size makes them unattractive and in practice do not provide a better technological commercial match. Therefore, the cooling situation must be validated. Any excess of the maximum temperature of 105°C inside each of the capacitor elements will cause damage and will significantly reduce its lifetime. You can measure the hot spot temperature in the middle of the capacitors surface, if accessible. The result comes close to the existing temperature inside because most of these DC-Link capacitors are bulky and the temperature rises very slowly compared to semiconductors. Nevertheless, the DC-Link capacitor in automotive Inverter designs must be cooled and mounted on a heatsink. At best, the cooling fluid of a liquid cooled heatsink should pass the capacitor first before cooling the hot semiconductor switches, respecting temperature limits and magnitude of the absolute dissipation in Watts. Another consideration, when selecting a DC-Link capacitor, is the derating as a function of the applied temperature and voltage. Please check the data sheets or ask manufacturer for details.

Other considerations, besides the temperature, that need to be taken into account are humidity, vibration or even (chemical) contamination as already mentioned.

For instance, when including an EMI-Filter system into the inverter [5 MOD.INV/MIB] like TDKs CarXield™, also the filter needs cooling to achieve maximum continuous performance.

Calculating capacitor values

For the capacitor the load caused by the ripple current and the resulting ripple voltage is the first selection criterion. The ripple

$$I_{Crms} = \frac{\sqrt{3}}{\sqrt{2}} * m * \cos\varphi * I_{Mrms} = 1.22 * 0.5 * 0.8 * I_{Mrms} \approx 0.5 * I_{Mrms}$$

current that the capacitor must handle, without overheating by dissipation in the ESR (Equivalent Series Resistance), is often the overriding factor. In most cases, this leads to a capacitance, which is well over the minimum calculations.

Capacitor - Ripple Current I_{Crms}

The AC current flowing through the capacitors ESR causes the heating effect as follow:

Formula 1: Simplified calculation of capacitors rms current (I_{Crms})

Presumptions:

- I_{Mrms} (I_{Phx}) = Motor Phase Current in Ampere
- Cos ~ 0.8 (typical value)
- m = modulation index (worst case mentioned above) = 0.5

Example:

- I_{Mrms} = 250A

➔ I_{Crms} = 1.22 * 0.5 * 0.8 * 250A 0.5 * 250A = 125A

Nevertheless, for 3-phase systems, the following formula match better:

➔ I_{Crms} = 1.3 * I_{Mrms} / 2

Formula 2: Most used simplified calculation of capacitors rms current (I_{Crms})

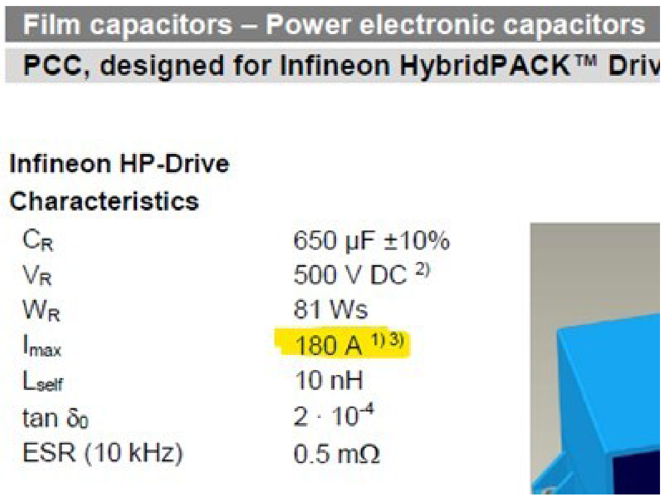


Figure 4: I_{Crms} with temperature restrictions

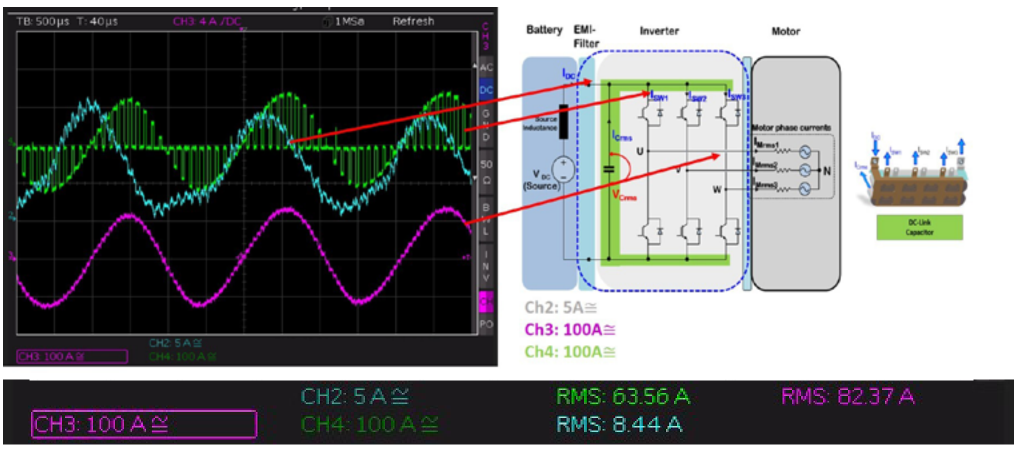


Figure 5: Measurements on an IFX HP-Drive module with a TDK film capacitor [Source: Mankel-Engineering.de]

Example:

➔ I_{Crms} = 1.3 * 250A * 0.5 = 1.3 * 125A = 162,5A

With these rough calculated capacitor ripple current, you can check in the capacitors data sheet (Figure 4), and determine which one may fit to your design to cover this value.

Figure 5 shows the example of a PWM inverter currents measurement.

The currents of **CH2** and **CH4** were each measured with a Rogowski coil and the measurement at **CH3** with an active AC/DC current clamp.

CH2 shows the current drawn from the DC supply, in this case the battery. The current amplitude has the frequency of the output frequency with a superimposed current ripple of the switching frequency. The current ripple depends on the DC link capacitance and the leakage inductance of the supply line.

CH3 shows the phase current with the ripple of the pulse width modulation. The current ripple mainly depends on the load inductance.

CH4 shows the current drawn by the pulse width modulation from the DC link capacitor in a half bridge. The current is driven into the load inductance by the pulse width modulation of the semiconductor switches, as well as the envelope of the output current.

In this case, when a special capacitor for the HP-Drive module is used, only the current per half bridge can be measured due to these specific connection conditions of the capacitor.

Capacitor - Ripple Voltage V_r
Explanation of used values in formulas - (Figure 6 (simplified) and 7).

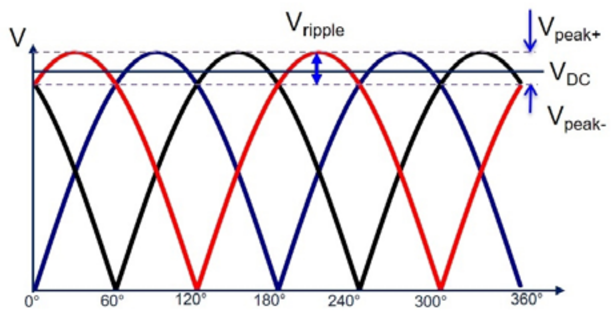


Figure 6: Simplified DC-link voltage switching ripple (Vr)
[4 Source: Rambow-Technology]
Rated Voltage (DC-Voltage) $V_R = V_{DC}$
Maximum Ripple Voltage $V_{ripple} = V_r = V_{pp} = V_{pkpk}$

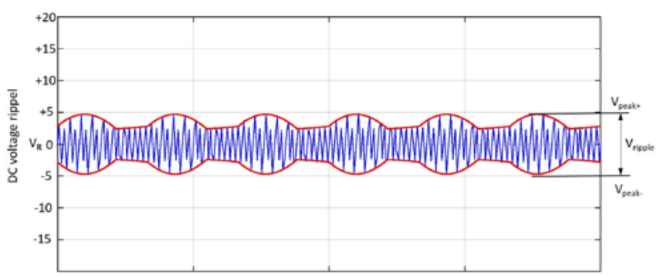


Figure 7: DC-link voltage switching ripple (Vr) - modified curve, results (blue trace) and calculated peak-to-peak Envelope (red trace) over time; m = 0.50
[4 Source: Curve modified by Rambow Technology]

$$V_{Crms} = V_{pk}\ x\ \frac{1}{\sqrt{2}} = V_{pk}\ x\ 0.7071$$

Formula 3: Simplified calculation of the Capacitor ripple voltage

If, for example, the OEM or Tier1 specify the ripple voltage (V_r) as +-12V, the peak voltage (V_{pk}) of the waveform is 12 V, but the ripple voltage is 24V.

V_{Crms} = V_{pk} * 0.7071 = 12V x 0.7071 = 8.48 V

Capacitor - Capacitance
Calculating the capacitance C while stands for the frequency in Hertz (Hz) and for the period duration in seconds (s).

$$f = \frac{1}{\tau} \qquad \omega = 2 * \pi * f$$

Rearranging equations:

$$C * 2 * \pi * f = \frac{I_{Crms}}{V_{ripple}}$$

$$\frac{1}{2 * \pi * f * C} = \frac{V_{ripple}}{I_{Crms}}$$

Equation:

$$C = \frac{I_{Crms}}{2 * \pi * f * V_{rippel}} \text{ uF}$$

Formula 4: Calculate capacitance value - expected to be most realistic!

Example:
V_R or V_{DC} = 400V
f=10kHz (10000Hz)
I_{Crms} = 180A
$V_{peak-peakk}$ = V_{ripple} = 8V
DC=m=0.5

Capacitance can be approximated by:

$$➔ \quad C = \frac{I_{CrmS}}{2 * \pi * f * V_{ripple}} = \frac{180}{2 * 3.14 * 10 * 1000 * 8} = 358\text{uF}$$

Power Dissipation
A DCLink capacitor will experience internal heating, which will increase as the frequency of the ripple current of the semiconductors increases. Based on above sample calculating the power capacitor losses with low ESR - e.g. ~0.5mOhm:

$P_C = I^2_{Crms} * R_{CESR}$

Formula 5: Capacitor Power Dissipation

P_C=180²A * 0.5mOhm = 32400 * 0.0005 = 16.2W

The following capacitance values for a 100kW inverter base on best practice expertise:
650uF for 450V systems ➔ Capacitor 650uF/500Vr
400uF for 800V systems ➔ Capacitor 400uF/855Vr

Do not forget - capacitors total heating and temperature rises depend on the following main factors:
- Self-heating
- DC-current on the bus-bars
- Heat Injection from the semiconductors (tabs)
- Cooling
- Time

Conclusion
Now you have calculated the needed capacitor values provisionally to choose the capacitor, but please keep in mind you are not finished. Measuring and evaluating your results in a final hardware environment of the device will validate your results and looking at the following Issues will help you to prevent unexpected thermal damages.

Issues
More capacitance will not decrease the ripple voltage
Looking to Figure 8 adding more capacitance than needed will not reduce the ripple voltage effectively. The allowable ripple voltage of ~12V will be achieved with ~350uF. A capacitance value between 500uF and 650uF seems to be a good solution handling the capacitor's ripple current. Spending more would not be cost effective.

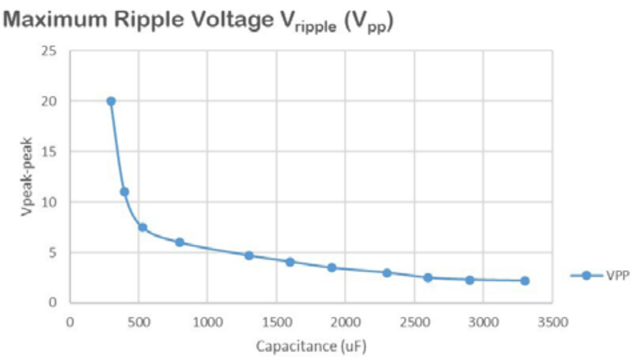


Figure 8: Example - Capacitance values versus ripple voltage [Source: Rambow-Technology]

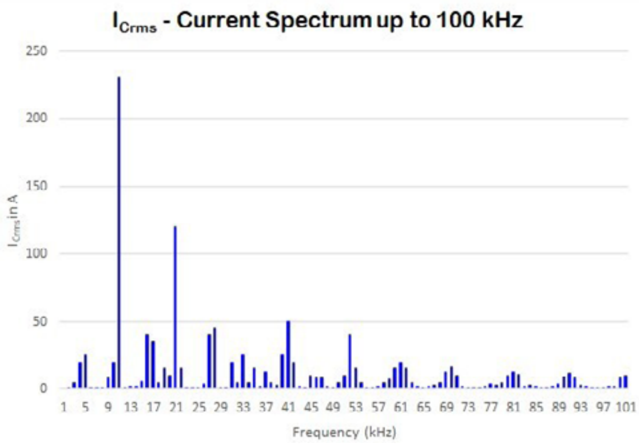


Figure 9: Amplitude of ICrms gaining losses up to 100 kHz [Source: Rambow-Technology]

Resonances causes capacitor losses
Resonance between capacitor and your switching circuitry lead to a wide frequency spectrum. Usually people like to stop measuring at 100 kHz for a 10 kHz inverter – such results are indicated in Figure 9 - which are seemingly good. However, you may be surprised when the capacitor fails "unexpectedly" due to temperature problems. The chart shows an analysis that obviously does not represent the performance of a well-designed inverter.

➔ Consider an extremely wide Frequency spectrum up to the MHz range (Figure 10)

With the use of "High Speed IGBTs" and even more with SiC wide bandgap semiconductors the switching frequency raises to 20 kHz and even more. On top, we have the inherently higher di/dt and dV/dt of these components compared with classical IGBT dedicated for motor control applications. Major losses produced by the semiconductor switching current relay on influence above 100 kHz. Consequently, it does not make any sense to consider an operation bandwidth only up to 100 kHz. At minimum it should cover all the harmonics from the PWM with a magnitude higher than 10% of the total I_{rms} (e.g. 300 kHz or even up to the MHz range).

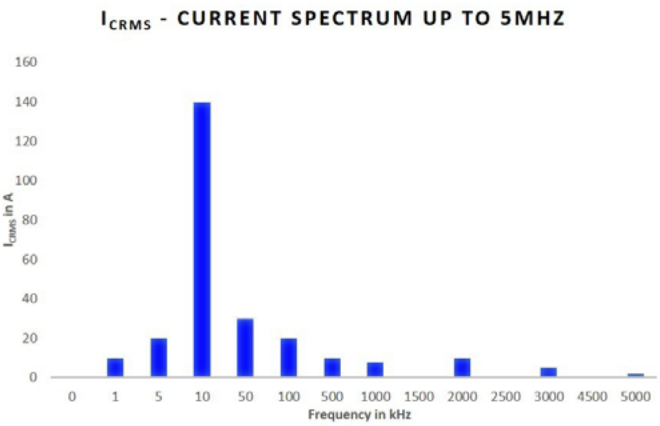


Figure 10: Amplitude of I_{Crms} gaining losses up to 5 MHz [Source: Rambow-Technology]

What is critical here?

Example - looking at the ESR of a power film capacitor and how its losses (ESR) change over frequency:

ESR @10kHz ~ 1 x ESR according the datasheet
ESR@50kHz ~ 2 x ESR@10kHz
ESR@50kHz to 100kHz ~ 4 x ESR@10kHz
ESR@100Khz to 300kHz ~ 6 x ESR@10kHz

The truth is that with above-mentioned ratios the power losses of the DCLink capacitor will increase drastically. Remember:

$P_C = I^2_{Crms} * R_{CESR}$

➔ Capacitors ESR should be low within the entire relevant current spectrum bandwidth.

With some design efforts, the Capacitor manufacturer and you can reduce these effects drastically.

Nevertheless, there are still some other considerations:
- Even if you are experienced, it is not easy to estimate the complete spectrum in advance.
- All the shown harmonics depend on pulse with modulation (PWM) strategy and parameters set by you.
- DCLink capacitor in automotive inverters are strongly affected by the switching semiconductors and their transients plus possible ringing effects with high order harmonics that are difficult to predict.

The selection of a suitable capacitor is physically possible with classic electro technical approaches and requires a precise model of the parasitic of a power stage built with this capacitor. That is a difficult task by nature. However, experience and best practice results can significantly help to shorten design iterations. The in-depth analysis paired with state-of-the-art field results will be part of dedicated seminars like "Elektroauto (xEV) E-Motor + Antriebsumrichter 500V + 800V / IGBT und SiC" by www.mankel-engineering.de.

References
Since this article describes a long-term used product, most formulas and pictures are widely used as standard in lots of publications with no reference.

[1 https://www.ti.com/lit/an/slta055/slta055.pdf]

[² https://www.electronics-tutorials.ws/de]

[³ Rohde&Schwarz Tutorial PWM: https://www.youtube.com/watch?v=nXFoVSN3u-E]

[4 Curve taken from Analysis of dc-Link Voltage Switching Ripple in Three-Phase PWM Inverters Marija Vujacic ID, Manel Hammami ID, Milan Srndovic ID and Gabriele Grandi * ID - page 11]

[5 Modular Inverter - MOD.INV/MIB by MankelEngineering.de ➔ Bodo's Power Systems magazine 10/2022 page 40]

[6source: TDK Data sheet Automotive Power Film Capacitor]

www.rambow-technolgy.com
www.mankel-engineering.de

Rugged 650 V and 1200 V IGBTs

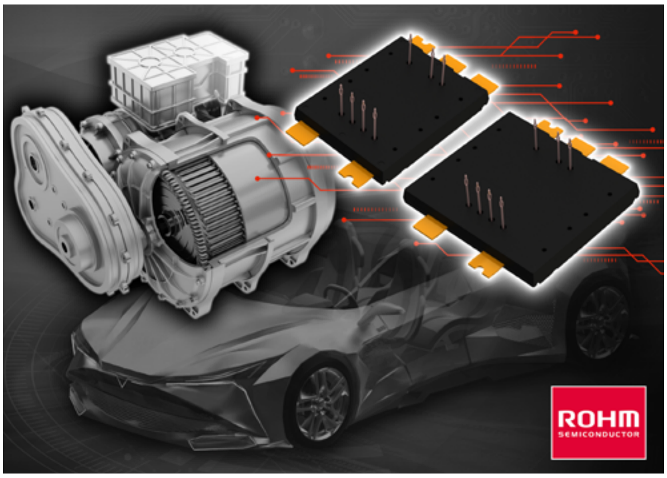
WeEn Semiconductors has introduced IGBTs with voltage ratings of 650 V and 1200 V, which incorporate a fast recovery anti-parallel diode and show "low leakage currents and exceptional conduction and switching characteristics at both high and low junction temperatures", the company says. Based on fine trench gate field-stop (FS)

technology, the IGBTs are said to provide a more uniform electric field within the chip, support higher breakdown voltages and offer improved dynamic control. WeEn claims that the devices offer "optimum trade-off between conduction and switching losses, as well as an enhanced EMI design". The IGBTs offer ratings of 650V/75A, 1200V/40A and 1200V/75A and are supplied in TO247 or TO247-4L packages depending on the selected device. All of the devices will operate with a maximum junction temperature (T_j) of 175 °C and have undergone high-voltage H3TRB (high-humidity, high-temperature and high-voltage reverse bias) and 100%-biased HTRB (high-temperature reverse bias) tests up to this maximum. Target applications include solar inverters, motor control systems, uninterruptible power supplies (UPS) and welding. A positive temperature coefficient simplifies parallel operation in applications where higher performance is required, while options for bare die, discrete and module product variants provide flexibility for a wide variety of target designs.

www.ween-semi.com

2-in-1 SiC Molded Module

Rohm Semiconductor introduced four models as part of the TRCDRIVE pack™ series with 2-in-1 SiC molded modules optimized for electric vehicle traction inverters. TRCDRIVE pack supports up to 300 kW and features high power density and a unique terminal



configuration, helping solve the key challenges of traction inverters in terms of miniaturization, higher efficiency, and fewer person-hours.

A trademark brand for ROHM SiC molded type modules developed specifically for traction inverter drive applications, TRCDRIVE pack reduces size by utilizing a structure that maximizes heat dissipation area. In addition, ROHM's 4th generation SiC MOSFETs with low ON resistance are built in, resulting in a power density 1.5 times higher than that of general SiC molded modules, while contributing to the miniaturization of xEV inverters. The modules are also equipped with control signal terminals using press-fit pins, enabling easy connection by simply pushing the gate driver board from the top, considerably reducing installation time. In addition, low inductance (5.7 nH) is achieved by maximizing the current path and utilizing a two-layer bus-bar structure for the main wiring, contributing to lower losses during switching. Despite developing modules, Rohm has established a mass production system similar to discrete products, making it possible to increase production capacity by 30 times compared to conventional SiC case-type modules.

www.rohm.com

BLDC Motor Hardware-Software Combo

Power Integrations complemented its hardware-software bundle for brushless DC motors (BLDC) with BridgeSwitch™-2, a high-voltage integrated half-bridge (IHB) motor-driver IC family targeting applications up to 1 HP (746 W). The ICs, which feature high- and low-side drivers and advanced FREDFETs with integrated lossless current sensing, deliver inverter efficiency of up to 99 percent. The IHB architecture eliminates hot spots, which increases design flexibility and reliability, slashes component count and saves PCB area. BridgeSwitch-2 is supported by Power Integrations' MotorXpert™ software suite which includes single-phase trapezoidal control and three-phase sensor-less Field Oriented Control (FOC) modules, speeding inverter development. BridgeSwitch-2 ICs handle operational exceptions in hardware, which permits the use of IEC 60730 Class A safety software, reducing certification time by months. Quiescent BLDC inverters can be ordered into sleep-mode, reducing driver power consumption to less than 10 mW; this leaves more power available under regulated standby power limits to be allocated for loads such as network access and monitoring. The IHB architecture reduces component count by 50 percent and PCB space

by 30 percent over discrete designs by eliminating shunt resistors and associated signal conditioning circuits. Shunt losses are also eliminated, improving efficiency. Precise motor control is achieved with the built-in real-time reporting of phase current (IPH) information. Accurate turn-on/off gate drive and a soft-body diode result in a typical EMI profile 10 dB lower than existing drivers, so a smaller EMI filter can be selected.

www.power.com

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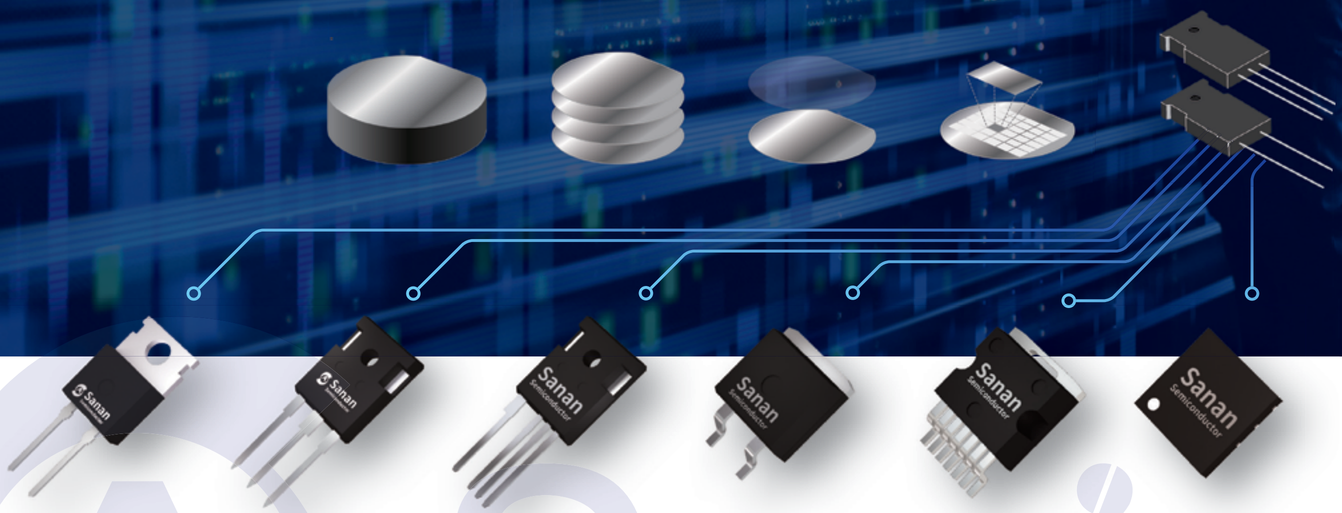

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700 V GaN Power Transistors

Infineon introduces the CoolGaN™ Transistor 700 V G4 product family. The devices are intended for power conversion in the voltage range up to 700 V. In contrast to other GaN products on the market, the input and output figures-of-merit of these transistors are claimed to "provide a 20 percent better performance, resulting in increased efficiency, reduced power losses, and more cost-effective solutions". The combination of electrical characteristics and packaging allows the usage in applications such as consumer chargers and notebook adapters, data center power supplies, renewable energy inverters, and battery storage.

The product series comprises 13 devices with a voltage rating of 700 V and on-resistance range from 20 mΩ to 315 mΩ. The increased granularity in device specification, combined with several industry standard package options including PDFN, TOLL and TOLT allow R_{DS} resistance and packages to be selected according to application requirements.

The devices are "characterized by a fast turn-on and turn-off speed and minimal switching losses". The on-resistance range enables power systems from 20 W to 25,000 W. In addition, the 700 V E-mode with a transient voltage of 850 V increases

the reliability of the overall system as it offers greater robustness against anomalies in the user environment such as voltage peaks.

www.infineon.com

Combination of Silicon Trench and SiC MOSFETs

As data centers become increasingly power-hungry to support the tremendous processing requirements of AI workloads, the need for boosting energy efficiency is paramount. The combination of Onsemi's latest generation T10 PowerTrench® family and EliteSiC

650V MOSFETs create a solution that offers high efficiency and high thermal performance in a smaller footprint for data center applications. Using the T10 PowerTrench family and EliteSiC 650V solution, data centers are able to reduce power losses that occur by an estimated 1%. If implemented in data centers globally, the solution could reduce energy consumption by 10 TWh annually or the equivalent of the energy required to fully power nearly one million homes per year. The $R_{DS(on)}$ is less than 1 Milliohm. The T10 PowerTrench Family also meets the stringent standards required for automotive applications. The combined solution also meets the stringent Open Rack V3 (ORV3) base specification required by hyperscale operators to support the next generation of high-power processors.

www.onsemi.com

Complete Design for an On-Board Charger Solution

Microchip Technology has announced an On-Board Charger (OBC) solution that uses a selection of its automotive-qualified digital, analog, connectivity and power devices, including the dsPIC33C Digital Signal Controller (DSC), the MCP14C1 isolated SiC gate driver and mSiC™ MOSFETs in an industry-standard D2PAK-7L XL package. This solution is designed to increase an OBC system's efficiency and reliability. To further simplify the supply chain for customers, the company provides the key technologies that support the other functions of an OBC, including communication interfaces, security, sensors, memory and timing. To accelerate system development and testing, Microchip offers a flexible programmable solution with ready-to-use software modules for Power Factor Correction (PFC), DC/DC conversion, communication and diagnostic algorithms. The software modules in the dsPIC33 DSC are designed to optimize performance, efficiency and reliability, while offering flexibility for customization and adaptation to specific OEM requirements. The dsPIC33C DSC and the MCP14C1 isolated SiC gate driver are

AEC-Q100 qualified, and the mSiC MOSFET is AEC-Q101-qualified. The dsPIC33C DSC is an AUTOSAR-ready device and is supported by the MPLAB® development ecosystem including MPLAB PowerSmart Development Suite.

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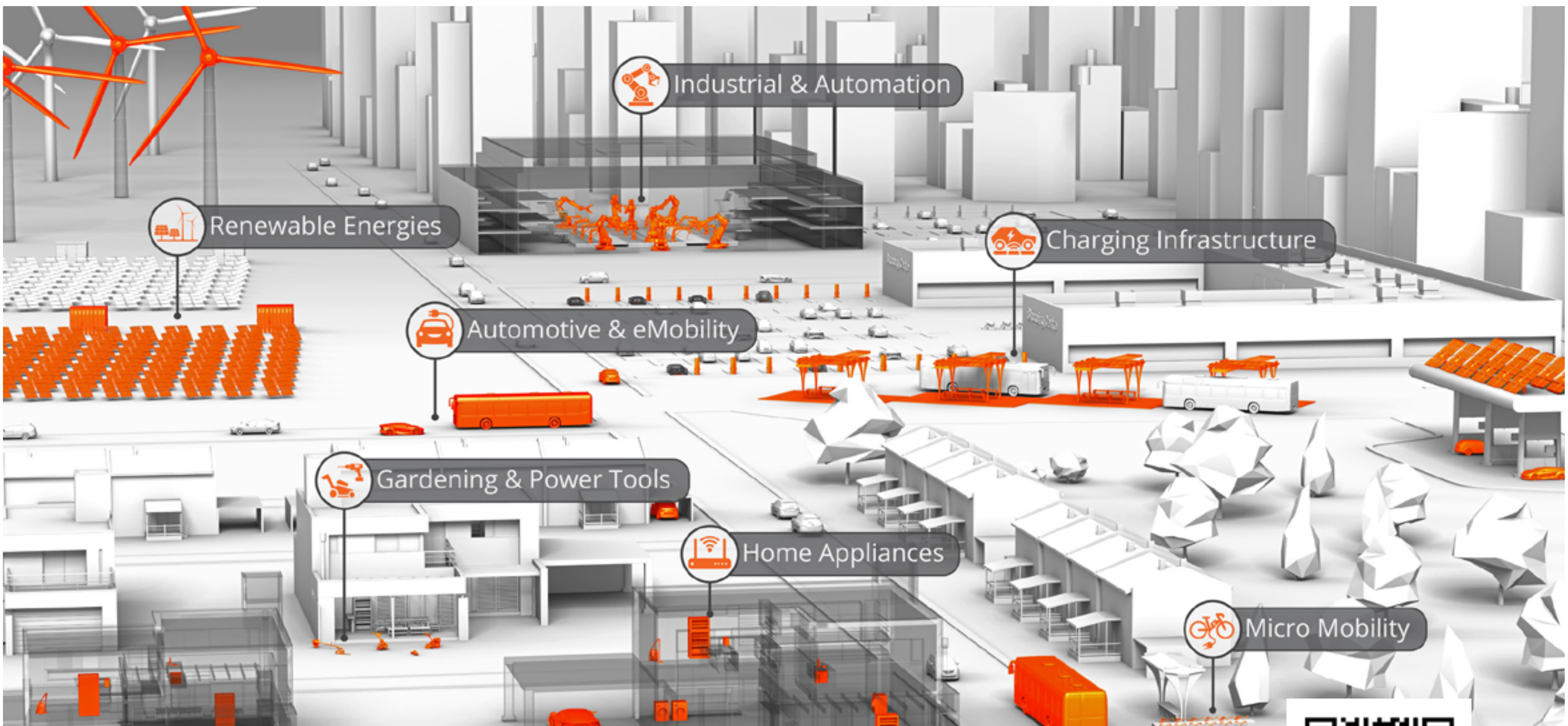

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