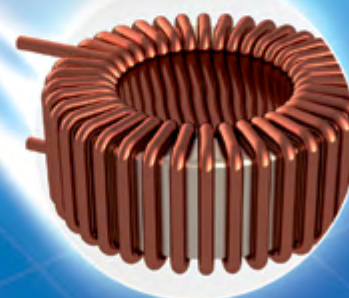


Bodo's Power Systems®

Electronics in Motion and Conversion

December 2021



**PULSED INDUCTANCE MEASUREMENT
ON MAGNETIC COMPONENTS FROM 0.1A TO 10KA**



POWER CHOKE TESTER DPG10/20 SERIES

Inductance measurement from 0.1 A to 10 kA

KEY FEATURES

Measurement of the

- Incremental inductance $L_{inc}(i)$ and $L_{inc}(fUdt)$
- Secant inductance $L_{sec}(i)$ and $L_{sec}(fUdt)$
- Flux linkage $\psi(i)$
- Magnetic co-energy $W_{co}(i)$
- Flux density $B(i)$
- DC resistance

Also suitable for 3-phase inductors

APPLICATIONS

Suitable for all inductive components from small SMD inductors to very large power reactors in the MVA range

- Development, research and quality inspection
- Routine tests of small batch series and mass production

KEY BENEFITS

- Very easy and fast measurement
- Lightweight, small and affordable price-point despite of the high measuring current up to 10000A
- High sample rate and very wide pulse width range => suitable for all core materials

AVAILABLE MODELS

Model	max. test current	max. pulse energy
DPG10-100B	0.1 to 100A	1350J
DPG10-1000B	1 to 1000A	1350J
DPG10-1500B	1 to 1500A	1350J
DPG10-1500B/E	1 to 1500A	2750J
DPG10-3000B/E	3 to 3000A	2750J
DPG10-4000B/F	4 to 4000A	7700J
DPG20-10000B/G	10 to 10000A	15000J

Season's Greetings

From all of us at Electronic Concepts Inc.



Contact ECI Today! sales@ecicaps.com | sales@ecicaps.ie

www.ecicaps.com

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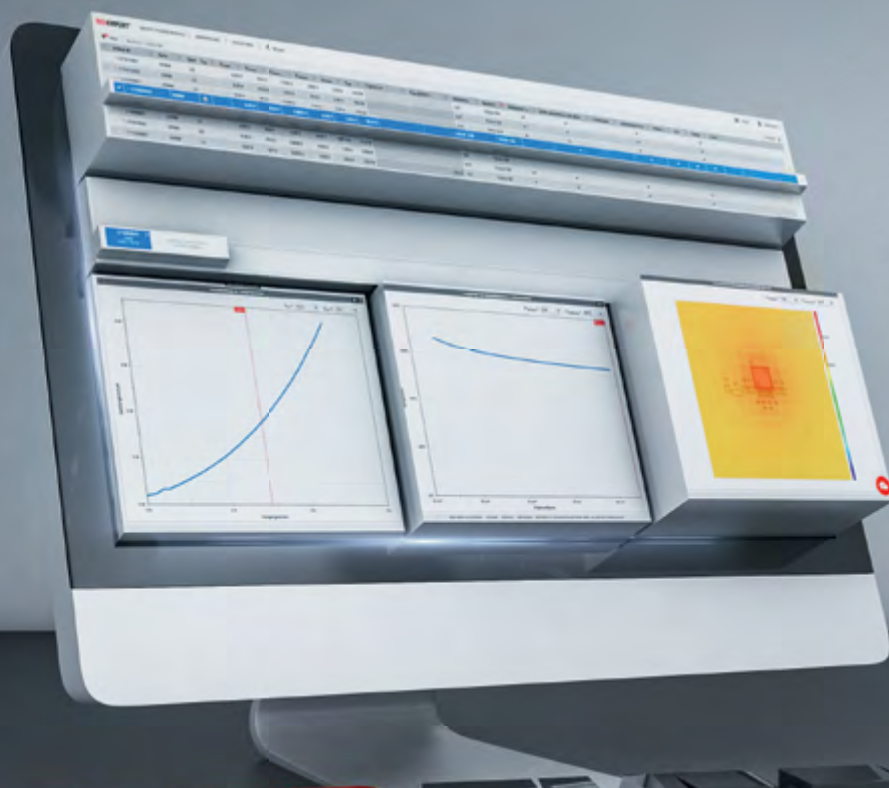
Merry Christmas and
a Happy New Year

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PULSED INDUCTANCE MEASUREMENT

SIMULATION OF THERMAL DISSIPATION ON PCB FOR POWER MODULES



RED EXPERT

RED EXPERT. Würth Elektronik's online platform for simple component selection and performance simulation.

- Simulation of Thermal Dissipation on PCB for Power Modules
- The world's most accurate AC loss model
- Filter settings for over 20 electrical and mechanical parameters
- Inductor simulation and selection for DC/DC converters
- Ability to compare inductance/current and temperature rise/DC current using interactive measurement curves
- Available in seven languages
- Online platform based on measured values
- Order free samples directly
- Direct access to product datasheets
- Comfortable and clear component selection

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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
Kurfürstenstraße 4 - 6
64546 Mörfelden-Walldorf
Germany

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Continuity Counts

The second pandemic year will end soon, and we hope you have the opportunity to end the year in a contemplative way and with your loved ones. Unfortunately, Covid still dominates many areas of our lives, and this will continue for some time. In such times it is even more important to experience continuity! Even if it is only in the form of a monthly magazine discussing power electronics. We would like to take this opportunity to thank all of our partners who made it possible for us to deliver the magazine on time, every month throughout 2021. And we are deeply grateful and happy to say that this will continue during 2022. This is not always straightforward in these times when raw material is becoming permanently more expensive and postal providers are raising prices almost arbitrarily as they please!

At the end of the year, it is important to rest and remember the friends who are no longer with us. To represent all those we have lost, let us name the following two colleagues: Dr. Artur Seibt died in early 2021. He contributed a number of articles over the years, and Bodo and Artur had a great friendship going back to Bodo's days working for Harris. Dr. Ray Ridley informed us that Sanjaya Maniktala, a respected expert in the area of power conversion, passed in February. Let us all take a few minutes to rest and remember those who have crossed our paths in the past. We must face the fact that we are all getting older and so are our friends in industry. It is good to see young engineers filling the positions and helping to show continuity!

As in the past couple of years, we will make a donation, instead of sending gifts and cards for Christmas. The postal service has become very expensive and the feedback we received motivates us to continue this tradition. We have chosen UNICEF again; as it is a global organization that fights for the rights and wellbeing of children. We are sure, that this is a worthy investment.



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 in North America. If you are using any kind of tablet or smart phone, you will find all of our content on the website www.eepower.com. If you speak the language, or just want to have a look, don't miss our Chinese version: www.bodospowerchina.com

My Green Power Tip for the Month:

We all love the festive lights in our homes at Christmas. Nevertheless, we should act with a sense of proportion. How much does it really need? Less is often more!

Kind regards

Events

LpS 2021

Online December 2
www.led-professional-symposium.com

DAC 2021

San Francisco, CA, USA
December 5 - 10 & Online
www.dac.com

E|DPC 2021

Online December 7 - 9
www.edpc.eu

SEMICON Japan 2021

Tokyo, Japan
December 15 - 17 & Online
www.semiconjapan.org

NEPCON 2022

Tokyo, Japan January 19 - 21
www.nepconjapan.jp

CWIEME Shanghai 2022

Shanghai, China March 7 - 9
www.coilwindingexpo.cn

CIPS 2022

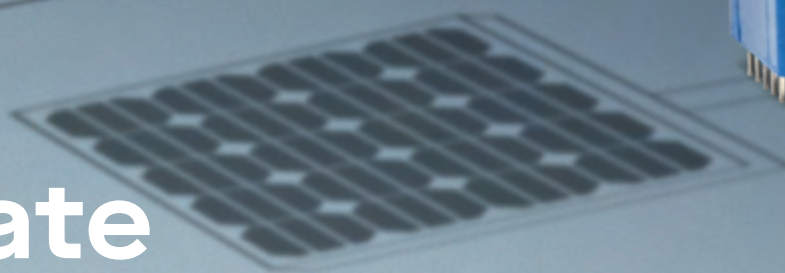
Berlin, Germany March 15 - 17
www.cips.eu

emv 2022

Cologne, Germany March 15 - 17
<https://emv.mesago.com>

APEC 2022

Houston, TX, USA March 20 - 24
www.apec-conf.org



Accurate everywhere

LXS, LXSR, LES, LESR, LKSR, LPSR series

New closed-loop current transducers, based on a custom Hall Effect LEM ASIC, perform at the level of fluxgate transducers, achieving the highest levels of quality and traceability using advanced manufacturing techniques. Offset drift is over four times lower than the previous generation of closed-loop transducers based on Hall cells and very similar to those using fluxgate. There are 6 families and 22 models available with various options, such as an integrated reference (V_{REF}), footprint (3 or 4 primary pins with different layouts), with an aperture and/or with integrated primary conductors and overcurrent detection.

www.lem.com

- 1.5 to 50 A nominal current
- PCB mounting
- Low offset drift (3 – 14 ppm/°C)
- Overcurrent detection output (LPSR models)
- -40 to +105°C operation
- 100 % compatible with previous LEM generation
- Multi-range configuration

LEM

Life Energy Motion

Joint Venture in SiC Power Module Business

Zhenghai Group and ROHM have signed a joint venture agreement to establish a new company in the power module business. The company, "HAIMOSIC (SHANGHAI) CO.,LTD." is scheduled to be established in China in December 2021, and will be owned 80% by Shanghai Zhenghai Semiconductor Technology Co., Ltd. (Zhenghai Semiconductor) of Zhenghai Group and 20% by ROHM. The company will engage in the joint venture business of development, design, manufacturing and sales of power modules using silicon carbide (SiC) power devices, with the aim of developing a power module business that is ideal for traction inverters and other applications in new energy vehicles. The agreement enables to develop highly efficient power modules by combining the inverter technology of the Zhenghai Group companies, the module technology of both companies, and ROHM's cutting-edge SiC chips. The module products to be developed through the new company are already scheduled to be used in electric vehicles, and mass production will begin from 2022. The Zhenghai Group and ROHM will work closely with this new company to contribute to further technological innovation through the development and widespread use of SiC power modules.

Isao Matsumoto, President and CEO of ROHM: "We are very pleased to establish a joint venture with the Zhenghai Group, which has a wide range of business-



es in China. As a leading company in SiC power devices, ROHM has been developing the world's most advanced devices and providing power solutions together with peripheral components. The development of power modules in the new company will encourage the use of SiC power devices in new energy vehicles, which are gaining momentum in China, as well as play an important role in other application research. Through the business of the new company with Zhenghai Group, we will aim for the further development and evolution of both companies."

www.rohm.com

Hitachi Energy Goes Live

Speaking from its global headquarters in Zurich, Switzerland, Claudio Facchin, CEO of Hitachi Energy, commented, "At Hitachi Energy, we are championing the urgency of a clean energy transition, through innovation and collaboration. There are many pathways towards a carbon-neutral future – to tackle this global challenge, we nurture diverse global teams bringing authentic passion and enduring ownership." He continued, "By 2050, global electrification will near-double in demand and electricity will be the backbone of the entire energy system. At Hitachi Energy we have pioneered many of the technologies needed for advancing a sustainable energy future for all – and we are committed to continue pushing the boundaries of innovation. Delivering on the promise of a carbon-neutral future will take passion, trust and innovation – and the benefits will be for our generations and those to come. With our new name – Hitachi Energy – we are broadening our commitment to creating real impact for our customers and partners, our people and society." Hitachi Energy is fostering collaboration with customers and partners to find global solutions to solve the global challenge of an inclusive and equitable carbon-neutral future. Earlier this year, the business launched EconIQ™ – its eco-efficient portfolio which delivers a superior environmental performance compared to conventional solutions. Its EconIQ high-voltage offering is



proven to significantly reduce the carbon footprint throughout the total life-cycle. The business also recently launched a portfolio of transformer products for offshore floating applications, designed to overcome the challenging offshore environment and efficiently harvest and integrate wind into the global energy system, directly supporting the transition to a sustainable energy future.

www.hitachienergy.com

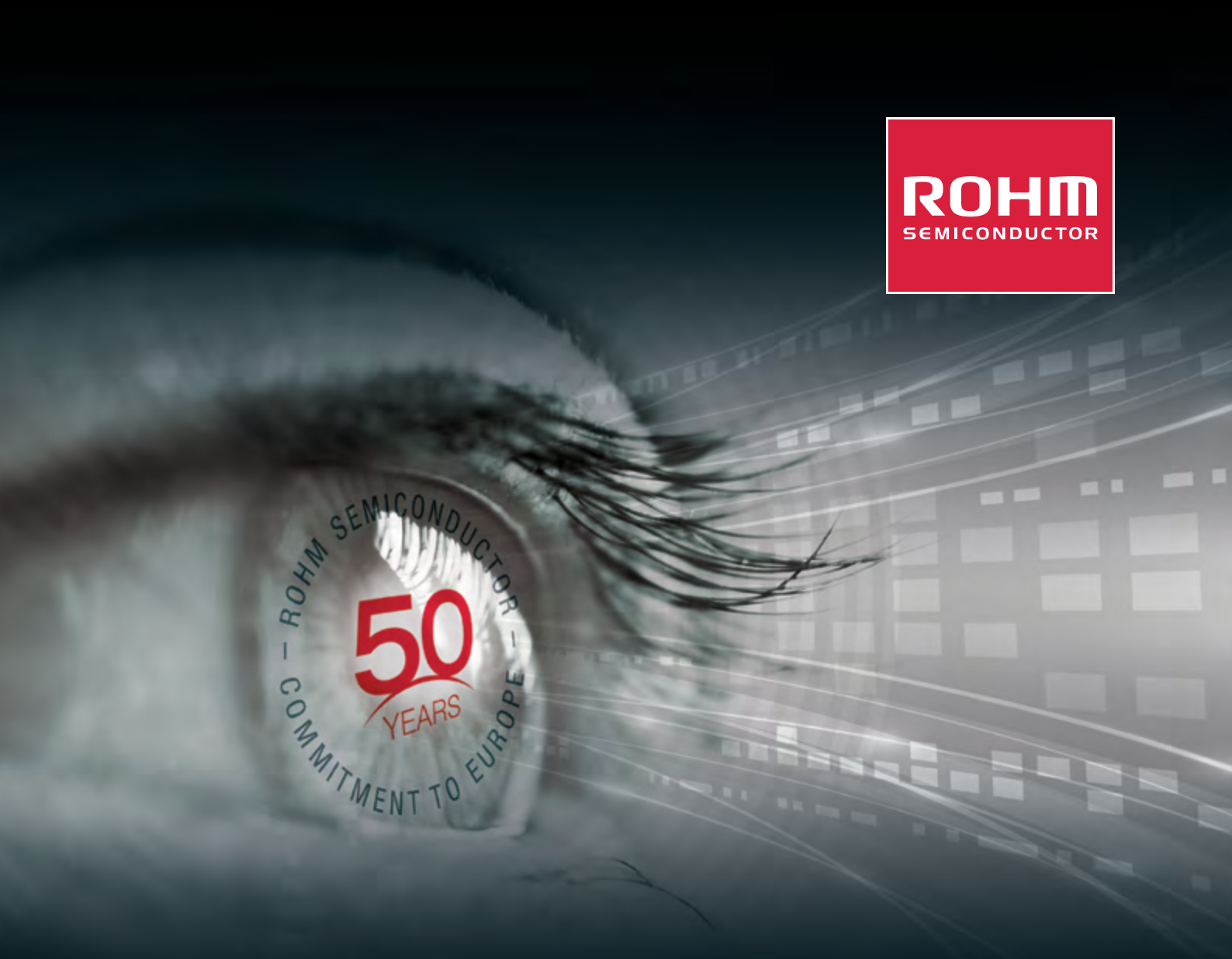
Expanding Wide Bandgap Semiconductor Offering

Nexperia announced its entry into the high-power Silicon Carbide (SiC) diodes market with the introduction of 650 V, 10 A SiC Schottky diodes. This is a strategic move for Nexperia, already a trusted supplier of efficient power Gallium Nitride (GaN) FETs, to expand its high-voltage wide bandgap semiconductor device offering. In an increasingly energy-conscious world, there is a burgeoning demand for high power applications with superior efficiency and power-density. In this regard, Silicon is fast approaching its physical limits. According to Mark Roeloffzen, General Manager of the Bipolar Discretes Group at Nexperia "Wide bandgap semiconductors like Gallium Nitride and Silicon Carbide are now well placed to meet the stringent needs of high-volume applications, bringing the promise of higher efficiency, greater power density, lower system cost and reduced operating costs for original equipment manufacturers. Nexperia's diverse portfolio of SiC diodes will bring greater choice and availability to this market." Nexperia's first SiC Schottky diode is an industrial-grade device with 650 V repetitive peak reverse volt-



age (VRRM) and 10 A continuous forward current (IF), designed to combine ultra-high performance and high efficiency with low energy loss in power conversion applications. Providing the added benefit of a high-voltage compliant real 2-pin (R2P) package with higher creepage distance, it is available in a choice of surface mount (DPAK R2P and D2PAK R2P) or through-hole (TO-220-2, TO-247-2) devices.

www.nexperia.com



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SEMICONDUCTOR

ROHM IN EUROPE: **WE SHAPE INNOVATIONS FOR THE FUTURE**

Our past experience paves the way for your future innovations. Since 1971, we have been assisting our customers all over Europe with our strong competence in analog and power technologies. ROHM's experts enable you to realize your product ideas: based on market insights and our broad portfolio, we individually support you from start to finish, from choosing the best product to the final design-in phase. With decades of expertise, we are a valuable partner in the automotive and industrial sectors. Thank you for your trust during all those years!

www.rohm.com



Qorvo Acquires United Silicon Carbide (UnitedSiC)

The acquisition of United Silicon Carbide expands Qorvo's reach into the fast-growing markets for electric vehicles (EVs), industrial power, circuit protection, renewables and data center power. United Silicon Carbide will become part of Qorvo's Infrastructure & Defense Products (IDP) business and will be led by Dr. Chris Dries, who was formerly United Silicon Carbide's president and CEO and is now general manager of Qorvo's Power Device Solutions.

Philip Chesley, president of Qorvo IDP, said, "The addition of United Silicon Carbide to our IDP business significantly expands our market opportunities in high-power applications. This acquisition enables Qorvo to deliver high-value, best-in-class intelligent power solutions covering power conversion, motion control and circuit protection applications."

Dr. Dries said, "Our team is thrilled to expand our SiC portfolio as part of Qorvo and continue to build the business with speed and scale, working to accelerate SiC adoption with the industry's highest performance devices. Our SiC technology, together with Qorvo's complementary Programmable Power Management products and world-class supply chain capabilities, enable us to deliver superior levels of power efficiency in advanced applications."

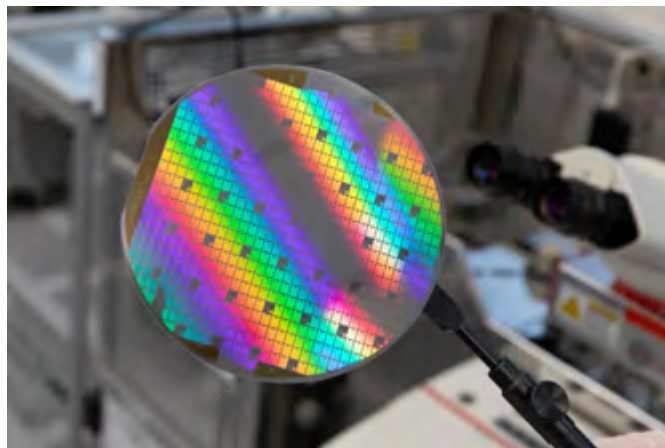


United Silicon Carbide's product portfolio now spans more than 80 SiC FETs, JFETs and Schottky diode devices. Based on a unique cascode configuration, the recently announced Generation 4 SiC FETs are specified at an industry-leading 750V at 5.9 milliohm RDS(on), enabling new levels of SiC efficiency and performance critical for EV chargers, DC-DC converters and traction drives, as well as telecom/server power supplies, variable speed motor drives and solar photovoltaic (PV) inverters.

www.unitedsic.com
www.qorvo.com

Consortium to Create European Supply Chain for SiC Semiconductors

Many of today's key projects focus on the same objective: to improve energy efficiency and thereby protect the environment. These projects are typically in areas such as electromobility, renew-



able energy, and edge and cloud computing – including the requisite data centers. Experts agree that silicon carbide (SiC) semiconductors and the electronic components containing them will ensure the most efficient use of the electricity at our disposal. The object of the publicly funded "Transform" project (trusted European SiC value chain for a greener economy) is to establish a resilient European supply chain for this technology, ranging from wafers and other basic materials right up to finished SiC power semiconductor devices and power electronic applications. In a consortium led by Bosch, a total of 34 companies, universities, and research institutes from seven European countries have joined forces to work toward this goal. "The aim of the Transform project is to secure a leading role for Europe in new technologies based on silicon carbide," says Jens Fabrowsky, who holds the position of executive vice-president in the Bosch Automotive Electronics division. Scheduled to run until 2024, the publicly funded project is focusing on five use cases in the automotive, industry, renewable energy, and agriculture sectors.

www.bosch-presse.de

PSMA White Paper - Energy Harvesting for a Green Internet of Things

PSMA has announced the availability of a White Paper entitled "Energy Harvesting for a Green Internet of Things." This seminal work is the result of a multi-month effort by a dedicated team of 28 international experts from a variety of backgrounds in academia and industry, led by Dr. Michalis Kiziroglou from Imperial College London and Dr. Thomas Becker of Thobecore Germany. The PSMA Energy Harvesting Technical Committee supported this work and is responsible for making the White Paper available.

The ubiquitous nature of energy autonomous microsystems, which are easy to install and simple to connect to a network, make them attractive in the rapidly grow-



ing Internet of Things (IoT) ecosystem. The growing energy consumption of the IoT infrastructure is becoming more and more visible and impactful. Energy harvesting describes the conversion of ambient energy into electricity, enabling green power supply of IoT key components such as autonomous sensor nodes. Energy harvesting could lead to a lower CO2 footprint of future IoT devices by adapting environmentally-friendly materials and reducing cabling and primary battery usage. The paper is available at no cost on the PSMA website Energy Harvesting Technical Forum at <https://www.psmacom/technical-forums/energy-harvesting/whitepaper>.

www.psmacom



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Power Device Division's new Power Electronics Research Laboratory is now open!

We are excited to announce the launch of Power Device Division's new testing lab based in Bracknell, UK. We have recently relocated our testing lab to a large premise, allowing us to expand our research and testing capabilities.

The launch of the new laboratory is an exciting time for us. We supply a range of testing, which offers a comprehensive suite of services for semiconductors; this can be used to investigate anything from power module fault analysis to customer application specific conditions. We can help our clients with designing in and problem-solving for the full range of our power modules (750 V to 6.5 kV), through various tests such as; Double Pulse testing, Short circuit conditions, Paralleled power modules testing and Gate Driver Performance.



IWIPP 2022 Update and Call for Papers

The International Workshop on Integrated Power Packaging (IWIPP) is a workshop focused on Power Packaging Technology which will be held August 24-26th, on the campus of Aalborg University, in Aalborg, Denmark. The contents of IWIPP 2022 will include 6 key-note addresses from leading power technology experts and a broad range of technical sessions, all of which are included in the registration fee. Packaging and related technologies are the key to creating high-density power sources. Attendance at this important workshop can keep you and your colleagues on the cutting edge of power packaging technology. If you have technology advancements or research accomplishments to present to the community, Technical Chairman Nick Baker, Assistant Professor, Aalborg University, invites you to submit a digest for review by the technical committee. The call for papers is available at now, the submission portal of the website is open and accepting submissions.

<http://iwipp.org>



Collaboration to Improve Performance of EV Inverter Assemblies

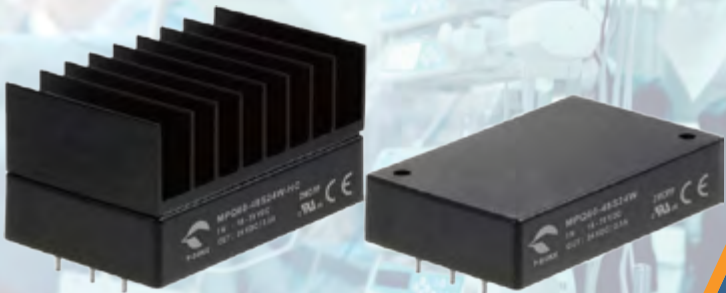
MacDermid Alpha Electronics Solutions has announced a cooperation with STMicroelectronics on a key sinter technology for Electric Vehicle inverter assemblies, designed to significantly increase vehicle efficiency and range, and lower production costs. Sinter technology is changing EV inverter assembly with pressure sintering providing a significantly lower thermal resistance, superior power cycling and mechanical reliability over conventional techniques. ST is offering its STPAK™ package for automotive traction inverters for assembly directly onto the heatsinks through sintering using ALPHA® Argomax® silver sinter paste. The ALPHA Argomax sinter paste, formulated using highly engineered silver particles,

has been specially developed for low-pressure sinter die and package attachment. The paste creates a strong attachment through silver metallic bonds, offering physical strength, unsurpassed electrical conductivity and optimal thermal properties resulting in long-term reliability improvement. "The collaboration between ST and MacDermid Alpha to develop and refine advanced sintering technology has been extremely effective in producing the perfect combination – STPAK package sintered with ALPHA Argomax", said Edoardo Merli, Power Transistor Macro-Division General Manager and Group Vice President of STMicroelectronics Automotive and Discrete Group.



"This unique attach process provides an unparalleled level of flexibility, reducing the overall number of power discretes needed and enabling significant cost savings", said Julien Joguet, Director of Marketing – Power Electronics at MacDermid Alpha. "ALPHA Argomax sinter package and die attach technology, which has already been deployed in more than 2 million electric vehicles, enables manufacturers to produce efficient and reliable electric vehicle powertrains, a key factor in the wider adoption of electric vehicles"

www.macdermidalpha.com



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Medical


Industry

UL US
CB Scheme
CE
UK CA

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- Leakage current < 4.5µA
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- Tiny quarter brick package
- 4:1 input voltage range


92.5% Eff.


-40°C
105°C


5000 M Altitude


5000 VAC Isolation


5 Year Warranty






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TRAIN



High Power next Core (HPnC)

with Fuji Electric's X series - 7G IGBT



MAIN FEATURES

▶ Latest chip technology

- Fuji Electric's X series IGBT and FWD with low losses

▶ High reliability

- CTI>600 for higher anti-tracking
- High thermal cycling capability with ultra sonic welded terminals and MgSiC base plate
- Improvement of delta T_j power cycle capability by using 7G Package Technology

▶ RoHS compliance

- Ultrasonic welded terminals
- RoHS compliant solder material

▶ Over temperature protection

- Thermal sensor installed

▶ Easy paralleling

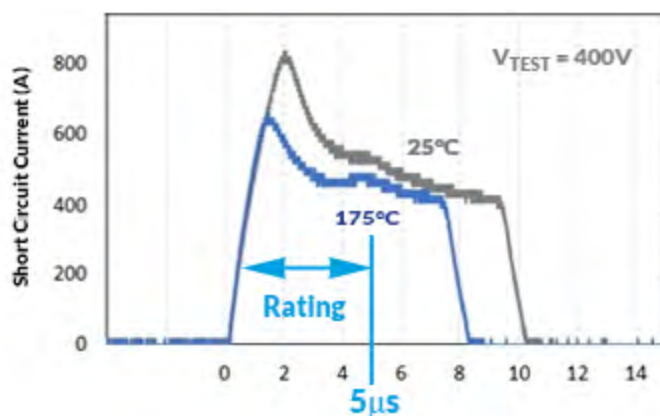
- HPnC module has a minimized current imbalance
- Easy scalability

750V Gen 4 SiC FETs Deliver Performance and Design Flexibility



UJ4SC075006K4S 6mΩ $R_{DS(on)}$ with lowest SCWT rating of 5μs

UnitedSiC has responded to power designers' requests for higher-performance, higher-efficient SiC FETs with the announcement of the industry's best 750V, 6mohm device. At a $R_{DS(on)}$ value of less than half the nearest SiC MOSFET competitor, the new 6mohm device also provides a robust short-circuit withstand time rating of 5μs. With 13 different $R_{DS(on)}$ and package combinations ranging from 6mΩ to 60mΩ, the 750V Gen 4 UJ4C/SC series of SiC FETs (info.unitedsic.com/gen4) provides designers with the industry's best performance and most device options, enabling more design flexibility to achieve an optimum cost/efficiency trade-off while maintaining generous design margins and circuit robustness.



Design Resources



FET-Jet Calculator

Get started evaluating and identifying the optimal SiC FET for your next high-performance power design (info.unitedsic.com/fet-jet).



SiC FET User Guide

Practical solutions and guidelines for using RC snubbers with fast switching SiC devices (unitedsic.com/sic-fet-ug).

www.unitedsic.com



*It's not you, Mark.
I just need
more space.*



WOW!

THIN, POWERFUL AND FREES UP SPACE.

Shrink your device with ultra low profile capacitance.
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or contact us at (864) 843-2277.



**CORNELL
DUBILIER**

Sanitary Switches



Switches that disinfect themselves. Sound too good to be true? Well, it is possible. Antimicrobial coatings inhibit the growth of microorganisms and even kill them. Perfectly suited for medical technology, publicly used sanitation areas, and the food service industry.

Antimicrobial? What does this mean? Antiviral and antibacterial are familiar to most of us. They fight viruses and bacteria, respectively. Consequently, antimicrobial stands for microbes. Microbes or microorganisms include bacteria, many fungi and spores, microscopic algae and protozoa. Viruses are also usually included, although these are not living organisms in the true sense of the word (they have no metabolism of their own).

Antimicrobial substances

Antimicrobial substances are substances that inhibit the growth of microorganisms or even kill them. This approach is not new, and consequently various solutions coexist on the market. All disinfectants, for example, are classified as antimicrobial substances. However, there are also high-tech surface structures that have an antimicrobial effect through the disinfecting action of silver and copper or by means of nanostructures made of titanium dioxide.

Photodynamic self purification

The principle of photodynamics is based on the excitation of a photocatalyst by means of light waves from the visible spectral range (400 - 700 nm). The transfer of energy to the ambient oxygen produces what is known as singlet oxygen (1O_2). This particularly reactive oxygen species effectively kills microorganisms by oxidation.

Fight the smear infections

A large number of infectious diseases is transmitted via contaminated surfaces. This is called smear infection. Antimicrobial coat-

ings, varnishes and paints can be applied to countless surfaces. They are therefore ideal for facilities where high and the highest standards of hygiene are required: Hospitals, the food industry, schools and kindergartens, or even retirement homes. Depending on the particular pathogen, microorganisms can remain active for up to 16 months: on the door handle, in public transport, on the computer keyboard or at the automatic pay station.

Tested on switches

In cooperation with a traditional German company that manufactures paints and varnishes for highly specialized applications, SCHURTER put the product to the test. The effect of a coating on switches that works according to this photodynamic principle was tested. The results were very convincing. Only switches with a circumferential groove - i.e. switches with a mechanical stroke - are somewhat more difficult to coat, since the coating could flow into the interior of the switch. For these, the coating would have to be limited to the actuator and would have to be applied before final assembly. All completely sealed SCHURTER switches (piezoelectric, capacitive or ToF) are perfectly suited for this upgrade.

Available on request

SCHURTER has therefore decided to offer this extremely effective upgrade as a customer-specific variant. After all, switches are one of the most common interfaces between man and machine (Metal Line Switches [1]). This makes it all the more important to find the ideal switch for a given application. SCHURTER is known for its customized solutions. Nothing is impossible.

www.schurter.com



RT BOX 1:
THE ORIGINAL

RT BOX 2:
MULTI-CORE

RT BOX 3:
HIGH I/O COUNT

THE REAL-TIME FAMILY HAS GROWN

Building blocks for HIL simulation
and rapid control prototyping

The Role of Power Optimization in the Transition to 5G

Interview with Raj Radjassamy, 5G wireless segment leader for ABB Power Conversion

By Bodo Arlt, Publishing Editor, Bodo's Power Systems



Bodo: In today's power designs, the footprint of power modules is increasingly shrinking while processing power continues to grow. Can you explain the paradox of processing capacity versus power design and the issues it can present? How does newer generation technology reflect this?

Raj: While this paradox is nothing new, what is new is how we are developing solutions to address the higher power demands of newer applications requiring

increased processing capacity. New generation applications such as edge data centers and 5G small cells have presented a big challenge and change the way we think about space. As computing needs continue to increase, so too will the demand for more power and more capabilities within smaller footprints.

For instance, to introduce 5G at scale, wireless networks are deploying miniaturized small cells that offer higher levels of connectivity within a smaller footprint. And some are incorporating small or "miniaturized" repeaters that use beamforming technology to extend and redirect millimeter waves, helping to ensure 5G connectivity across the network while also lowering power consumption and energy needs. Powering these miniaturized cells and repeaters requires scaling down the size of power components – from embedded, board-mounted DC/DC converters to the rectifiers used to power small cell radios and equipment.

Other industrial applications also will need to adopt similar power supply structures to maintain a competitive advantage, from autonomous mobile robotics (AMRs) to smart-city devices powering the industrial internet of things (IIoT). In EV charging, which is becoming more widely adopted nationwide, a lot of energy must be pumped into a small space within a short period of time to provide efficiency for drivers looking to charge vehicles quickly while they're on the go.

An additional and sometimes overlooked factor that can come into play is how outdoor versus indoor power needs are addressed. In both applications, power and connectivity are top priorities, but there are other unique aspects that need to be considered for each. While aesthetics is a key consideration for outdoor standalone power supplies, it is less of a concern when used in enclosed cabinets and indoor power rooms.

Bodo: I'd love to break these down a little bit more, especially seeing as designing in an aesthetically pleasing way is an added challenge. Can you provide some examples? How would this work outdoors, for example with EV charging or 5G connectivity?

Raj: As mentioned, with the transition to 5G, smaller radios and power infrastructure are being implemented. This presents a shift from the larger macro cell sites and towers that we've grown used to. This smaller, more power-dense equipment is being deployed in

greater numbers in high-visibility environments – such as throughout smart cities – to help ensure reliable connectivity and improve throughput and latency.

Because this equipment will be more prevalent and decentralized, creating aesthetically pleasing "street furniture" designs that both meet power needs and are small enough to blend in with the surroundings is essential. This unique need has triggered several new "smart power pole" and "smart streetlamp pole" designs that not only blend well with the surrounding but also contain the hardware needed for a 5G small cell or repeater. That said, developing aesthetically pleasing equipment designs cannot come at the cost of reliable, high-quality operation.

Bodo: And what about some indoor examples? What is the difference when solving for edge computing and data centers, for example?

Raj: When it comes to edge computing and data centers, designing for power optimization and the miniaturization of power remain both a challenge and a priority.

In the current environment of ever-evolving technology, there continues to be increased demand for smaller and smaller high-density power supplies to support new technologies. This is true at every layer of the data center – both in large-scale, centralized data centers and edge facilities.

Maximizing power with miniaturized components typically starts at the board level, where every millimeter of space is important. This aspect is significant for data center power

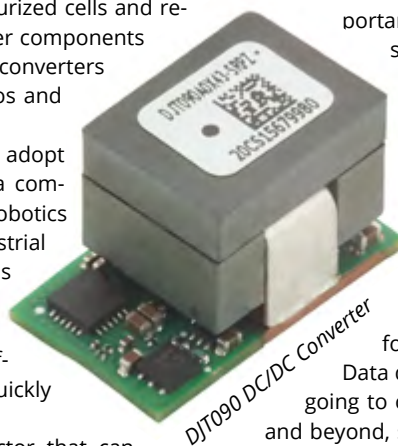
supplies, as engineers are called on to create circuits with increasingly higher power densities, better efficiencies, and higher reliability. One way to tackle this is through the miniaturization and use of point-of-load DC/DC converters to support distributed power and DC power architectures. In edge data centers, there is an even greater emphasis on density since these facilities need to pack as much computing and networking power as possible into even smaller footprints.

Data demands and computing capacity needs are only going to continue to increase (and exponentially) in 2021 and beyond, so it's imperative to keep making advancements in power density to help propel the technology of the future.

Bodo: As next-gen power continues to evolve, what will the next challenge be? As you try to meet the next paradoxical question, what are your answers?

Raj: That is the million-dollar question. We are always working with our customers and keeping our pulse on the industry. While the constant challenge is to reduce the height of the power solutions, the newer challenge is in the "contactless" or "wireless" charging of mobile robots and EVs. The power demands for these applications are not only very high (several KWs), but they also require efficiencies greater than 90% to justify the convenience of a wireless charger when compared to wired charger.

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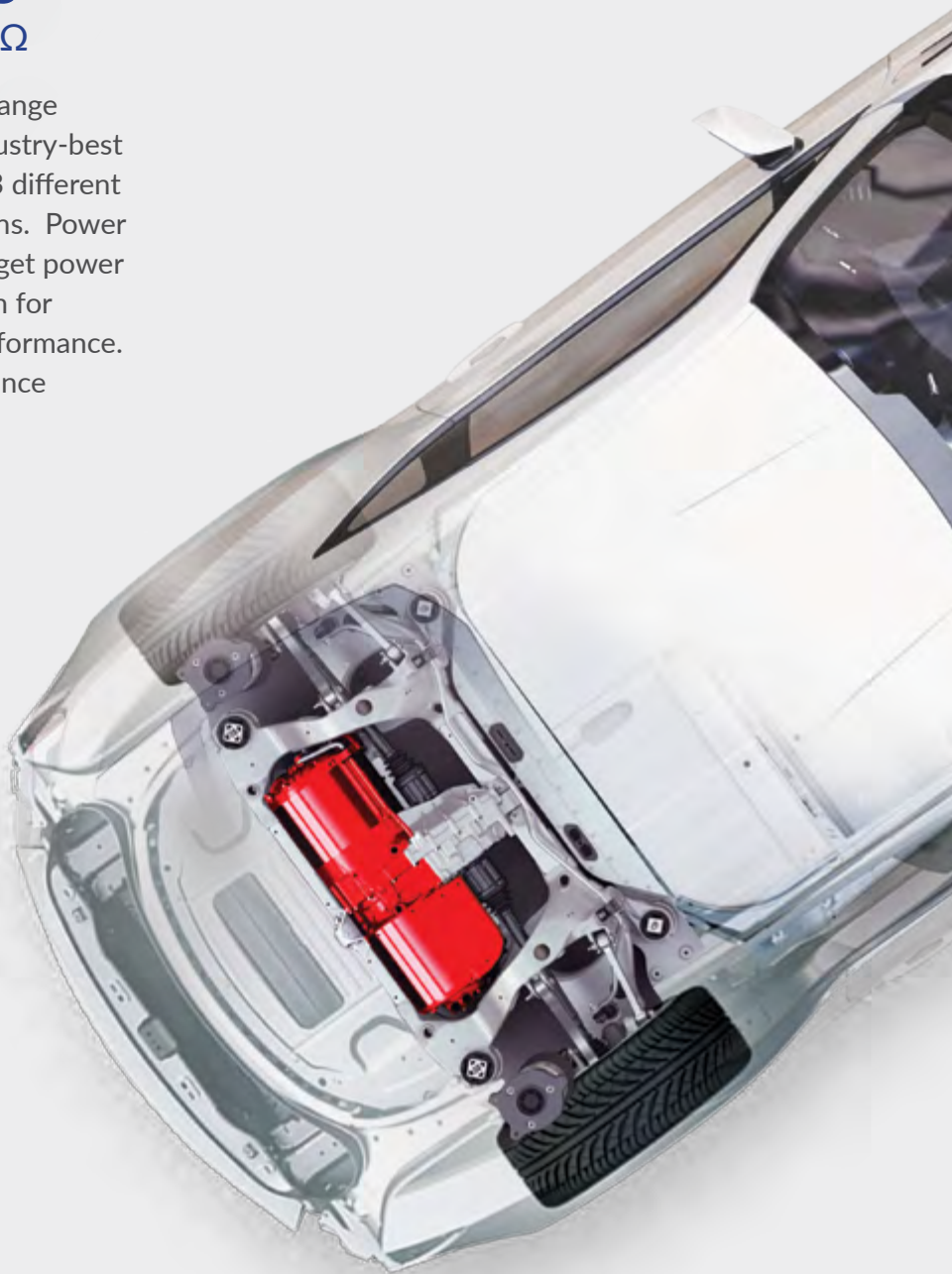


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Pulsed Inductance Measurement on Magnetic Components from 0.1A to 10kA

Pulse measurement using the Power Choke Tester DPG10/20 series with IGBT power stages has prevailed over other measurement methods for inductance measurement on inductive power components due to its many advantages. The second part of this series of articles explains the two traditional measurement methods (LCR meter with DC bias and reactance determination with mains voltage/mains current) as well as the pulse measurement method using thyristors and demonstrates their inherent disadvantages.

By Hubert Kreis, Chief Executive Officer, ed-k, Germany

With the exception of air-core coils, all power inductors exhibit a certain saturation behaviour, i.e. the inductance decreases as the current increases. This has to do with the core materials, which lose permeability to a greater or lesser extent from a certain induction B and then, in the extreme case, behave like air. The saturation behaviour of an inductor can be influenced by

- the type of core material
- the core geometry
- the number of turns and
- the air gap.

However, there are often differences between the calculated inductance at a certain current (e.g. the rated current) and the real inductance, because

- there are production spreads of the cores
- the data sheet specifications for the core are imprecise or incomplete
- the inductor geometry causes an inhomogeneous field distribution
- manufacturing tolerances occur
- there are temperature influences.

Therefore, the saturation behaviour $L(i)$ must be measured during the development, manufacture and quality inspection of power inductors.

With this measuring principle, a square-wave voltage pulse is applied to the test specimen, as in most real power electronics applications. A current curve is then established in the test specimen, whose slew rate di/dt is dependent on the current-dependent inductance $L(i)$. When the preset maximum current or a preset pulse duration is reached, the measuring pulse is switched off again. Fast IGBT switches are used for this purpose.

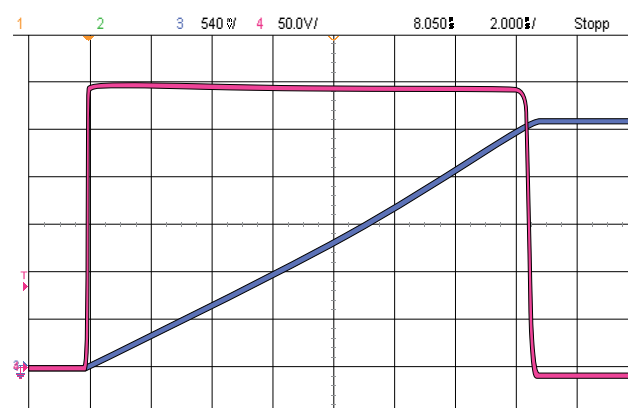


Figure 2: Current and voltage curve of the measuring pulse

CH1: Current 2A/div
CH2: Voltage 50V/div

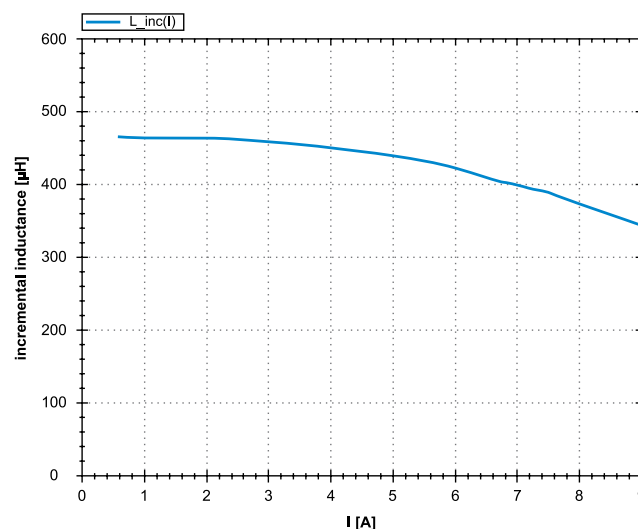


Figure 3: Diagram of the incremental inductance $L_{inc}(i)$ of a Magnetics® High Flux core 58894A2 with 76 turns



The pulse measurement method of the Power Choke Tester DPG10/20 series was presented in detail in the first part of this series of articles.

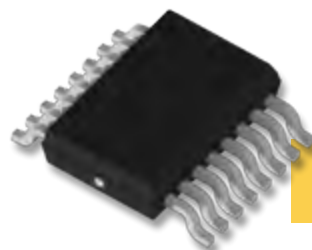
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From the curve of the current $i(t)$ and the voltage $v(t)$ on the test specimen, the following variables can be calculated with a single measuring pulse:

- Incremental inductance $L_{inc}(i)$ and $L_{inc}(fUdt)$
- Secant (amplitude) inductance $L_{sec}(i)$ and $L_{sec}(fUdt)$
- Flux linkage $\psi(i)$
- Magnetic co-energy $W_{co}(i)$
- Flux density $B(i)$, if the core cross-section and number of turns are specified
- Also suitable for 3-phase chokes with the optional 3-Phase Extension Unit

The DC resistance is measured separately.

Pulse measurement with switchable IGBT power transistors using the Power Choke Tester DPG10/20 series enables an extremely wide range of applications that cannot be achieved with any other measurement method and any other commercially available inductance meter.

The current range of the available models presently extends from < 0.1 A to 10 kA. The pulse energy stored in the choke can lie between a few μJ and 15 kJ. The Power Choke Tester DPG10/20 series is therefore suitable for virtually all inductive power components, from small SMD chokes to power chokes weighing several tonnes in the MVA range, e.g.

- smoothing chokes for switch mode power supplies, DC/DC converters, etc.
- filter chokes for UPS, inverters, etc.
- mains chokes for PFC, etc. and commutation inductors
- suppressor chokes and current-compensated chokes
- coils of electromagnets, valve actuators, etc.
- transformers for flyback converters
- motors and power transformers
- and many other inductive components

The device is operated using high-performance software for Windows and is very simple and intuitive to use thanks to a graphic user interface. The measurement results are presented in both graphical and table form. The measurement record is generated in pdf format. The data can be exported and saved in various data formats (XML, CSV).

	DPG10-100B	DPG10-1000B	DPG10-1500B	DPG10-1500B/E	DPG10-3000B/E	DPG10-4000B/F	DPG20-10000BG
Pulse current range 1	1A	10A	10A	10A	30A	40A	100A
Pulse current range 2	10A	100A	100A	100A	300A	400A	1000A
Pulse current range 3	100A	1000A	1500A	1500A	3000A	4000A	10000A
Pulse energy, max.	1350J	1350J	1350J	2750J	2750J	8000J	15000J
Pulse voltage	10 - 400V						20 - 780V
Pulse width, max.	3 μs - 70ms						
Dimensions [mm ³]	370 (W) x 320 (L) x 167 (H)					470 x 500 x 167	470 x 500 x 340
Weight [kg]	9.0	9.0	9.0	10.7	10.7	21.5	41

Table 1: Performance data of the models of the DPG10/20 series

For routine testing in mass production, the Power Choke Tester DPG10/20 series is easy to integrate into automated test environments by means of a DLL or LabVIEW.

Application examples

This is a single-phase PFC choke with an amorphous tape-wound core AMCC63 for active 3-phase power factor correction. The rated inductance is 500 μH and the rated current 40 ARMS. The peak value in the application is around 70 Apk at the rated RMS current.

The inductance of this choke decreases moderately up to about 60 A (approx. 20%), which is reasonable for an economical design of the choke and does not entail any difficulties in the application.

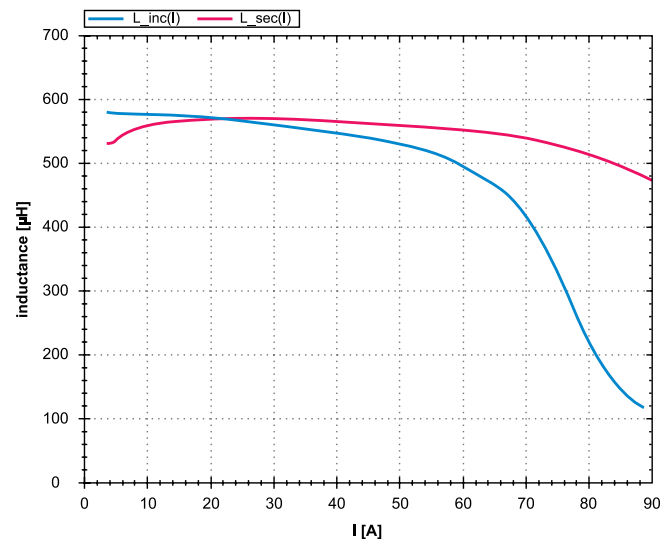


Figure 4: Incremental inductance and secant inductance of a PFC choke with an amorphous tape-wound core

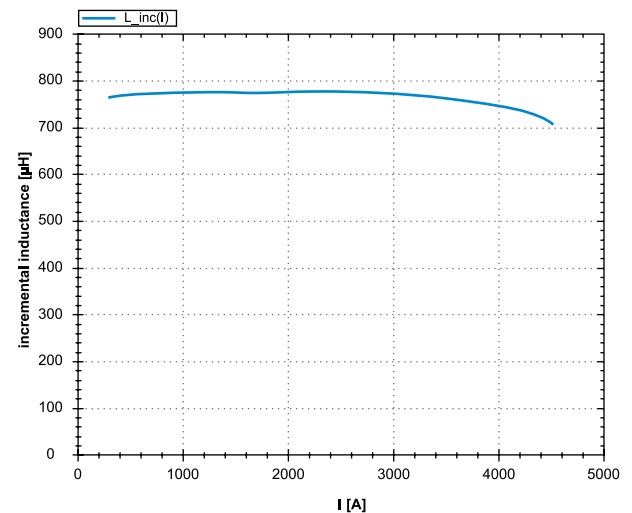


Figure 5: Large reactor for railway applications

However, the inductance decreases very quickly after that. At 90 A the choke only has a incremental inductance of 110 μH ! Therefore, this choke is not suitable for overload operation, even if short-term overload operation wouldn't cause any thermal problem for the choke.

In the diagram of the secant inductance, on the other hand, the strong saturation of the core material at currents exceeding 60 A is much less discernible. For that reason, the incremental inductance is generally more meaningful than the secant inductance for power electronics applications.

This example shows a large power choke for a railway application. The rated current is 2100 A and the rated inductance 770 μH . The incremental inductance decreases in the overload range at 4000 A by about 4%.

Other measurement methods

a) Small-signal measurement (LCR meters with DC bias)

The realistic measurement principle is one of the major advantages of pulse measurement using the Power Choke Tester DPG10/20

series. At the same time, it is a major disadvantage of the measurement principle of LCR meters with DC bias. This measurement principle uses sinusoidal voltages and currents with a selectable frequency in the millivolt and milliampere range, which are superimposed on an adjustable DC current. The inductance, resistance and Q factor can then be calculated from the amplitude and phase angle of the voltage and the current through the test specimen.

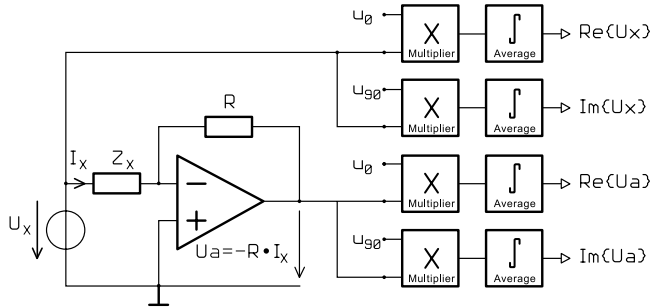


Figure 6: Small signal measurement of LCR meters (auto balancing method)

Such a modulation of the core material with tiny hysteresis curves around an operating point cannot be found in real power electronics applications. The measurement result of such a small-signal measurement is accordingly not very meaningful. The difference between these measurement results and those of the DPG10/20 pulse measurement method depend a great deal on the core material and cannot generally be stated for an entire group of materials. In some cases the differences are relatively small, while in other cases they can be considerable.

Due to the large DC bias units required, this method is restricted to low measuring currents (20-200 A) and necessitates very expensive devices.

The generation of an entire measurement curve $L(i)$ takes a relatively long time and thus thermally stresses the test specimen. In the overload range, this can make the measurement of the saturation behaviour impossible due to excessive heating. At least the behaviour cannot simply be measured at defined temperatures, because the temperature is determined by the self-heating.

The pulse measurement method, on the other hand, does not lead to any measurable heating of the test specimen on account of the short pulse duration. The behaviour can thus be determined at any desired temperature, for example, in the climatic chamber.

b) Conventional determination of reactance with mains voltage and mains current

When measuring with mains currents and mains voltages, the rated current and rated voltage (50 Hz or 60 Hz) are usually applied to the test specimen. The RMS values of the current and voltage are measured. According to general AC theory, the inductance is then calculated, neglecting the ohmic resistance, as

$$L = \frac{V_{rms}}{2\pi f \cdot I_{rms}}$$

Taking the ohmic resistance into account the equation results

$$L = \frac{\left(\sqrt{\left(\frac{V_{rms}}{I_{rms}} \right)^2 - R^2} \right)}{2\pi f}$$

The fundamental problem with this is that no sinusoidal voltages and currents are present due to the extremely non-linear behaviour of the core material. This applies especially to iron core materials, which usually have a very much lower permeability at the origin of the B-H curve than in the normal operating range, which then decreases again as the saturation increases.

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If sinusoidal currents are applied to the mains choke, a non-sinusoidal voltage results on the test specimen. Conversely, non-sinusoidal currents result if a sinusoidal voltage is applied.

In practice, neither sinusoidal currents nor sinusoidal voltages result with this measurement method if an electronically controlled amplifier is not used for the supply. The measured variables feature significant harmonic contents. The normally round sine crests of the current become pointed and in the extreme case even needle-shaped.

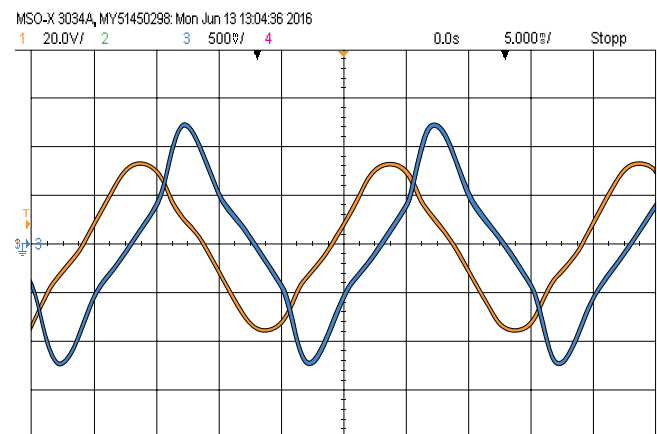


Figure 7: Current and voltage shape for a measurement with 50Hz mains voltage
CH1: Voltage 20V/div
CH3: Current 5A/div

With such distorted curves, a RMS value measurement of voltage and current and the subsequent calculation of the inductance according to equation (1) or (2) are wrong for two reasons:

- The equations come from the general AC theory. However, this is valid only for sinusoidal variables and linear relationships.
- For the RMS value measurement, the measured variable is by definition quadratically evaluated and integrated over a period.

This is derived from the heating effect of an alternating current in an ohmic resistance. The RMS value of an alternating current is equivalent to the heating effect of a corresponding direct current. This has nothing to do with magnetism! For the current and voltage, this systematically produces overly high values in comparison with the fundamental wave due to the high crest factor.

In principle, therefore, this measurement method is of little use in the non-linear range. Due to a lack of better alternatives, this measurement method was justified in the past, at least up to the saturation limit of the core material. With the advent of the pulse measurement method with switchable power transistors, however, a measurement method is available that is more precise, faster, simpler and, from certain power ratings, also cheaper.

When comparing the measurement results, the conventional measurement corresponds most to the secant inductance $L_{\text{sec}}(i)$ determined with the pulse measurement method (up to the saturation limit). However, the additionally available curve of the incremental inductance $L_{\text{inc}}(i)$ can provide further interesting information about the characteristics of the components and the magnetic circuit.

c) Pulse measurement method with thyristors (SCRs)

In the pulse measurement method with thyristors (silicon controlled rectifier SCR that can't be switched off), only a capacitor is discharged via the test specimen. This produces a damped resonance circuit consisting of the capacitor, the test specimen and a limiting inductor connected in series with the test specimen to protect against short-circuit. The incremental inductance and the secant inductance can then be calculated from the sampled curves $i(t)$ and $v(t)$ in the same way as in the method with switchable IGBTs. Furthermore, the losses and material properties can be calculated from the damped oscillation.

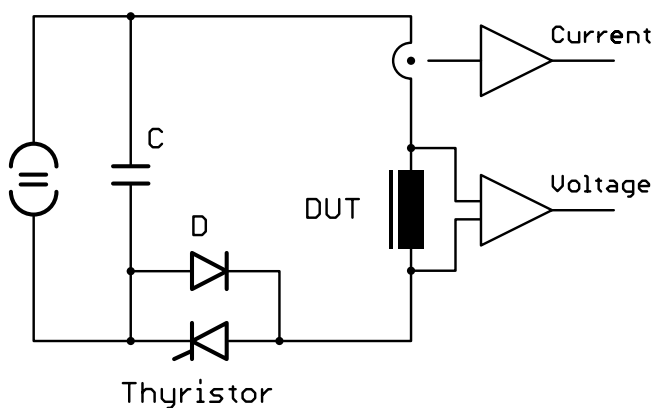


Figure 8: Simplified circuit diagram

However, this method has a serious disadvantage, because only one measuring parameter can easily be set – namely the charge voltage of the capacitor.

The oscillation frequency depends only on the capacitance or inductance of these components and cannot be influenced. Hence, the pulse width also cannot be influenced.

A stepless change of the capacitance of the capacitor would be necessary in order to change the oscillation frequency. Even a coarse-stepped adjustment of the capacitance is so complex that an automatic adjustment with an appropriate step size can probably never be reasonably accomplished.

Hence, the measurement usually doesn't take place with the correct frequency (and voltage curve form) that is intended for the test specimen in the real application. The calculation of the losses on the basis of the decay behaviour, which is theoretically possible with this method, is thus cast into doubt, as this is of course also frequency-dependent.

As the entire energy stored in the capacitor is always discharged into the test specimen, this limits the area of application enormously. The maximum measuring current and the pulse energy can only be influenced by the voltage. Here, too, it would be necessary to adjust the capacitance over a very wide range for differently sized test specimens that require a low or a high pulse energy. On the other hand, the measurement method using the Power Choke Tester DPG10/20 series with switchable IGBTs enables easy adjustment of the pulse energy simply by selecting the adjustable parameters measuring voltage and measuring current by up to ten orders of magnitude!

Calibration

The calibration of an inductance meter that can supply measuring currents up to > 10000 A is a big challenge. Inductance standards for such high pulse currents are not commercially available. The inductance standards normally used in calibration laboratories are only suitable for low currents and their resistance is much too high.

Calibration using only a static or dynamic measurement of the accuracy of the voltage and current measurement is not permissible. It leads to incorrect results. The linearity and the pulse behaviour of the complete signal chain and dirt effects play a decisive role, so that conclusions about the accuracy of the inductance measurement cannot be drawn from the static accuracy of the voltage and current measurement.

For that reason ed-k has developed its own inductance standards, which have been optimised to suit the special requirements of the measuring principle. These include a current-independent inductance (saturation-free), a sufficiently low ohmic resistance, and frequency independence of the inductance and the resistance over a wide frequency range.

In order to make it possible for overseas customer to have a calibration carried out by a local calibration laboratory or to do it themselves, ed-k has developed a calibration kit that contains not only the necessary inductance standards, but also corresponding resistance standards and calibration instructions. In Europe, however, the manufacturer's calibration service is more cost-effective and includes a much more extensive test.

Summary

Pulse measurement using the Power Choke Tester DPG10/20 series with fast IGBT switches has great advantages over other measurement methods:

- Enormously wide range of applications. It is suitable for almost all types of inductive power components from small SMD chokes to power chokes weighing several tonnes in the MVA range.
- Very wide current range, currently available from < 0.1 A to 10000 A
- Pulse energy currently available from μJ to 15 kJ
- Suitable for all core materials from many hundreds of kHz to < 5 Hz
- Small, light and relatively inexpensive despite the very high measurement currents
- Very simple measurement, measurement results within seconds
- No thermal influence on the test specimen
- Also suitable for 3-phase chokes

Conclusion

Due to the enormous restrictions, the pulse measurement method with silicon controlled rectifiers (SCRs) is not well suited for inductance measurement and is not in widespread use.

Only the pulse measurement using the Power Choke Tester DPG10/20 series with switchable IGBTs enables measurement of the inductance with the same voltage, the same curve form and the same pulse width as in the real application. Hence, it provides more realistic measurement results than the other measurement methods and has prevailed in many sectors on account of its enormously wide range of applications and numerous other advantages.



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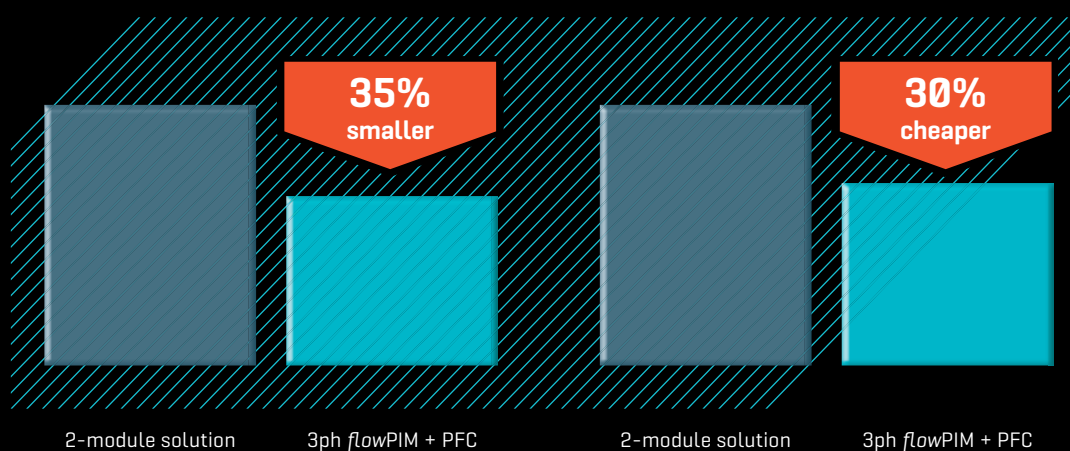
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Demonstrating the design of a bi-directional DC-DC converter for automotive 48 V power distribution, showing how GaN technology is a powerful enabler for efficient electrification.

The trend towards increasing electrification in the automotive industry enables car makers both to deliver new innovations to market cost-effectively and to meet increasingly stringent emissions legislation. Raising the vehicle's main bus voltage to 48 V helps meet the demands of power-hungry systems such as the start-stop motor/generator of a mild hybrid vehicle, as well as loads such as electric power steering, electric supercharging, and vacuum and water pumps.

By Yuanzhe Zhang, Director, Applications Engineering, Efficient Power Conversion Corporation

Compared to the traditional 12 V automotive power standard, 48 V distribution can deliver four times the electrical power without increasing cable thickness, weight, and cost. By 2025, one in every 10 vehicles sold worldwide, is projected to be a 48 V mild hybrid.

However, dropping established 12 V electrical systems immediately is not an economical option. In practice, 48 V and 12 V infrastructures will coexist in vehicles for several generations to come. To make such a dual-voltage setup work satisfactorily, each being powered from 48 V and 12 V batteries respectively, a bidirectional DC-DC converter is needed to transfer power seamlessly between the two battery voltages. Depending on the vehicle, the required power rating of the converter can range from about 1.5 kW to 6 kW.

GaN and Power Conversion

When designing an automotive converter, size, cost, and reliability are critical factors. To meet these criteria, the simplest bi-directional topology; the synchronous buck/reverse-boost converter, is chosen. Maximising energy efficiency is also paramount and, here, designers can take advantage of gallium nitride (GaN) technology to achieve significantly greater efficiency than is possible using traditional silicon power transistors. Gallium nitride benefits from exceptionally high electron mobility as well as low temperature coefficient, which allows power transistors to have very low on-resistance (R_{ON}) thereby minimising on-state conduction losses. The lateral transistor structure also results in exceptionally low gate charge (Q_G) with zero reverse-recovery charge (Q_{RR}). In addition, GaN FETs also have much lower output capacitance (C_{OSS}) than comparable MOSFETs [1].

GaN FETs suitable for 48 V applications have about four times better figure of merit (die area $\times R_{ON}$) compared to similar MOSFETs. For the same gate voltage of 5 V, GaN FETs have at least five times lower gate charge than silicon MOSFETs. As a result, GaN FETs can operate more efficiently and at high switching frequencies than silicon MOSFETs, allowing designers to specify smaller capacitors and inductors in their designs. With lower losses across the switching and on states, the heatsink size can also be reduced, ultimately enabling smaller, slimmer module or permitting higher power ratings within the same footprint. Ultimately, this gives vehicle designers extra freedom to pack more new features within the tight space constraints presented by today's vehicles.

Designing the Converter

Figure 1 shows a simplified schematic block diagram for a 1.5 kW bi-directional 48 V/ 12 V converter, which can be scaled to 3 kW relatively easily by paralleling two converters to make it four phases. The two-phase design shown in the diagram can operate up to 1.5 kW with a maximum current of 62.5 A per phase on the 12 V port. This is made possible by using the EPC2206 eGaN® (enhancement-mode GaN) AEC-Q101 qualified FET, which has 2.2 m Ω R_{ON} and rated peak DC current of 90 A. The two-phase design also reduces the required current rating of the inductors.

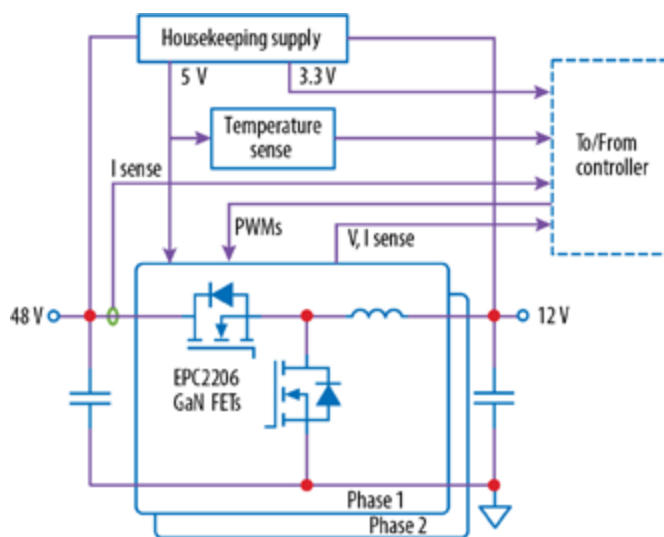


Figure 1: Simplified schematic of two-phase bi-directional converter with eGaN FETs.

In this design, the inductor values and switching frequency are determined using an analytical loss model so that the efficiency at 50% of full rated power is maximized. With the selected 2.2 μ H inductor, as shown, and 250 kHz switching frequency, the peak inductor current is 70 A.

To ensure accurate phase-current balancing, current sensing using a precision shunt resistor is preferred over inductor DCR current sensing. However, shunt resistors that are rated for above 70 A usually have a large footprint and therefore also high parasitic inductance that can result in high noise, which can saturate the current-sense amplifier and thus void the measurement. A simple

solution to overcome this problem was to add an RC filter network with a matched time constant that cancels the shunt inductance. This design uses a current-sense amplifier with a maximum bandwidth of 500 kHz and 50 V/V gain, which results in 10 mV/A total current-sensing gain when used with a 200 $\mu\Omega$ shunt resistor.

It is also critical to ensure a symmetrical layout between the two phases, so that phase currents are balanced and any effects due to mismatching of gate drive delay, switching transition speed, overshoot, or other parameters, are minimised. The internal vertical

loop [2] approach when designing with GaN power devices is to place decoupling capacitors close to the FETs and position a solid ground plane beneath. The microcontroller chosen for this application has a high-resolution PWM module that allows accurate control of the duty cycle and dead-time of 0.25 ns, permitting these to be optimised to take full advantage of the GaN FETs performance.

Digital average current mode control is implemented for both buck and boost modes. The control block diagram is shown in Figure 2. Using the same current reference, I_{REF} , for the two independent current loops regulates the current in both inductors to the same value. The bandwidth of the two inner current loops is set to 6 kHz, and the outer voltage loop bandwidth is set to 800 Hz.

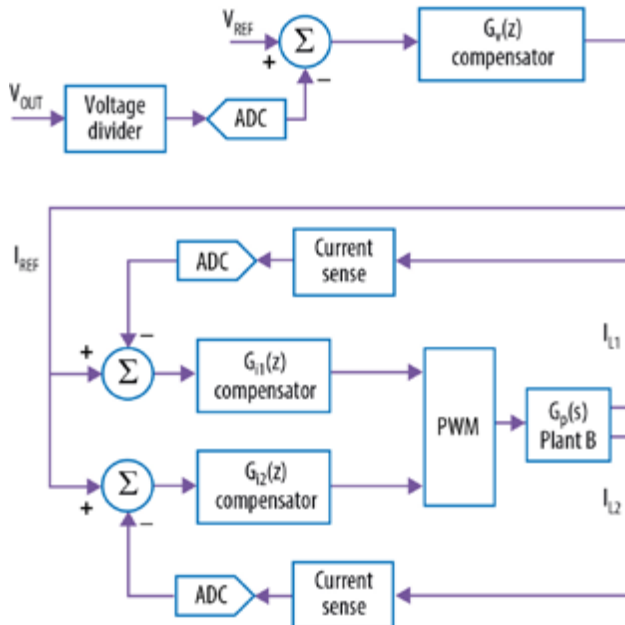


Figure 2: Digital average current mode control diagram.

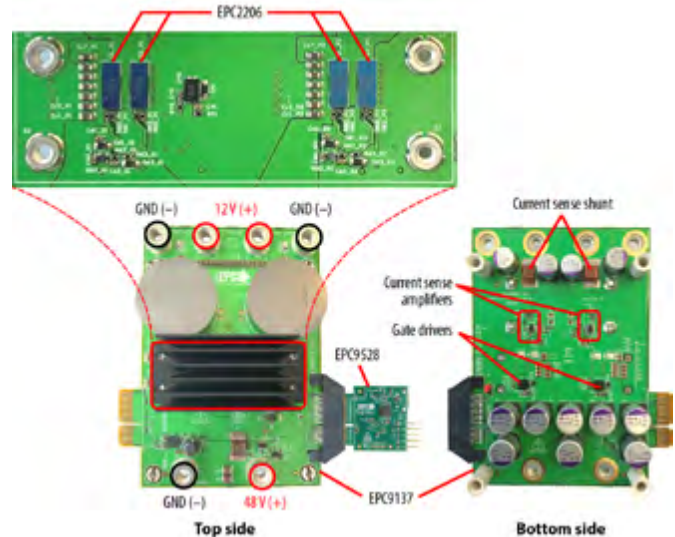


Figure 3: Photo of the EPC9137 converter with the EPC2206 GaN FETs.

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The GaN FETs require a heatsink to operate at the full output power of 1.5 kW. A standard commercially available 1/8th-brick heatsink is used. Four metal spacers are installed on the PCB to provide the appropriate clearance for the heatsink mounting. An electrically insulating thermal interface material (TIM) with thermal conductivity of 17.8 W/mK was applied between the FETs and heatsink.

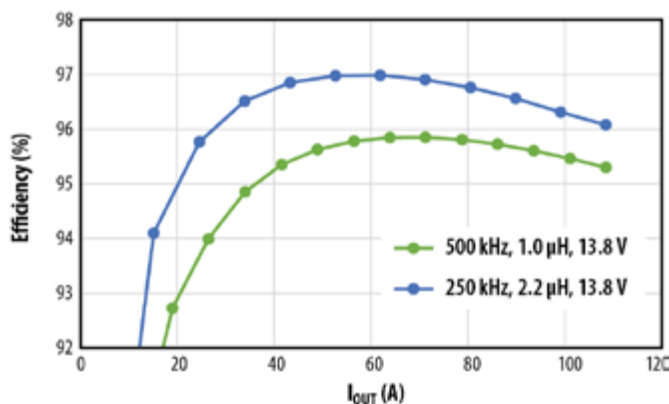


Figure 4: Measured converter efficiency of the EPC9137 at 250 kHz and 500 kHz, 48 V input and 13.8 V output.

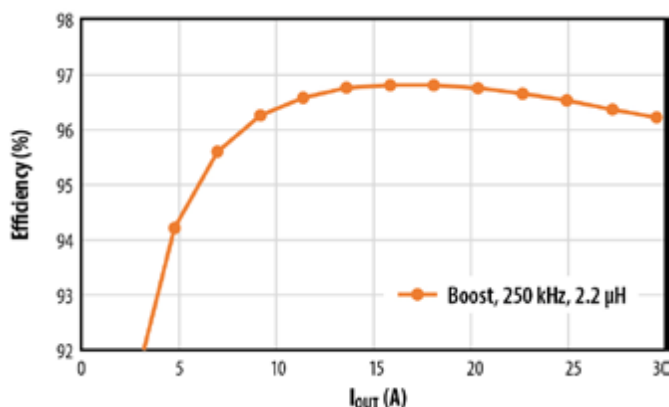


Figure 5: Measured EPC9137 converter efficiency at 250kHz, 13.8 V input and 48 V output.

Performance Analysis

Figure 3 shows a photo of the EPC9137 [5] converter. With the heat-sink installed and 1700 LFM airflow, the converter was operated at 48 V input, 13.8 V output and tested at both 250 kHz and 500 kHz. Figure 4 shows the efficiency results. At 250 kHz, using a 2.2 μH inductor, the converter achieved a peak efficiency of 97%. When operated at 500 kHz, using a 1.0 μH inductor, the peak efficiency was 95.8%.

The EPC9137 converter was also tested at 13.8 V input and 48 V output for boost-mode operation, as shown in Figure 5.

At full load, EPC eGaN FETs can operate with 96% efficiency at 250 kHz switching frequency, enabling 750 W/phase compared to silicon-based solutions, which are limited to 600 W/phase due to the limitation on the inductor current at the 100 kHz maximum switching frequency.

Conclusion

Car makers facing demands to increase the pace of vehicle electrification, both to compete in the marketplace and to meet toughening environmental legislation. This design example for a bi-directional DC-DC converter shows how EPC's automotive-qualified eGaN FETs, such as the EPC2206, can help integrate a 48 V bus, needed to electrify power-hungry loads and meet rising power demands throughout the vehicle. When transferring power between 48 V and 12 V domains, the EPC9137 converter achieves maximum efficiency greater than 96% with 250 kHz switching frequency, and above 95% at 500 kHz.

References

- [1] A. Lidow, M. De Rooij, J. Strydom, D. Reusch, and J. Glaser, GaN Transistors for Efficient Power Conversion, 3rd ed. John Wiley & Sons, 2019. ISBN: 978-1119594147.
- [2] D. Reusch and J. Strydom, "Understanding the Effect of PCB Layout on Circuit Performance in a High-Frequency Gallium-Nitride-Based Point of Load Converter," in IEEE Transactions on Power Electronics, vol. 29, no. 4, pp. 2008-2015, April 2014, doi: 10.1109/TPEL.2013.2266103.

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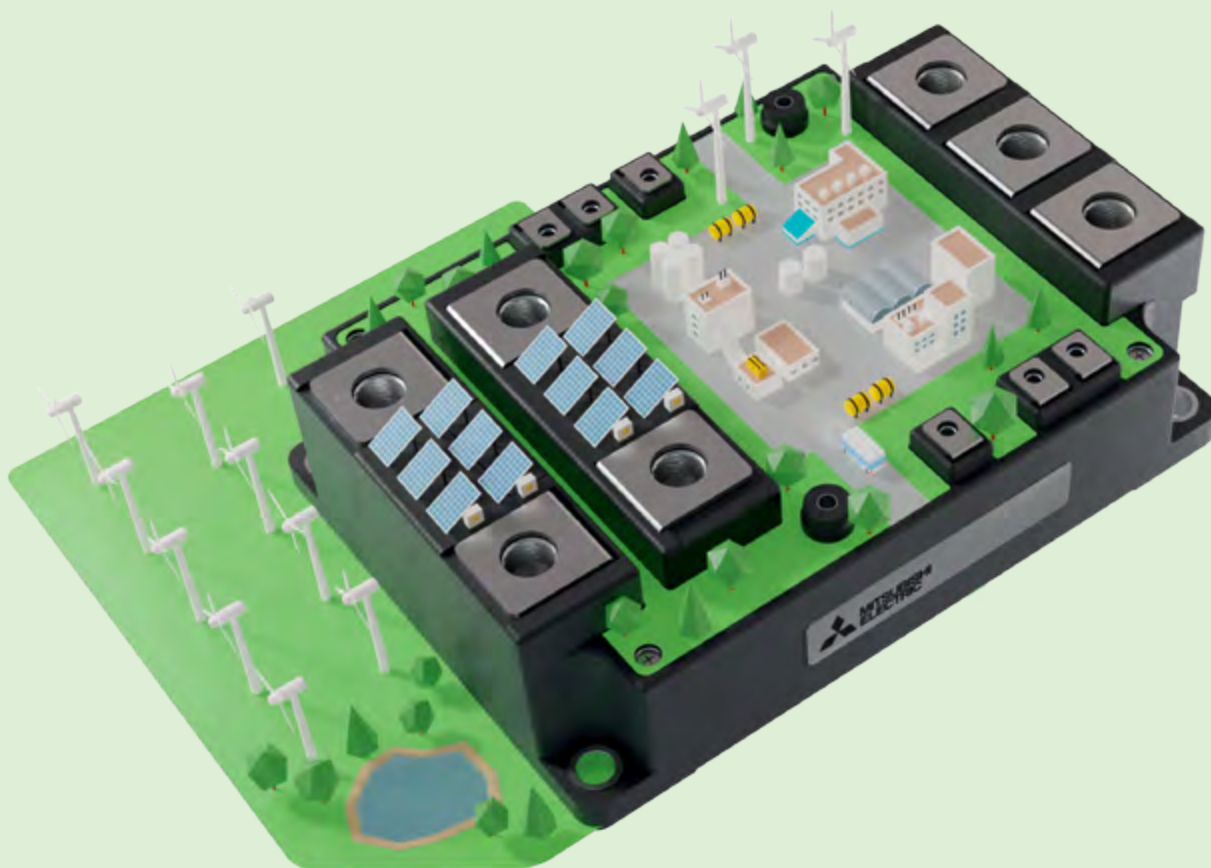
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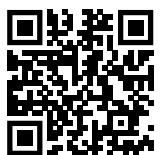


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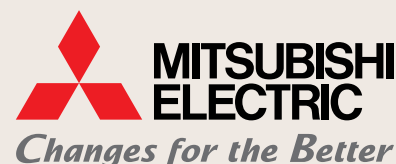
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Driving SiC MOSFETs & IGBTs with Current Source Gate Driver: Reducing Turn-On Loss by up to 26%

This article outlines how ROHM's new current source gate driver – the BM60059FV-C – offers a possibility of reducing switching losses by up to 26% while operating at a limited dv/dt.

By V. Thayumanasamy, F. Filsecker, C. Felgemacher, J. Kleinpaß, K. Lenz, ROHM Semiconductor

When a parameter is changed, it often entails a number of other changes. Finding the perfect design is therefore often very difficult. If a power semiconductor is controlled in such a way that it switches faster, switching losses are reduced and resulting in better system efficiency. On the other hand, it is precisely this high switching speed that can have a negative impact on the service life of other components such as motor insulation and can cause EMI issues. Constant Current Drive Technology can reduce the switching losses with a limited dv/dt.

On the other hand, it is precisely this high switching speed that can have a negative impact on the service life of other components such as motor insulation and can cause EMI issues. With its new gate driver BM60059FV-C, ROHM offers a possibility of reducing switching losses by up to 26% operating at a limited dv/dt.

Current source drivers (CSD) and voltage source drivers (VSD):

Figure 1 shows block diagrams of gate driver BM61M41RFV-C, a conventional voltage source driver versus BM60059FV-C, a current source driver. The ideal turn-on characteristic of an IGBT and the corresponding gate current for individual type of driver are also

shown. In this whole article only the turn on characteristics will be considered.

The well-known turn-on characteristics are split into six intervals (T0 – T6). Neglecting the parasitics, internal gate resistance of the power device and internal $R_{DS(on)}$ of the push-pull stage MOSFETs, the peak gate current at the instant T0 is given by,

$$I_{G_Peak} = \frac{VCC2}{R_g} \quad (1)$$

where VCC2 is the supply voltage of the gate driver with respect to the driver ground GND2, R_g is the external gate resistance. In the time T0-T2 the input capacitance (C_{GE} and C_{GC}) of the IGBT is getting charged. The cumulative gate current during this interval can be expressed as,

$$I_{Gate}(t) = \frac{VCC2 - V_{GEO}}{R_g} \cdot e^{-(t-T_0)/(R_g \cdot (C_{GE} + C_{GC}))} \quad (2)$$

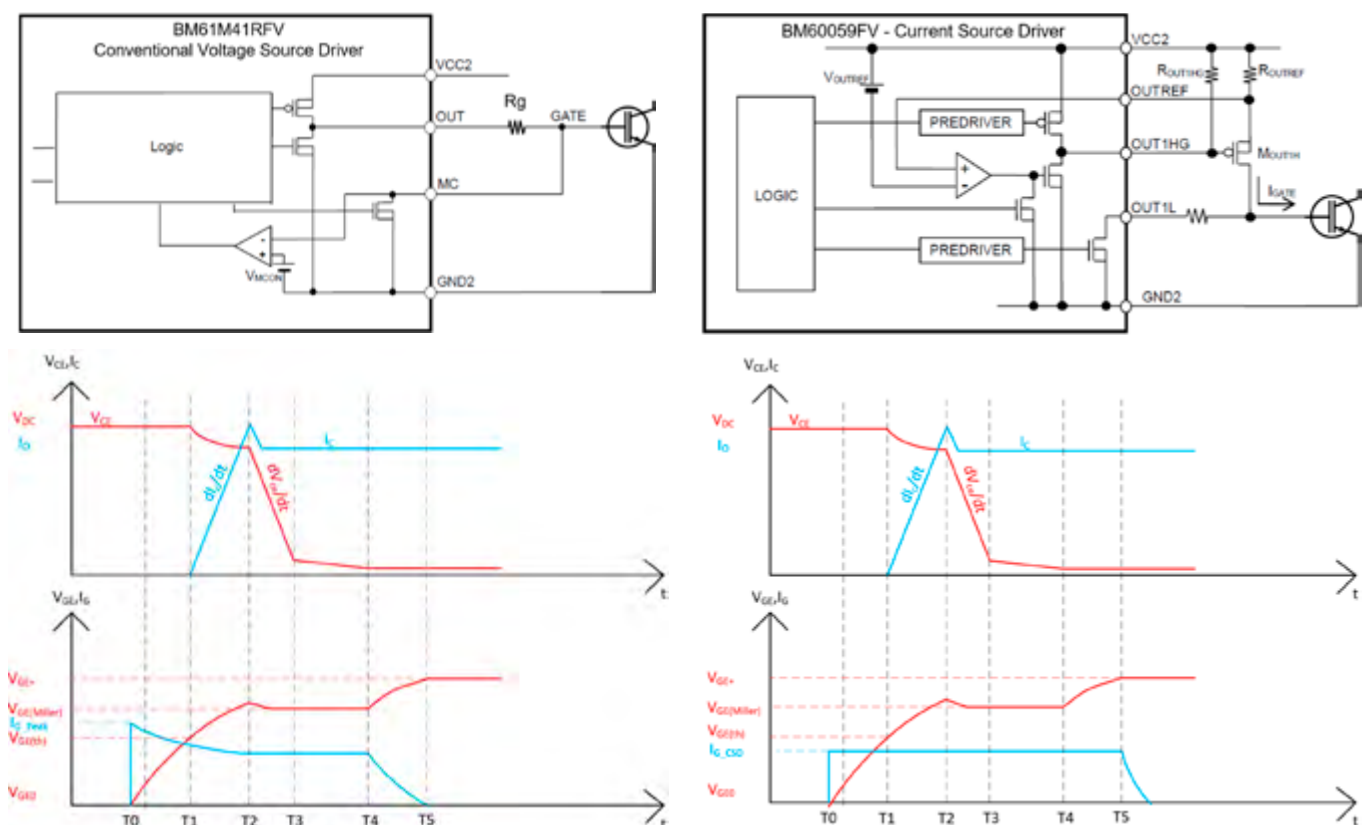


Figure 1: Typical turn on characteristics of an IGBT using voltage source driver BM61M41RFV-C (left) and current source driver BM60059FV-C (right)

During the interval T2 to T4, in the so-called Miller plateau, the gate voltage remains constant and so does the gate current. This current can be expressed as,

$$I_{Gate(T2 - T4)} = \frac{V_{CC2} - V_{GE(Miller)}}{R_g} \tag{3}$$

During T4 to T5, VCE has already fallen to a very low value. This will make the gate current decay with a time constant given by,

$$\tau_{T4-T5} = R_g \cdot (C_{GE} + C_{GC}) \tag{4}$$

The gate voltage further increases to VGE+ with the same time constant and the turn on process is complete. A more detailed explanation and equations can be found in [1].

On the other hand, for a current source driver, the gate current from the instant T0 to T5 remains constant and is expressed with a simple equation,

$$I_{G-CSD} = \frac{V_{OUTREF}}{R_{OUTREF}} \tag{5}$$

where VOUTREF is a fixed internal reference voltage of the gate driver BM60059FV-C and is typically 2V and ROUTREF is the external resistance that needs to be adjusted as per the switching speed needs.

Figure 2 shows the gate current and gate voltage waveforms of three different ROUTREF settings while driving a 1200V IGBT with the driver BM60059FV-C. A constant gate output current in each of the cases can be clearly observed.

The region of interest while comparing a current source driver and a voltage source driver is the period T2-T3 where the dv/dt is determined by the gate current during the Miller plateau. In this region only the gate-collector capacitance is being charged, whose value is strongly dependent on the voltage. At a high collector-emitter voltage, the Miller capacitance is low and upon turn-on, as the voltage starts to fall its value increases. The Miller plateau is also load dependent and especially at high load currents, its voltage VGE(Miller) is higher [1]. From equation 3, it is evident that at higher Miller plateau voltages, the gate current is lower. Thus, by using a voltage source driver one can expect the turn-on dv/dt to be steadily decreasing with increasing load, leading to higher turn-on losses. On the other hand, a current source driver with its ability to maintain a constant gate current output, a constant dv/dt can be achieved over the complete load range. This translates into a reduction of turn-on losses at high load current, when using current source drivers instead of voltage source drivers. To verify the benefits and expectations of a constant current source driver, a test board was developed where discrete IGBTs and SiC-MOSFETs were tested. A standard voltage source driver was also implemented on another board, see Figure 3.

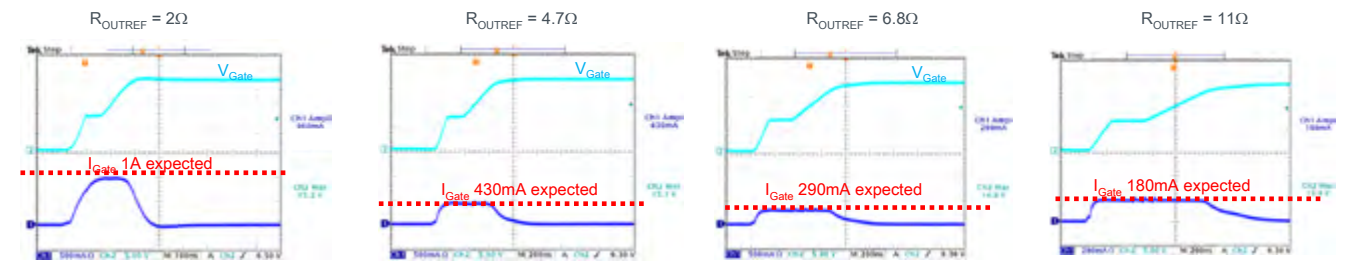


Figure 2: Gate current and gate voltage measurement with a constant current source driver BM60059 and a 1200V IGBT at no load for different ROUTREF values

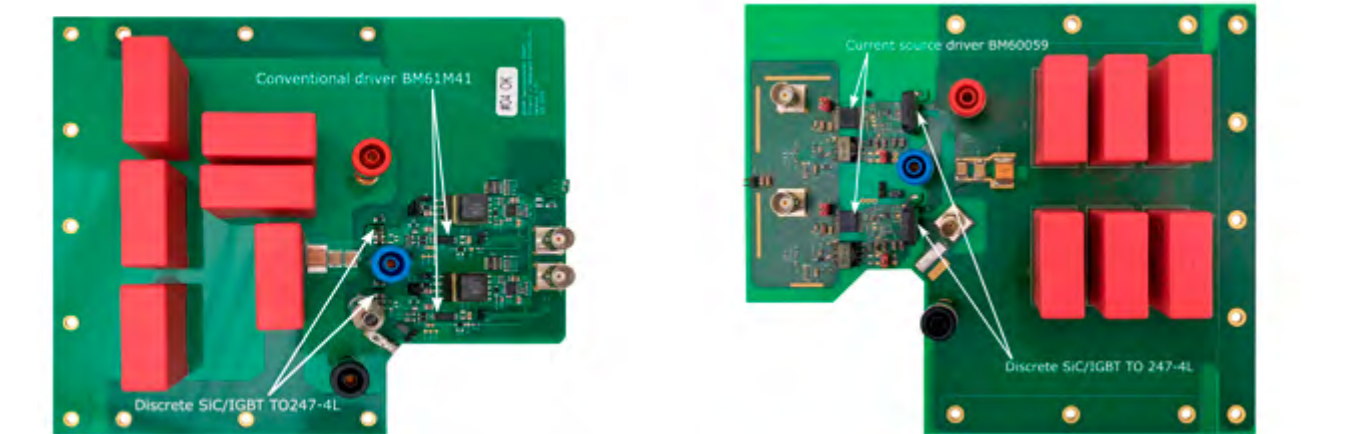


Figure 3: Half bridge test board with voltage source driver (top) and current source driver (bottom)

Power device	Gate drive voltage	Conditions	Type of gate driving
1200V, 100A, TO-247-4L IGBT	15V - Turn on 0V - Turn off	V _{DC} = 600V T _{amb} = 25°C	VSD (ROHM Driver: BM61M41RFV)
1200V, 100A, TO-247-4L IGBT	15V - Turn on 0V - Turn off	V _{DC} = 600V T _{amb} = 25°C	CSD (ROHM Driver: BM60059FV)
1200V, 55A, TO-247-4L, 40mΩ SiC MOS	18V - Turn on 0V - Turn off	V _{DC} = 600V T _{amb} = 25°C	VSD (ROHM Driver: BM61M41RFV)
1200V, 55A, TO-247-4L, 40mΩ SiC MOS	18V - Turn on 0V - Turn off	V _{DC} = 600V T _{amb} = 25°C	CSD (ROHM Driver: BM60059FV)

Table 1 : Tests and conditions

Experimental Results:

Both the current source driver and the conventional voltage source driver boards were evaluated using double pulse tests. A 1200V, 100A discrete IGBT and a 1200V, 55A, 40mΩ SiC-MOSFET were evaluated. Both devices are housed in a TO-247-4L package, which includes a driver emitter/source pin. Only unipolar gate drive was used for both cases: 15V/0V for the IGBT and 18V/0V for the SiC-MOSFET. Table 1 shows the list of tests that were performed with the corresponding conditions. Voltage source drive and current source drive will be hereafter mentioned as VSD and CSD respectively.

For all the tests an active Miller clamping function was used. For the analysis only the turn-on losses were considered. The power devices were evaluated for different load conditions and different switching speeds. Figure 4 shows the dv/dt comparison of voltage

source driving and current source driving of IGBT and SiC MOSFET for different gate resistances. The gate resistance in a VSD is represented as R_g and the equivalent resistance to control the gate current for a CSD is given as R_{OUTREF} .

It is quite evident from the figure that at slower switching speeds ($dv/dt < 10V/ns$), a CSD maintains a constant dv/dt over the complete load range for both SiC MOSFET and IGBT, which is not possible with a conventional driver. For normal to high switching speeds, CSD and VSD behave similarly. This means that only applications where a low dv/dt is mandatory will benefit from CSD.

Use case of current source drivers:

In applications such as motor drives, it is common to limit the dv/dt of the switching power devices to 5V/ns. A higher dv/dt can eventually damage the motor windings and lead to premature aging. For industrial motor drives, IGBT based inverters are the norm and the

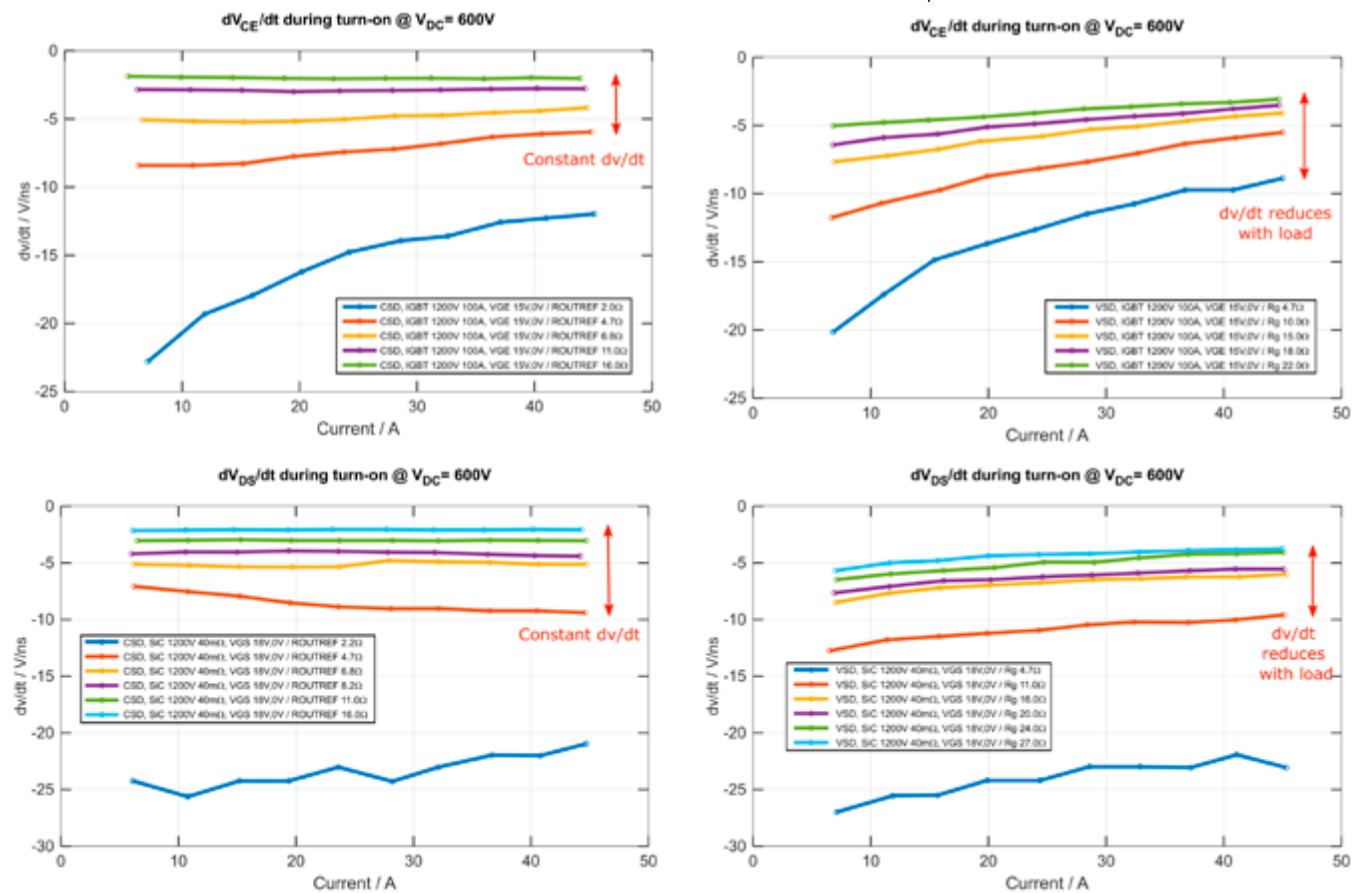


Figure 4 : Measurement results dv/dt during turn on CSD with IGBT (top left), VSD with IGBT (top right), CSD with SiC (bottom left), VSD with SiC (bottom right)

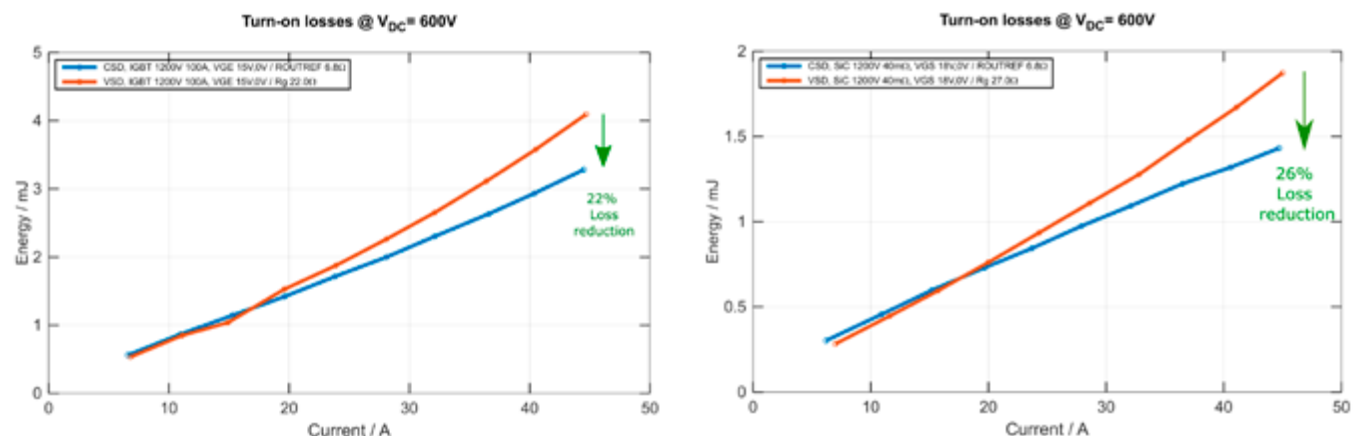


Figure 5: Comparison of turn on losses with maximum dv/dt limited to 5V/ns (left: IGBT, right: SiC-MOSFET)

benefits of current source driving of IGBT has been discussed in [2]. It has also been reported that using SiC-MOSFETs with limited dv/dt using conventional gate drivers can result in much better efficiency compared to an IGBT-based motor drive [3]. The benefit of using SiC-MOSFETs in drives application can be further exploited using CSD.

Hence, four possible solutions with a maximum dv/dt of 5V/ns are analyzed:

1. Voltage source driving of IGBT
2. Voltage source driving of SiC-MOSFET
3. Current source driving of IGBT
4. Current source driving of SiC-MOSFET

In the case of the 1200V, 100A discrete IGBT with VSD a gate resistance of 22 Ω is needed to limit the maximum dv/dt to 5V/ns. With CSD, a gate current setting of 290mA (ROUTREF value of 6.8 Ω) is needed. For a 1200V, 55A SiC-MOSFET using a VSD, a gate resistance of 27 Ω is needed to limit the dv/dt to 5V/ns and with current source driver, gate current setting of 290mA (ROUTREF value of 6.8 Ω) is needed. Figure 5 shows the turn on energy loss comparison of CSD and VSD of SiC and IGBT where the maximum dv/dt at any load is limited to approximately 5V/ns.

For an IGBT-based solution, the turn-on losses using both CSD and VSD start with an approximately similar value at low load (0.5mJ) but at high load there is a 22% loss reduction by using a CSD. Likewise for a SiC based solution, both the CSD and VSD start with turn-on losses of 0.25mJ but at high load there is a 26% loss reduction by using CSD. Summing up, the turn-on losses can be reduced using a CSD mainly at high load conditions due to their ability to maintain a constant dv/dt at any load. Clearly this is an advantage when using CSD in slow switching applications.

Conclusion:

In conventional gate drivers where gate resistors are used to limit the switching speeds of the power semiconductors, the dv/dt upon commutation is strongly load current dependent. On the other hand, a constant dv/dt can be realized over a complete load range with a current source driver. ROHM's new isolated gate driver BM-60059FV-C offers this feature upon turn-on. Experimental verifications show that at high load range and slow switching speeds (<5V/ns), current source driving of SiC-MOSFETs or IGBTs reduces turn-on losses by up to 26% in comparison to the conventional method. In applications such as motor drives where the dv/dt is commonly limited to 5V/ns, current source drivers increase the efficiency and offer a promising solution.

References:

- [1] Dierk Schröder, Leistungselektronische Bauelemente, Second edition
- [2] W.Frank, H.Hüsken, "Current Source Gate Drivers Boost the Turn-On Performance of IGBT", Bodos Power, November 2018
- [3] B. Sahan, A. Brodt, D. Heer, U. Schwarzer, M. Slawinski, T. Villbusch, K. Vogel „Enhancing Power Density and Efficiency of Variable Speed Drives with 1200V SiC-TMOSFETs“, Power Conversion and Intelligent Motion Conference PCIM 2017
- [4] BM60059FV-C, ROHM Isolated Gate driver datasheet

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The advertisement features a silver BS&T Pulse power supply unit with red and blue connectors. Below it, three callouts indicate test capabilities: "Test 1 $\phi \rightarrow 3 \phi$ ", " $10^3 \text{ V} \rightarrow 10^4 \text{ V}$ ", and " $10^3 \text{ A} \rightarrow 10^4 \text{ A}$ ". To the right, the website www.b-stone.de and the logo "Bs&T Pulse" are displayed. At the bottom, a graph shows V/F (V) on the left y-axis (ranging from -200 to 400) and Int (A) on the right y-axis (ranging from 0 to 1000) against time (s) on the x-axis (ranging from 0 to 1.2). The graph shows a red curve for V/F and a blue curve for Int, both exhibiting a sharp rise and then a gradual decay.

Seven Steps to Highly Effective GaN Designs

Today, we operate in a very fast-moving world, looking for shortcuts, opportunities to “copy and paste” to complete tasks in a short period of time. Although GaN power transistors are relatively new, design “rules of thumb” has been established and proven to meet fast time-to-market objectives. Over the years, seven steps to a successful design have been developed and proven – backed by ongoing and updated documentation and customer training.

By Juncheng (Lucas) Lu, GaN Systems Applications Engineering Manager, GaN Systems

This article provides an overview of these seven steps and links to application notes to inform users and customers of the latest information needed to optimize their GaN designs.

Step 1 – Gate Drive Selection

Driving the gates of GaN enhancement mode high electron mobility transistors (E-HEMTs) has similarities in common with driving the gates of silicon (Si) MOSFETs – but with a few beneficial differences.

Driving GaN E-HEMTs does not eliminate any popular Si gate drivers; they simply make GaN easier and more effective to use. This means high-voltage (>600V) quasi-resonant and fixed frequency flyback adapters, chargers, and other low-power AC/DC controllers can be used for different LLC and power factor correction (PFC) configurations in GaN designs.

Simple circuitry provides the transition capability for using a Si controller for GaN devices. For a single GaN device, the isolated, negative $V_{GS(OFF)}$ EZDrive® circuit is a low-cost, easy way to use a 12V driver to drive a 6V GaN transistor for use with any controller or driver with single, dual, or high-side/low-side drivers. A new driver, the Heyday HEY1011, provides significant size reduction and board space savings in GaN designs. With its ability to eliminate bootstrap and isolated supplies, it is also the smallest isolated gate drive solution in the market. Figure 1 shows an evaluation board using a HEY1011 with an integrated power rail.

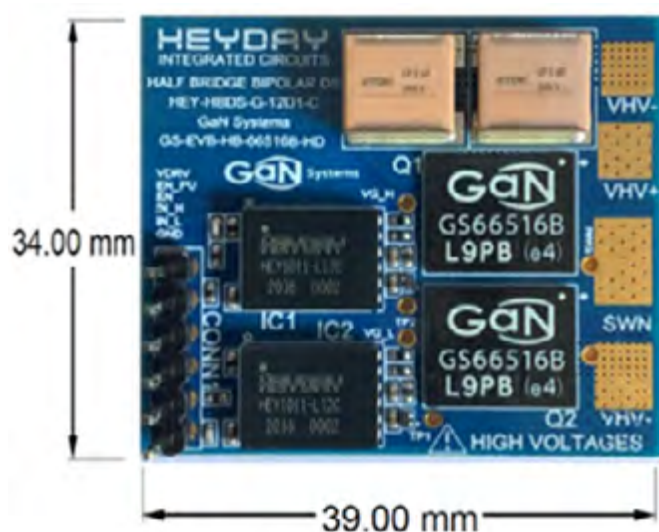


Figure 1: The GS EVB HB 66516B HD, a 650 V GaN E-Mode half-bridge evaluation board, features a HEY1011 L12C gate drive solution.

Step 2 – Topology and Schematic Review

Designers need to constantly be on the lookout for the newest products since using an available, compatible controller simplifies the GaN designer's task. Depending on the desired topology, such as critical conduction mode (CrM) or continuous conduction mode

(CCM), an appropriate controller may already exist and be part of an evaluation tool. For example, an onsemi NCP1680 CrM analog bridgeless totem pole (BTP) PFC controller used in a 300W GaN evaluation demo board shown in Figure 2 results in high efficiency. As illustrated, 99% efficiency was achieved at full load at the highest (265V) voltage (plus, the controller's design includes features for more efficient operation under light loads.)

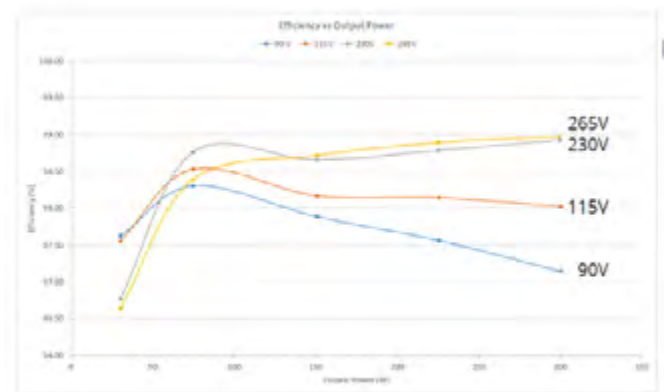


Figure 2: A BTP PFC controller offers thermal and power density advantages over a boost PFC topology.

Step 3 – Power Loss Calculation

Applying simple calculations can make the novice or experienced GaN designer more comfortable with using new technology. For example, in the application note “GaN Switching Loss Simulation using LTSpice” (GN008), a half-bridge double-pulse test circuit in LTSpice, is used as the test bench to evaluate switching performance under different electrical parameters. In the paper, the simulated switching losses are compared with lab measurements to verify the accuracy and suitability of the process. Additionally, “Modeling the Thermal Behavior of GaNPX® packages” (GN007) explains how RC thermal models found on GaN product pages can be used to perform detailed thermal simulation using SPICE. The App Note describes how to use the four-layer GaNPX package's RC model in a SPICE simulation. A simple boost converter circuit is used to verify the functionality of the RC thermal model.

Step 4 – Layout Considerations

Since GaN E-HEMTs switch much faster than Si MOSFETs, they require proper engineering considerations for printed circuit board (PCB) layout design to minimize parasitic inductance issues. Specifically, parasitic inductances can cause higher overshoot voltages, ringing/oscillation, and electromagnetic compatibility (EMC) issues, which can lead to overstressing the E-HEMTs. The application note “PCB Layout Considerations with GaN E-HEMTs” (GN009) provides an overview of best engineering practices for PCB layout of designs using embedded GaNPX-packaged E-HEMTs. Layout guidelines are introduced for the following four circuit configurations:

- Isolated gate driver circuit for single GaN E-HEMTs
- Isolated gate driver circuit for paralleled GaN E-HEMTs
- Half-bridge bootstrap gate driver circuit
- EZDrive circuit

Optimum board layout combined with low package inductance enables GaN E-HEMTs to exhibit optimum switching performance.

Step 5 – Circuit Test Validation

GaN E-HEMTs have very low parasitic parameters. However, without proper care, the parasitic elements introduced by test equipment and measurement techniques, especially operating at higher frequencies, can overshadow the GaN device parameters and lead to erroneous measurement results.

Application note “Measurement Techniques for High-Speed GaN E-HEMTs” (GN003) explains the importance of measurement techniques and provides examples in several areas. Also, it discusses the Double Pulse Switching Test used to characterize hard switching turn-on and turn-off, including the Switch Test Setup and an example of test results. GaN Systems routinely tests Double Pulse Testing on every design we do and every customer we support. There is no better way to verify a good layout.

For switching energy, Eon/Eoff measurement probing techniques to increase measurement accuracy of VGS, VDS, and IDS are described, including switching loss distribution of GaN E-HEMTs and an Eloss measurement example.

Step 6 – Thermal Design Optimization

Good thermal design is essential for power-handling devices such as GaN transistors. Improved thermal capabilities can be obtained using an insulated metal substrate (IMS) instead of an FR4 PCB. Compared to FR4 PCB heat transfer, the IMS design reduces the heatsink volume for high-power applications. Figure 3, from GN002, Thermal Design for Packaged GaN[®] Devices, depicts different (increasingly better) cooling techniques, including top cooling. As shown, when using high-performance GaN devices (both lower R_{θJA} and lower on-resistance and parallel devices), much lower power losses and higher power operation can be achieved. In addition, SPICE (LTSPICE/PSpice) and PLECS models can assist the system designer to optimize thermal and electrical performance.

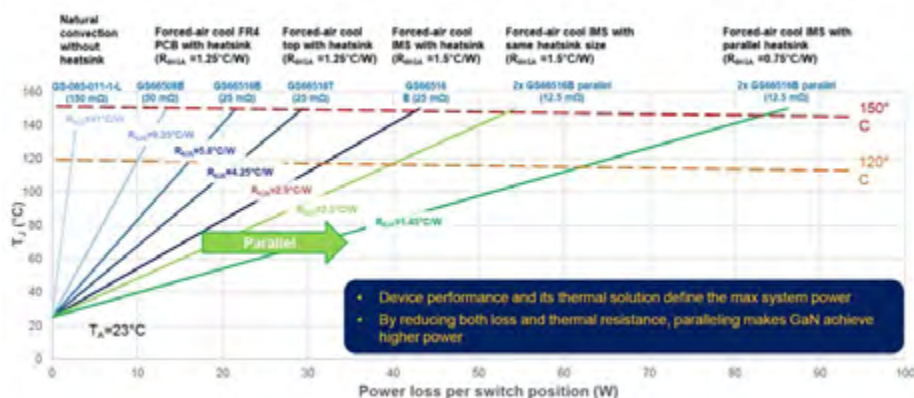


Figure 3: Several design changes can increase the power-handling capability while significantly reducing the heatsink to ambient thermal resistance (R_{θJA}) in a specific GaN design.

The new IEC 62368-1 hazard-based product-safety standard (replacing IEC 60950) reduces maximum touch temperature requirements, adding challenges in traditional thermal designs. While heat transfer improves with horizontal heat spreaders, vertical thermal conduction has become critical. An optimized thermal stack can include an advanced, 0.2 mm, thermal interface material (TIM), 3-mm copper shielding, and a 5-mm copper slug to achieve the lowest R_{θJA}.

Step 7 – Electromagnetic Interference (EMI) Avoidance

The perennial power electronics issue – if not dealt with properly in the design – is EMI and EMC. In general, GaN technology helps reduce EMI due to Zero Reverse Recovery but controlling drive parameters is essential to control EMI. Also, copper shielding is recommended for EMI compliance. However, layout is the most important way to minimize EMI, and this final step reiterates considerations in Step 4.

Two reference designs bring out important circuit aspects to avoid EMI problems. One is a 65W Type-C USB Power Delivery (PD) quasi-resonance (QR) charger, which addresses EMI for CISPR22 Conduction and Radiation Class B compliance. The second reference design is a 100W PFC QR USB PD charger with two Type C ports with EMI capability to pass EN55032 Class B with >6dB margin.

The Next Step – Ship the product!

Seven is the lucky number for GaN designs and design engineers – if they follow the steps presented here – which offers a great overview of maximizing performance success. To dive deeper into each step, review the list of application notes at the end of this article. Additionally, the GaN Systems website provides reference designs, webinars, technical papers, and more to help optimize these steps. Shorten design cycles and get products to market faster. With this guidance, design engineers can have confidence in their designs and leverage all the advantages GaN enables.

References:

1. GN012 https://gansystems.com/wp-content/uploads/2021/03/GN012_Gate-Driver-Design-with-GaN-E-HEMTs_210204-1.pdf
2. GN010 https://gansystems.com/wp-content/uploads/2020/07/GN010_EZDrive-Solution-for-GaN-Systems-GaN-Transistors-20200715.pdf
3. GN004 https://gansystems.com/wp-content/uploads/2020/09/GN004-Design-Considerations-of-Paralleled-GaN-HEMTs_200910.pdf
4. GN008 https://gansystems.com/wp-content/uploads/2018/05/GN008-GaN_Switching_Loss_Simulation_LTspice_20180523.pdf
5. GN007 <https://gansystems.com/wp-content/uploads/2021/07/GN007-%E2%80%93Modelling-Thermal-Behavior-of-GaN-Packages-Using-RC-Thermal-SPICE-Models-Rev-210720.pdf>
6. GN009 https://gansystems.com/wp-content/uploads/2019/01/GN009-PCB-Layout-Considerations-with-GaN-E-HEMTs_20190118.pdf
7. GN003 https://gansystems.com/wp-content/uploads/2018/08/GN003-Measurement-Techniques-for-High-Speed-GaN-E-HEMTs_20180816.pdf
8. GN002 <https://gansystems.com/wp-content/uploads/2021/03/GN002-Thermal-Design-for-GaN-Packages-Rev.201127-1.pdf>

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About the Author



Juncheng (Lucas) Lu is an applications engineering manager at GaN Systems. Prior to GaN Systems, he was a research engineer at Delta Power Electronics Center in Shanghai. His research interests are high power and density power supplies, electric vehicle battery chargers, wideband gap device applications, power modules. He holds 13 U.S. Patents (or Pending). Lu received a B.S. from Zhejiang University and M.S. degree from Kettering University.

Monitoring DC/AC Current in Locations Where Other Current Sensors Cannot

Electrification of Road, Off-road, Marine and Air vehicles; development of Renewable Energy Electrical Sources and Energy Storage; monitoring and improving the efficiency of existing Electrical Grid, Transit, and Industrial Installations, can benefit from electrically isolated Current Transducers for condition monitoring and fault diagnosis.

By Lou Law and Ian Walker, GMW Associates



Fixed aperture magnetic core based Current Transducers provide dc and ac response with excellent accuracy but they are often difficult to install on existing systems. Split Current Transducers are typically designed for hand-held measurements by an operator rather than semi- or permanent installation and are not suitable for operation over a wide temperature range, in moist, dirty or high vibration environments or where high fault current overloads are possible. Generally the Transducer apertures are limited and inadequate for high current, large cross-section cables or bus bars.

Rogowski Coil based current transducers can be designed for very high peak current and with long, small cross-section Coils to enclose almost any current conductor and for operation in harsh environments. But the Rogowski Coil response is proportional to frequency so the response does not extend to dc and the S/N degrades at low frequency.

GMW has developed a range of Current Transducers using an array of magnetic sensors to measure the magnetic field generated by the enclosed electrical current. This approach is particularly suitable for the measurement of high dc and ac current with frequency response up to about 75kHz (-3dB). There is no magnetic core and thus no magnetic hysteresis effects or damage from pulse or

continuous high current overload. The Transducer cross-section is small, and unlike a magnetic cored transducer, independent of the current rating. The Transducer aperture geometry can be designed to match specific cross-section current conductors with large apertures. For the measurement of high peak and/or high di/dt currents with a dc component a GMW Coreless Current Transducer can be co-located with a Rogowski Coil in a compact combination with no interaction between the two.

Ampere's Circuital Law:

Magnetic core or Rogowski Coil current transducers that provide an output signal accurately proportional to the enclosed current

$$\oint_C \mathbf{B} \cdot d\mathbf{l} = \mu_0 I_{enc}$$

$\mathbf{B}$ is the magnetic flux density in Tesla.
 μ_0 is the permeability of a vacuum.
 I is the current enclosed in Ampere.

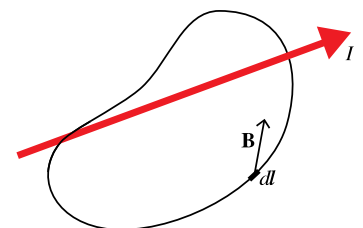


Figure 1: Ampere's Circuital Law

for frequencies from dc to over 2GHz are implementations of Ampere's Circuital Law as summarized in Figure 1.

Approximating Ampere's Circuital Law:

The GMW Current Probes utilize an array of "point" magnetic field sensors that can enclose the current to be measured. The Ampere's Line Integral can be approximated by a summation of magnetic field measurements made at points around the current, see Figure 2.

For "point" magnetic sensors providing an output signal proportional to B , the Line Integral can be approximated by a summation:

$$I = \frac{1}{\mu_0} \oint \mathbf{B} \cdot d\mathbf{l} \sim \frac{1}{\mu_0} \sum_{r=1}^n C_r \cdot B_r$$

Where B_r is the field component along the tangent to the enclosing line and C_r are constants that can be determined by magnetic modeling.

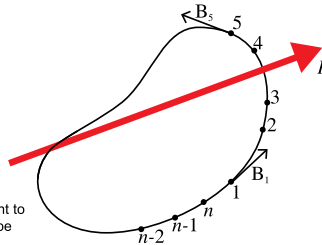


Figure 2: Summation Approximation to Ampere's Circuital Law

Different Probe Geometries:

Ampere's Law applies to any closed curve and thus the geometry of the Coreless Current Sensor can be tailored to the shape and dimensions of the primary conductor and associated insulation. Geometries GMW has developed include:

CPC Current Probe Clip:

Current Ranges: +/-250A to +/-2000A. Output Signal: 0 +/-2V. Sensitivity Accuracy, +/-1%. Aperture: 27mm circular. Mass: 30g (1oz). Operating Temperature: -40C to +100C. Dust & Moisture: Sealed IP65, EN60529. Power: +5V, <85mA (USB Port).



Figure 3: The very small size of the CPC Current Probe Clip enables it to be used in parallel with a Rogowski Coil to measure dc and low frequency current components on a vehicle charging cable without disconnection of any cables. Courtesy Argonne National Laboratory, Ted Bohn.

CPCO Current Probe, Clamp-On:

Current Ranges: +/-0.5kA to +/-16kA. Output Signal: Voltage or Current. Sensitivity Accuracy, +/-1%. Aperture: 77mm or 160mm circular. Mass: 120g or 300g. Operating Temperature: -40C to +85C. Dust & Moisture: Sealed IP65, EN60529. Power: +11V to 31V, <0.8W.

CCS Coreless Current Sensor, Slip-On:

Current Ranges: +/-0.5kA to +/-12kA. Output Signal: 0 +/-2V. Sensitivity Accuracy, +/-1%. Aperture: U-shape, 30mm wide x 90mm deep. Mass: 65g. Operating Temperature: -40C to +85C. Dust & Moisture: Sealed IP65, EN60529. Power: +5V, <150mA.

No Artifacts or Damage from any Primary Current Overload:

During an overload primary current the Magnetic Sensors of the Probe electrically limit and the Probe Signal output electrically limits at about 1.25 time the nominal range with no overshoot, sagging, ringing or damage from any continuous overload current.



Figure 4: Four CPCO Clamp-On, 160mm aperture, 12kA Current Probes used to monitor bus bar current in an electrochemical application with reliable operation in a harsh environment.

Within less than 10us of the primary current being within range the output signal follows the primary current with no baseline shift. This enables the current range of a Coreless Current Sensor to be selected for optimum signal to noise for the normal operation currents even though there may be very high fault current peaks.

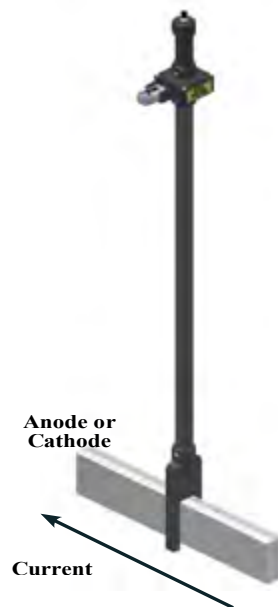


Figure 5: Hand Current Probe Assembly with Slip-On CSS, Insulating Handle and Data Logger for monitoring Bus Bar or Cable Current.

Current Probe Rejection of External Magnetic Fields:

The Summation Approximation to Ampere's Law provides high rejection of external magnetic fields arising from nearby currents or magnetic materials.

Signal Stability after Repeated Thermal Cycling:

Different Models of CPC Current Probe Clip and CPCO Current Probe Clamp-On have been exposed to 50 thermal cycles between -40C and +85C and the maximum changes observed are: Zero Offset, +/-0.4% of full-scale; Sensitivity, +/- 0.5%.

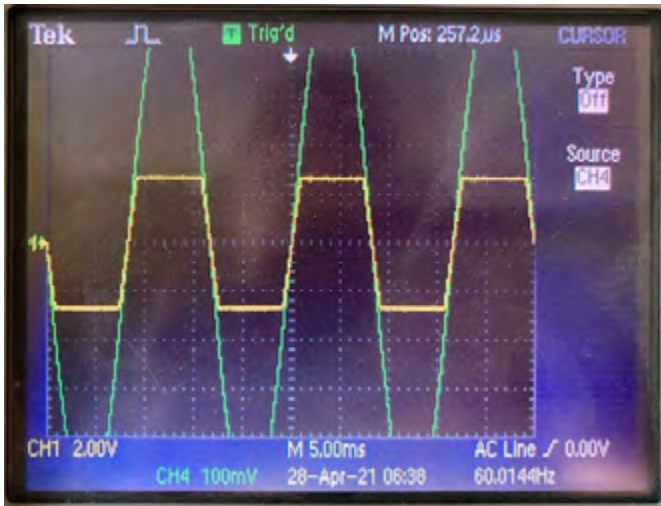


Figure 6a: The Output Signal from a CPC Current Probe Clip with nominal range of $\pm 250\text{A}$ operating with a 750Arms , $\pm 1060\text{A}$, 60Hz primary current. The Scope Sensitivity is 200A/division vertical and 10ms/division horizontal. The green trace is the primary current measured with a Fluxgate Transducer, the yellow trace is the CPC 250A Current Probe signal showing the clean electrical limit with the same sign as the primary current and no artifacts.

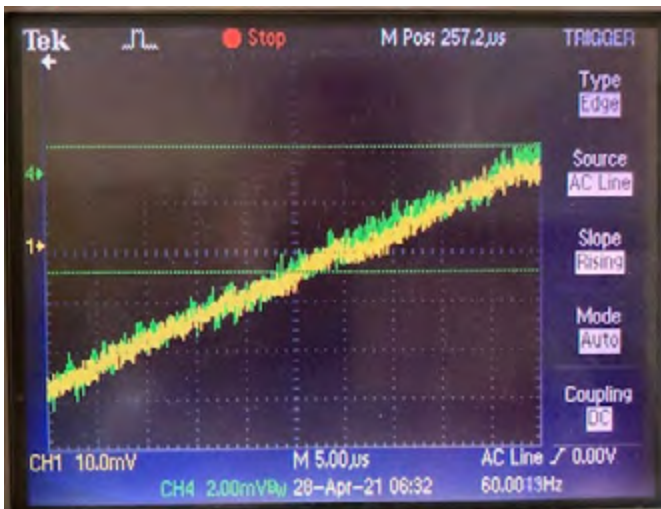


Figure 6b: The same measurement as Figure 6a with the vertical and horizontal sensitivities increased to show that there is negligible base-line and phase shift after a high current overload.

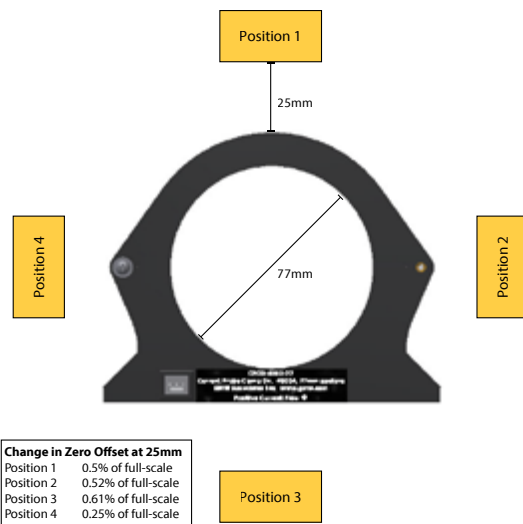


Figure 7: The Zero Offset change of a CPCO with 77mm aperture and $\pm 4\text{kA}$ range arising from a 1kA dc current at 25mm from the CPCO surface.

Low Signal noise down to dc:

The output signal noise of the Coreless Probes has no switching frequency peaks and is repeatable from Probe to Probe enabling continuous spectral analysis of the current to monitor for mechanical damage, vibration, insulation degradation or load changes. DC or low frequency current components can be monitored with high resolution on nominally ac primary current for protection of high efficiency ac power transformers.

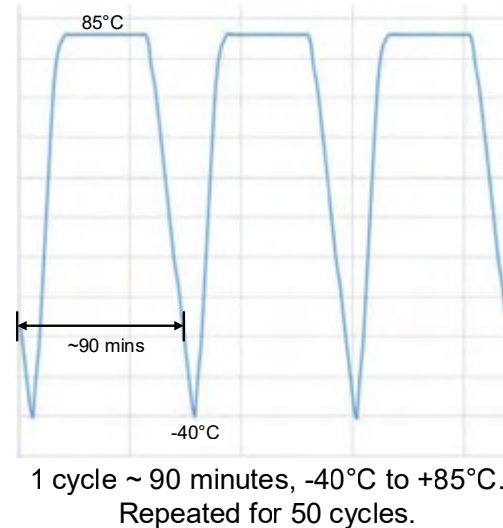


Figure 8: Temperature Cycle of CPC Current Probe Clip and CPCO current Probe Clamp-On to measure Zero Offset and Sensitivity Stability.

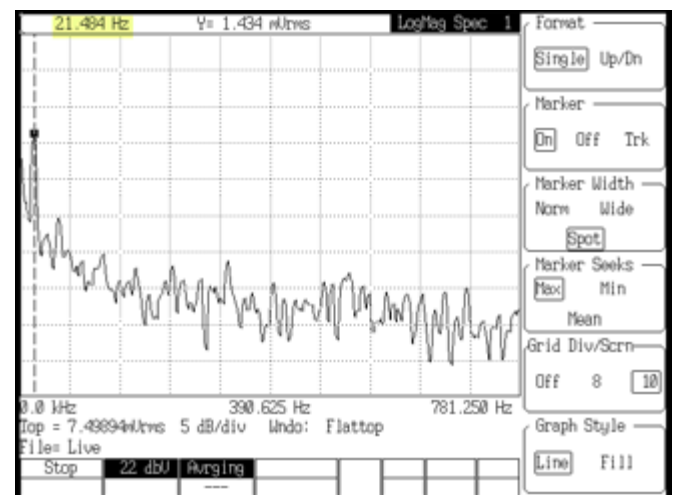


Figure 9: The noise spectrum of a CPCO with 77mm aperture and $\pm 4\text{kA}$ range with a primary current of about 0.15Arms at 21Hz . The primary current is clearly resolved.

Conclusion:

GMW Coreless Current Sensors with Clamp-On, Clip-On or Slip-On geometry and large apertures can provide isolated and continuous monitoring of high currents without disconnection of existing conductors in locations with restricted space and high magnetic fields from nearby currents or transformers. Accurate amplitude and phase response with low noise from dc to over 40kHz (-3dB) enables power and spectrum condition monitoring of electrical systems even in harsh environments with wide temperature variations, moisture, dust and mechanical vibration.

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Using GaAs Diodes to Reduce Cost in High Power LLC Converters

GaAs power diodes are wide bandgap semiconductor devices which exhibit excellent performance at about 70% of the cost of Silicon Carbide (SiC). In a previous article in this magazine in April 2021, it was demonstrated how GaAs diodes were able to offer system performance levels on a par with SiC in a 10kW Phase Shifted Full Bridge converter. This article extends this work to benchmark performance of GaAs, SiC and Hyperfast Silicon diodes in a 10kW LLC converter, a topology also commonly used for high efficiency EV charging.

By Dr. Iain Mosely, 3-5 Power Electronics

LLC Converter and Diode Types

The LLC is a popular topology which offers zero voltage switching for the primary side bridge transistors, Figure 1. It allows high switching frequencies to be used whilst maintaining excellent efficiency levels since switching loss in the primary MOSFETs is minimal. On the secondary side, power loss is incurred in the output rectifiers and the nature of this loss depends on the static and dynamic characteristics of the diodes used. The dynamic behavior of the diodes (Q_{rr} and body capacitance) also influences other aspects of the converter behavior.

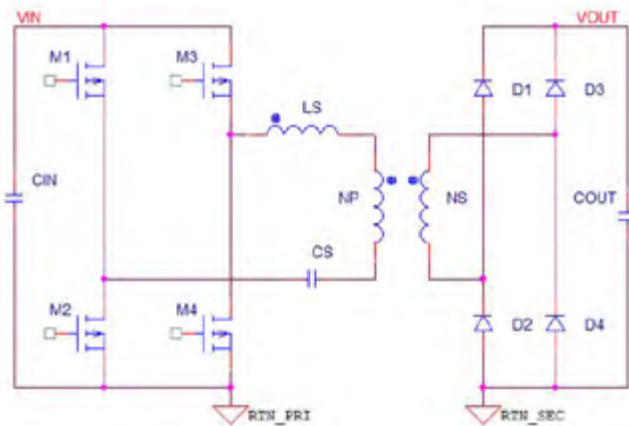


Figure 1: LLC Topology

For the work in this article, similarly rated SiC, GaAs and Hyperfast Silicon diodes were benchmarked as output rectifiers (D1-D4) for the 10kW LLC. These different diode types have differing static and dynamic behaviors:

SiC This is unipolar technology and has effectively zero reverse recovery loss, Q_{rr} . Losses will be incurred due to the forward conduction drop and to a lesser extent the diode non-linear parasitic body capacitance. The forward conduction drop has a positive temperature co-efficient and therefore diode conduction loss will increase with temperature.

GaAs This is bipolar technology so has a small but finite Q_{rr} . Losses will be incurred due to the forward conduction drop and the interaction of Q_{rr} in the operation of the converter. Note that the parasitic body capacitance is significantly lower than that of SiC. The Q_{rr} and forward voltage drop have only a small temperature dependence.

Hyperfast Silicon This is also bipolar technology but with significantly higher Q_{rr} than GaAs. As temperature increases, forward conduction drop reduces and Q_{rr} increases significantly. For any reasonable switching frequency, diode dynamic behaviour causes degradation in performance at higher temperatures.

10kW LLC Prototype

A 10kW LLC prototype was designed to allow practical benchmarking of the three diode types. The system was designed to operate from an 800Vdc input, 100kHz to 200kHz switching frequency and develop an output voltage from 400V to 600V with a maximum output power of 10kW. The system design parameters are:

Primary series inductance, $L_S=24\mu\text{H}$

Primary referenced magnetizing inductance, $L_{MAG}=129\mu\text{H}$

Primary series capacitance, $C_S=70\text{nF}$

Primary turns, $N_P=11$ and secondary turns, $N_S=7$

Low loss custom magnetics were fabricated for the prototype and the design parameters result in a system with a series resonant frequency of 123kHz. Operation of the converter from 100kHz to 200kHz will allow for examination of the performance both above and below resonance. Operation below resonance allows for natural commutation of the output diodes with low di/dt whereas above resonance operation will result in an increase in the output diode di/dt . The magnitude of Q_{rr} and its effects on the converter performance depend on di/dt of the diode and it is therefore useful to examine how the overall performance changes in these modes of operation with the different diodes. In the prototype hardware, diode di/dt varies from about $28\text{A}/\mu\text{s}$ below resonance to about $100\text{A}/\mu\text{s}$ above resonance. Note that a typical hard-switched topology would subject diodes to di/dt levels closer to $1000\text{A}/\mu\text{s}$.

Waveform Benchmarking

To help understand the differences in diode behaviour in the LLC in practice, the transformer primary current and secondary current in the converter were captured with an input voltage of 800Vdc, 100kHz switching frequency and 575V/17A/10kW load on the output.

Figure 2 shows that the GaAs and SiC based current waveforms are very similar and are typical for below resonance operation. In the case of Hyperfast Silicon, the impact of diode Q_{rr} on the measured currents is clear with the secondary current changing polarity at the end of the resonant pulse before settling back to zero. During this Q_{rr} period, the current in the primary resonant tank drops below where it would normally be with GaAs and SiC and this represents additional power dissipation incurred by the output rectifiers due to the Q_{rr} . In the case of the Hyperfast Silicon, the output rectifiers failed shortly after the waveform was captured, most likely

the result of the extra diode dissipation heating the part, leading to increased Qrr which then leads to greater heating and thermal runaway.

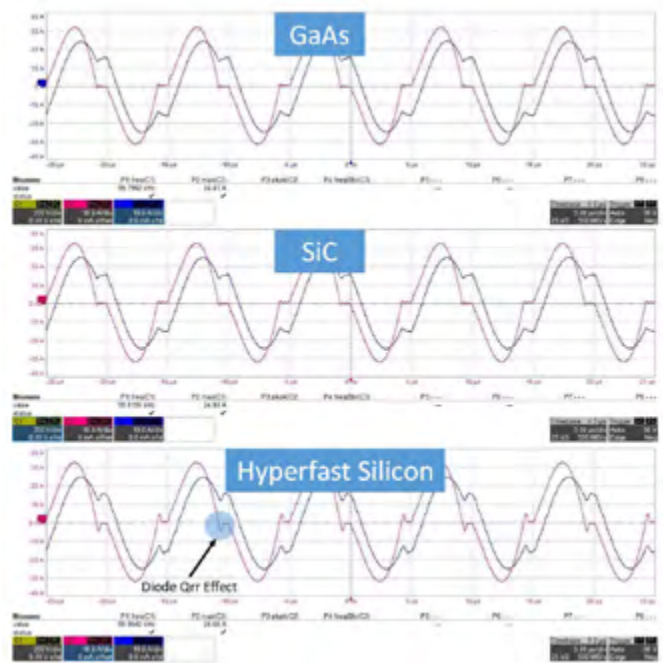


Figure 2: Primary (Blue) and Secondary (Red) Currents, 800V Input, 100kHz, 573V/17A/10kW Output

System Power Loss (GaAs and SiC Only)

The conversion efficiencies of the 10kW SiC and GaAs based LLC prototype are very similar, peaking at around 98% which makes benchmarking a challenge. A useful way to compare performance in these cases is to plot the overall power loss as a comparison metric instead. Figure 3 shows the measured overall loss in the 10kW LLC as a function of the DC output operating point, all with an 800Vdc input and 100-200kHz switching frequency. The green line in the figures shows the boundary of operation between above and below resonance. It is interesting to note that the boundary curve maps directly onto a point of inflexion in the power loss contours. This indicates that operation above resonance increases power loss in the converter, irrespective of the diode type used.

From the power loss plots, it is possible to see that performance with GaAs and SiC is very similar. Both technologies support highly efficient operation above and below resonance and over a similar output operating range. At very light loads, GaAs results in lower overall power loss, possibly as it has lower body capacitance than SiC. At higher power levels, the small Qrr related loss in the GaAs part leads to a lower overall loss in SiC technology.

The power loss difference at three key operating points is tabulated in Figure 4 and shows how close GaAs performance is to that of SiC. When driving 10kW output power at 578V output, the difference in system power loss between the SiC and GaAs solutions is only 13W.

Note that the Hyperfast Silicon diodes failed quickly during benchmarking tests, and it is believed that they suffered excessive heating

Point	Frequency	Diode Type	Output Voltage and Current	Output Power	Total Power Loss	Efficiency (%)	Power Loss Difference
	(kHz)		(V) / (A)	(kW)	(W)	(%)	(W)
1	100	GaAs	578/17.3	10	226	97.8	13
		SiC	577/17.4	10	213	97.9	
2	130	GaAs	503/19.9	10	241	97.6	31
		SiC	503/19.9	10	210	97.9	
3	160	GaAs	451/22.2	10	301	97.1	43
		SiC	450/22.2	10	258	97.5	

Figure 4: Performance Comparison at Key Operating Points

because of their Qrr which is also strongly temperature dependent. The measurements and observations so far indicate that Hyperfast Silicon is not a contender for high frequency, high power resonant applications. A similar conclusion was drawn in our Bodo's article in April 2021 with operation of the Hyperfast Silicon parts in a 10kW PSFB running at 100kHz.

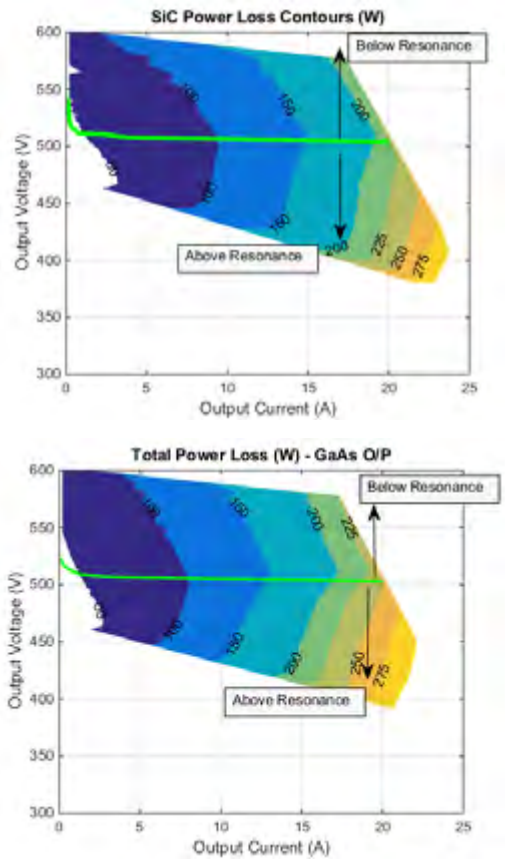


Figure 3: Power Loss Contours for 10kW LLC. SiC Solution (Left), GaAs Solution (Right)

Measurement Accuracy

Benchmarking of diode performance in the 10kW LLC application requires accurate measurement of system input and output powers. Whilst accurate test equipment was used to perform the measurements detailed in this report, measurements will encompass uncertainty which can make comparison of small differences and the conclusions drawn from them inaccurate. For the work presented in this article, component operating temperatures were also monitored, and the trends in temperature observed correlate well with the differing power levels measured.

Conclusions

The impact of power diode characteristics on the system level performance of a converter depends on many parameters including topology, operating frequency, and temperature. In the case of high frequency resonant converters, diode dynamic characteristics influence an important part of the loss budget. The experimental work described in this article demonstrates that the very low and

stable Qrr offered by new GaAs power diodes allows for LLC system performance levels very close to those of SiC. Importantly, the cost of these GaAs diodes is only around 70% of equivalent SiC parts, offering the designer an ideal opportunity to trade off a small performance reduction for a significant cost saving.

Multiply the Power of a Boost Converter with a Versatile Phase Expander

There's a general understanding in the engineering community that multiphase functionality required when boost converters must supply high output voltages, work from low input voltages, provide high step-up ratios, or support high load currents. Multiphase boost designs have a number of advantages over single-phase designs, including: increased efficiency, improved transient response, and reduced input and output capacitance values (due to reduced inductor ripple current and ripple current in the input and output capacitors) resulting in reduced thermal stress on the components of the entire boost converter power train.

By Victor Khasiev, Senior Applications Engineer, Analog Devices

The easy part of designing a multiphase boost converter is connecting the input supply and output rails to reduce the size and cost of the input/output filters. The difficult part is connecting the outputs of the error amplifiers and feedback pins of the phase controllers to ensure balanced current sharing and correct phase synchronization. Both signals are extremely sensitive to noise and, even with a very careful layout, can be affected by the sharp current and voltage changes typical in boost converter applications. Some boost controllers come with multiphase functionality to solve this problem, but many do not. For controllers that do not have multiphase circuitry included, the LT8551 multiphase boost converter phase expander solves the problem by operating alongside, and detecting the states of, the switching components of the primary controller. The LT8551 duplicates its functionality, measures the primary controller inductor current, and adjusts the inductor current in each added phase. The LT8551 is an excellent choice for automotive and industrial applications due to its high input/output voltage (up to 80 V) and ability to produce very high power boost converters, including those with bidirectional current flow.

Functionality of the Converter

Figure 1 and Figure 2 show a complete LT8551-based phase expander solution. To clarify functionality, the phase expander U1 is divided into three subcircuits: U1.1, U1.2, and U1.3. The interface, U1.1, communicates with the primary controller U2 and any external signals. The power stages U1.2 and U1.3 implement actual power conversion and control the MOSFET switches. All three sections of U1 shown in Figure 1 and Figure 2 are integrated in the LT8551 controller.

The primary controller, U2, senses the output voltage through its FB pin. It also completes the functionality of the peak current-mode control with its ITH pin as the output of the error amplifier. All high impedance circuitry (off the FB pin) and noise sensitive components (off the ITH pin) are adjacent to U2 and do not connect to external components. This approach enables compact and noise-shielded layouts.

Instead of using the typical feedback and error amplifier signals to expand phases, the LT8551 implements an elaborate (but more

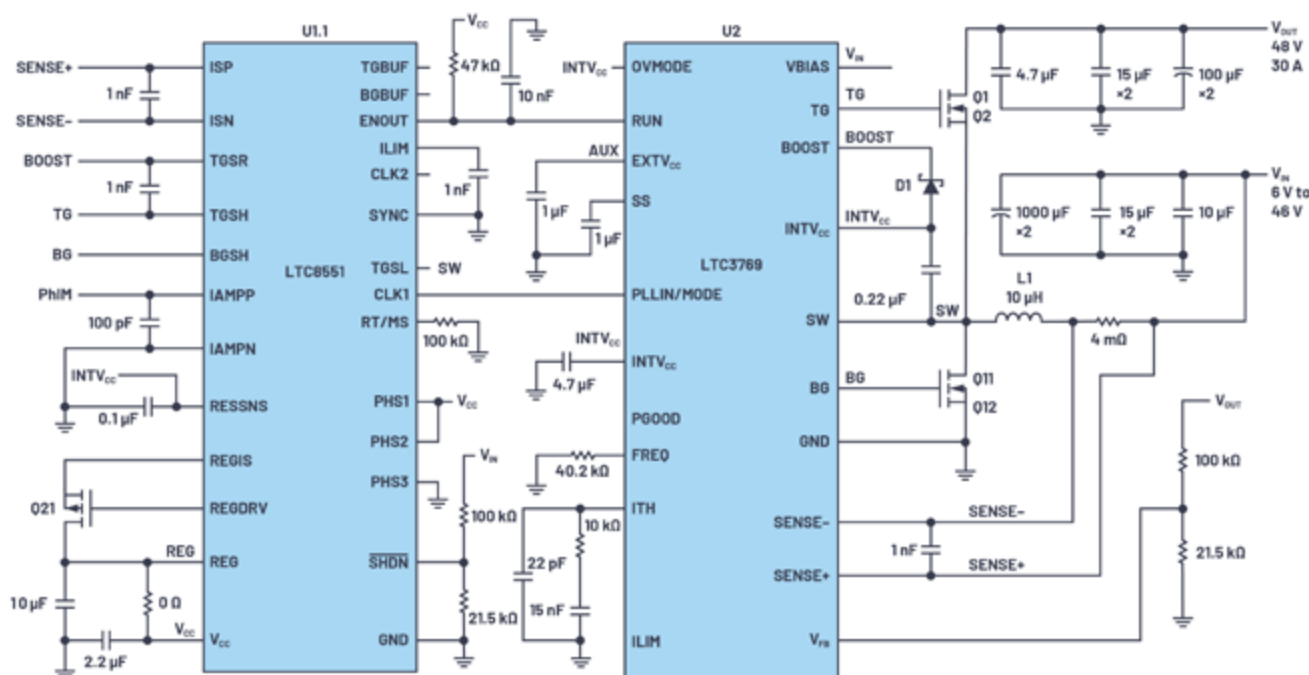


Figure 1: The interface of the LT8551 phase expander U1.1 to the primary controller U2. The four additional (expanded) power phases of the solution are shown in Figure 2.

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robust) switch state detection scheme. The subcircuit U1.1 relies on the robust signals of the gate drive voltages, BG and TG, and switching node signal, SW, of the primary controller to manage the four phases comprising the power trains driven by U1.2 and U1.3. The controller U1 equally balances the inductor currents among all phases (extender and primary). This is done by measuring the output currents of each channel via the corresponding current sense ISP_x, ISN_x pins, and the ISP and ISN terminals connected to SENSE+ and SENSE- of U2. The INTV_{CC} and bootstrap voltage (BOOST) signals are also factored into the control equation.

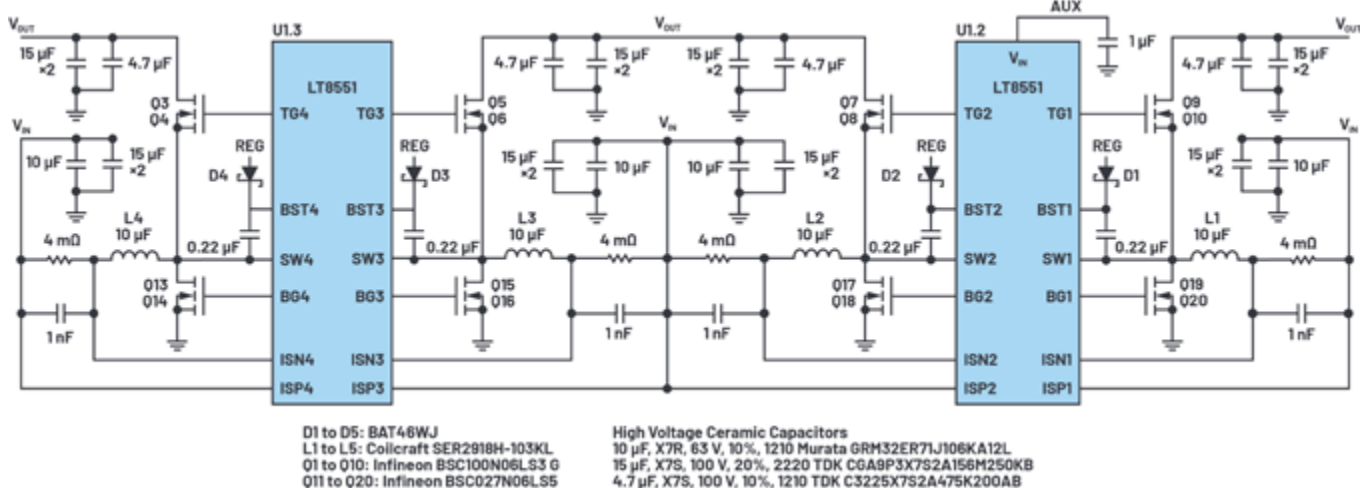


Figure 2: An electrical schematic of the LT8551 power section, U1.2 and U1.3. The LT8551's interface to the primary boost controller is shown in Figure 1. The V_{IN} = 6 V to 46 V, while the V_{OUT} = 48 V at 30 A.

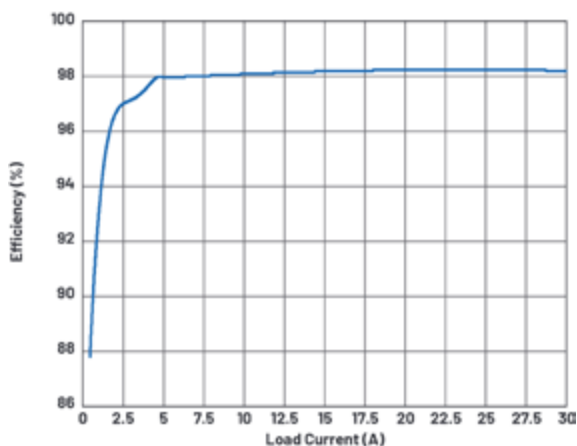


Figure 3: Converter efficiency at V_{IN} = 24 V with convection cooling (no air flow).

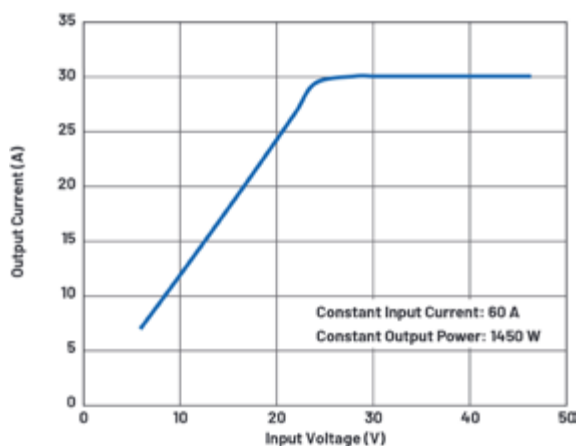


Figure 4: Converter input voltage vs. load current derating curve.

The schematics in Figure 1 and Figure 2 illustrate a minimum configuration for a boost converter featuring up to five phases. The LT8551 can be used to scale up nearly any single-phase boost controller up to 18 unique phases, with a corresponding multiplication of available output power. In >5-phase configurations, one LT8551 is the master, with additional LT8551 controllers acting as slaves. The CLK1 signal of the master synchronizes primary and slave controllers, whereas the CLK2 signal defines the phase angles for the consequent phases, with up to 18 unique angles. The 18-phase limitation does not necessarily limit the number of channels—if chan-

nels are allowed to share the same phase angle, then the number of power phases is essentially unlimited.

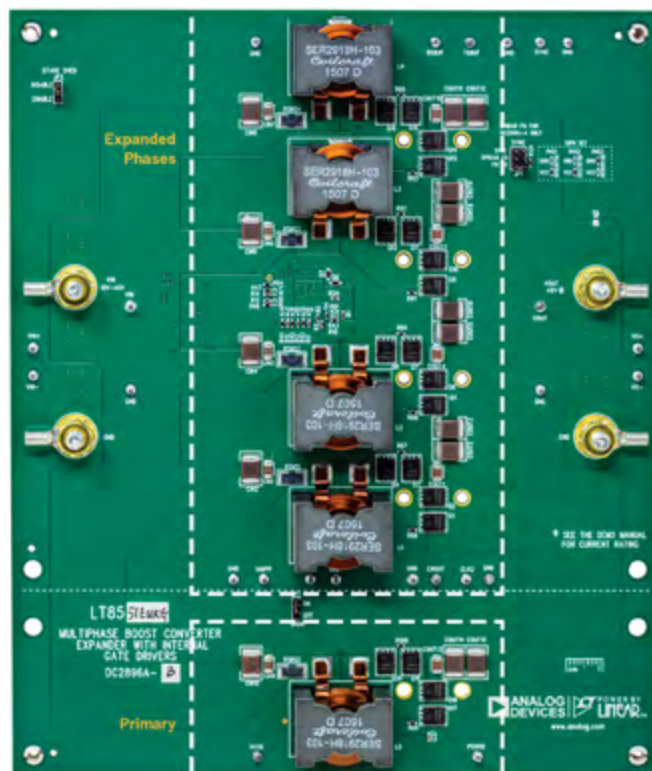


Figure 5: An LT8551-based demonstration circuit DC2896A-B.

The power train configuration shown in Figure 1 and Figure 2 comprises N-channel power MOSFETs Q1 through Q20, inductors L1 through L5, and input and output filters. The efficiency of the converter is shown in Figure 3, with a maximum output current of 30 A, an output voltage $V_{OUT} = 48$ V, and an input voltage $V_{IN} = 24$ V. The load current should be reduced to lower than V_{IN} to limit the input current and thermal stress. The load current derating curve is presented in Figure 4. The LT8551 includes internal inductor current balancing circuits that provide excellent current sharing between the phases, from $\pm 6\%$ to $\pm 10\%$ at maximum.

To reduce thermal stress on both controllers, especially at higher voltages, use the auxiliary power source (AUX). One solution can be found in the LT8551's schematics. A photo of the DC2896A-B evaluation circuit, with designated primary and expanded phases, is shown in Figure 5. The thermal image of the expanded phases is shown in Figure 6.

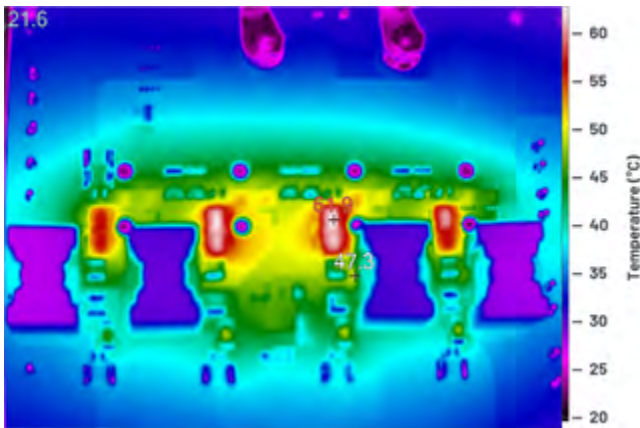


Figure 6: An LT8551-based demonstration circuit thermal image with convection cooling (no air flow). $V_{IN} = 24$ V, $V_{OUT} = 48$ V at 25 A.

Conclusion

The LT8551 phase expander gives power supply designers a flexible tool to build high power, high efficiency boost converters by expanding switching phases until the desired limit of power is reached. High frequency (up to 1 MHz) helps minimize power components' size, and integrated gate drivers, along with accurate inductor current monitoring and balancing, help prevent saturation and evenly spread heat across a board's surface.

About the Author



Victor Khasiev is a senior applications engineer at ADI with extensive experience in power electronics both in ac-to-dc and dc-to-dc conversion. He holds two patents and has written multiple articles. These articles are related to using ADI semiconductors in automotive and industrial applications. Topics cover step-up, step-down, SEPIC, positive-to-negative, negative-to-negative, fly-back, forward converters, and bidirectional backup supplies. His patents include efficient power factor correction solutions and advanced gate drivers. Victor enjoys supporting ADI customers by answering questions about ADI products, designing and verifying power supply schematics, laying out printed circuit boards, and troubleshooting and participating in testing final systems.

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Benefits of Rugged DC-Link Capacitors in Harsh Applications

The DC-link capacitor has a key role to play in several application sectors that are rapidly evolving such as electrically-propelled vehicles and renewable energy. However, as designers seek ever greater performance and reliability, DC-Link capacitors must work in increasingly challenging environments.

By Matteo Taglioli, Business Line Manager, Automotive Film Capacitors at KEMET Corporation, a YAGEO Group Company

According to a Precedence Research report covering the electric vehicle market, the global electric vehicle market is expected to reach a compound annual growth rate (CAGR) of 40.7% from 2020 to 2027. As a result of this market expansion, the demand for high-performance, rugged DC-Link capacitors that are suited to automotive use will increase at a similar level.

This article, will look at where DC-Link capacitors are commonly used and examine the critical considerations for choosing the correct device for an application.



DC-Link capacitors – an overview

DC-Link capacitors are an essential element within power conversion systems, especially in modern applications such as electrically-propelled vehicles where they are used in inverters that drive the motors and onboard chargers (OBC). Other applications include renewable energy systems, including photovoltaic and wind power inverters and industrial motor drives. Acting as a charge reservoir to smooth out the ripples inevitably introduced by switching power conversion solutions, DC-Link capacitors play a vital role in enhancing energy density and reducing ripple and noise.

However, components for use in power systems increasingly have to contend with harsh environments. In almost every application, space is at a premium meaning that designs are compact and, therefore, cooling is more challenging, leading to higher temperatures. Additionally, the advent of wide-bandgap semiconductors (SiC & GaN) allows designers to operate power conversion designs at higher temperatures, reducing active cooling needs and increasing efficiency – albeit by exposing components to additional thermal stress.

The automotive arena is particularly challenging as long-term vibration is an additional challenge while the vehicle is in motion alongside the thermal challenges and extreme space and weight constraints. With battery voltages increasing to reduce losses and extend range, the voltage across the DC-Link capacitor increases, putting a greater strain on the dielectric material.

Strong and rapidly increasing demand for electric vehicles, and within the renewable sector, requires high-performance components that are compact, lightweight, and have high dielectric capacitance coupled with high heat resistance for extended operational profiles. Additionally, capacitors used in converter and motor drive inverters require greater assurance of high-temperature performance than ever before, further adding to the challenges designers face in these demanding sectors.

Selecting a DC-Link capacitor

Within electrically propelled vehicles, one or more traction inverters is/are required to convert the high-voltage DC battery voltage into a three-phase drive for the electric traction motor(s). The DC-Link capacitor is an essential element of this system, ensuring a smooth and stable DC voltage on the DC-bus.

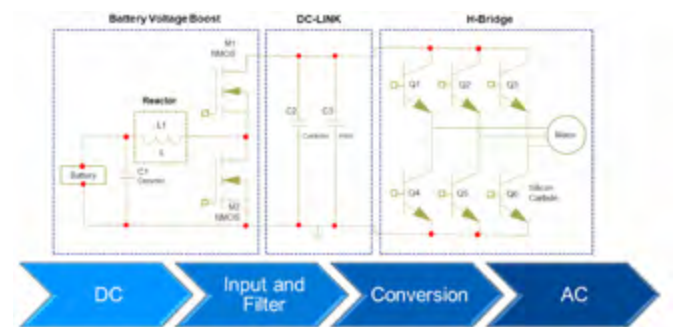


Figure 1: The DC-Link capacitor is an essential element of electric vehicle motor drive systems

[Source: <https://ec.kemet.com/blog/dc-link-design-tips/>]

The sole role of the DC-Link capacitor is to balance the fluctuating instantaneous power on the DC-bus created by switching activity within the battery controller (stage 1) and especially reflected ripple and noise from the high-frequency power switching devices within the three-phase drive (stage 3). To achieve this, it acts as a charge reservoir to buffer the sporadic demands for heavy current from the inverter in stage 3.

This formula gives the minimum capacitance needed to achieve a states ripple voltage:

$$C_{min} = \frac{I_{out} \times dc \times (1 - dc) \times 1000}{f_{sw} \times V_{P(max)}}$$

C_{min} = required minimum capacitance

I_{out} = output current

dc = duty cycle

f_{sw} = switching frequency

$V_{P(max)}$ = peak-to-peak ripple voltage

It is possible to use different technologies such as aluminum electrolytic, film, or ceramic type devices for the DC-Link capacitor with the (sometimes difficult) choice depending upon the application it is to be used in. The first step in choosing a DC-Link capacitor is

to consider the voltage ratings and nominal capacitance values of potentially suitable devices, ensuring high ripple current ratings. All DC-Link capacitors are required to regulate voltage and absorb the ripples that occur in the current waveform. As designs move to faster switching MOSFETs and IGBTs, the increasingly fast ripple affects performance as every 'real' capacitor contains some impedance and self-inductance. As the operating frequency of the inverter increases, some capacitor technologies are precluded – such as not using film capacitors above 1MHz.

Fully understanding the application is crucial when selecting DC-Link capacitors. As well as the DC bus voltage and operating frequency, designers must take the anticipated lifetime of the application into account and understanding the maximum possible ripple current and whether it is steady-state or variable. Ideally, the capacitor selected for a DC-Link application will have low values of self-inductance as well as low Equivalent Series Resistance (ESR) and high ripple current tolerance. The operating frequencies and operating temperature need to be compatible with the application. In general, film capacitors can cope with high ripple current and offer a longer operational life while offering substantially higher values than ceramic types.

Meeting the challenge

Meeting all the parametric needs for a DC-Link capacitor will be challenging, requiring designers to review many candidates before finding the optimum device.

One device that is a strong contender is KEMET's new high temperature, power film DC-Link capacitor. Denoted the C4AK series, it is specifically designed for continuous operation in rugged applications with elevated temperature profiles – such as those found in automotive applications.

C4AK devices offer a range of capacitance values from 1.5uF to 60uF and are rated for DC voltages up to 900V, making them suited to a wide range of EV powertrain uses. Even in harsh environmental conditions, they achieve a lifetime of 4,000 hours at 125°C and 1000 hours at 135°C, ensuring the long-term reliability of vehicles. The devices have been tested to the automotive AEC-Q200 standard, providing further reassurance to designers of their suitability.

A real-world example that has a current of 12A, operating voltage of 700V, switching frequency of 10kHz, and requires a DC-Link capacitor of 20uF. The application profile requires an operating temperature of 50°C for two-thirds of the time and 100°C for the remainder. KEMET's new C4AKOBW5200A3LJ DC-Link capacitor achieves this application profile easily, handling both the current and voltage while delivering a predicted lifetime of 66,400 hours.

Conclusion

DC-Link capacitors are essential for many modern systems including electric vehicles, renewable energy, and industrial applications. However, market pressure is forcing designers to deliver ever more compact solutions which require high-performance components that can cope with elevated temperatures and the need to operate over long lifetimes. KEMET's C4AK series addresses many of the challenges experienced in selecting a DC-Link capacitor for automotive applications. It combines long-term reliability with 900V operation at ambient temperatures as high as 135°C, making it ideal for demanding automotive applications.

www.kemet.com



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Integrated USB Type-C Charger Unification

Infineon's EZ-PD™ BCR (Barrel Connector Replacement) is a highly integrated USB-C controller, together with the USB-C connector, it replaces barrel connectors, custom connectors or legacy USB connectors in electronic devices. The EZ-PD BCR solution supports the USB Power Delivery (PD) standard that interoperates with all USB-C power adapters without the need of firmware development.

It minimizes BOM (bill of material) cost for the USB-C power-sink system and it guarantees USB-C specification compliance and interoperability through USB-IF certification. At the power-source, in the charger, the latest CoolGaN™ Integrated Power Stage (IPS) 600 V leverages the markets most reliable GaN and driver technologies, uniting ultimate efficiency and reliability with ease-of-use. GaN technology allows for higher switching frequency and more output power in the same size or smaller charger with the same power level. An integration results in very high power density making this device the first choice for fast charger designs. CoolGaN has an advanced breakdown field of ten times and an electron mobility of



two times higher compared to silicon devices. The key for the high frequency operation capability of CoolGaN lies in a ten times lower output and gate charge, compared to silicon-based devices and a reverse recovery charge of virtually zero.

www.infineon.com

3-Phase Gate Driver for EV and Hybrid Cars

Allegro MicroSystems is expanding its QuietMotion™ product line with the introduction of the A89307 automotive-qualified gate driver integrated circuit (IC). Designed for battery cooling fans and HVAC systems in electric (EV) and hybrid vehicles, the A89307 offers low noise and vibration by using a Field Oriented Control (FOC) algorithm to drive continuous sinusoidal current to the load, helping automakers reduce noise and improve battery life, offering more miles per charge and lowering vehicle carbon footprints. "By design, EV and hybrid vehicles are quieter than traditional models with internal combustion engines—especially when they're stopped—and drivers are becoming increasingly sensitive to noise created by components such as cooling fans," said Steve Lutz, Product Line Director for Motor Drivers at Allegro. "The A89307's hardware-based algorithm makes it easier for designers to reduce fan noise while improving cooling performance and increasing miles per charge. That's good for drivers, and good for the environment." The A89307 includes a hardware-based algorithm, which requires no external sensors or software development; the user simply selects parameters using a simple GUI interface and loads them into the IC's on-chip E2EPROM. With only five external components, the A89307 helps designers lower material costs by reducing BOM components



and facilitating very small system footprints for in-motor PCBs. Its fully integrated algorithm can even eliminate the need for a separate microprocessor.

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48 V Open Rack Power Shelf

Advanced Energy introduced a high-density, high-efficiency 48 V, 30 kW dual-feed Open Rack version 3 (ORv3) power shelf that minimizes the power consumption and improves the reliability of compute and storage applications in hyperscale and enterprise data centers. Featuring power supplies with demonstrated efficiency of 97%, Advanced Energy's Artesyn 2U shelf incorporates a hot swappable controller and can accommodate up to twelve 48 V, 3 kW open rack rectifiers with power up to 30 kW. These rectifiers include an embedded automatic transfer switch (ATS) capability that switches input to a secondary AC source on detection of primary AC power loss without any interruption to output voltage. "Minimizing power consumption and driving down costs are key challenges for data center operators as they look to meet the increased power demands of the latest high-performance processors," said Harry Soin, senior director of technical marketing for hyperscale data centers at Advanced Energy. "Evolving rack power from 12 V to 48 V architectures reduces conduction losses by a factor of 16, while open



systems compliance ensures interoperability and reduced total system costs. Advanced Energy's Open Rack power shelf and rectifiers directly address these requirements while adding ATS technology to ensure optimal availability."

www.artesyn.com

Real-Time Autonomous Sensing and Protection

Navitas Semiconductor has announced the launch of GaNFast™ power ICs with GaNSense™ technology. GaNSense technology integrates critical, real-time, autonomous sensing and protection circuits which further improves Navitas' industry-leading reliability and robustness, while increasing the energy savings and fast-charging benefits of Navitas' GaN IC technology. Gallium nitride (GaN) is a next-generation semiconductor technology that runs up to 20x faster than legacy silicon and enables up to 3x more power and 3x faster charging in half the size and weight. Navitas' GaNFast™ power ICs integrate GaN power and drive plus protection and control to deliver simple, small, fast and efficient performance. GaNSense technology integrates real-time, accurate and fast sensing of system parameters including current and temperature. This technology enables a patent-pending loss-less current-sensing capability, which improves energy savings by up to an additional 10% compared to prior generations, as well as further reducing external component count and shrinking system footprints. In addition, if the GaN IC identifies a potentially dangerous system condition, the IC is designed to transition rapidly to a cycle-by-cycle sleep-state, protecting both the device and the surrounding system. GaNSense also integrates an autonomous standby-power feature which automatically reduces standby power consumption when the GaN



IC is in idle-mode, helping to further reduce power consumptions, which is especially important to the growing list of customers aggressively pursuing their own environmental initiatives.

www.navitassemi.com

HIPAK NEXT GENERATION 3300 V AND 6500 V

HiPak IGBT modules are renowned for their high performance in traction, industrial or renewable energy applications. Now the performance has moved up a gear with the arrival of the Trench TSPT⁺ for 3.3 kV 1800 A and Enhanced Planar SPT⁺⁺ for 6.5 kV 1000 A IGBTs. With TSPT⁺, Hitachi Energy offers the next generation IGBT cell featuring a further 30 percent reduction in losses and opening up the possibility to increase current density.



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3-40W High Isolation DC/DC Converter for Railway Applications

RHKW/RHDW series are high performance DC/DC converters with 3000VAC reinforced isolation and 4.5 mm clearance/ creeping distances for safety critical application. These of board mountable DC/DC converters have been designed especially for the demanding, ruggedized railway and industrial applications. The series consists of 3-40W DC/DC converters with single and dual output models in a DIP24 (3-10W) or 2"x1" (40W) package. They have an input range of 36-160VDC and are equipped with circuits for over/under-voltage protection, over-current and short-circuit and over-temperature protection.

These high-density power converters are realized by using a patented transformer design, which lets the converters perform with an efficiency of up to 90%. The high dielectric strength plastic housing with high-thermal conductivity, comparable with metal casing, performs the isolation between input-case-output and allows for an operating temperature range of -40°C to +105°C. Our highly experienced R&D designers have equipped these converters additionally with internal EMI circuits: IEC/EN 55032 Class A and IEC/EN 50121-3-2, to simplify the design for saving space on PCB. This series is certified according to IEC/EN/UL 62368-1, EN 50155 and EN 45545-2. Additionally, shock and vibration are compliant with EN 61373 and MIL-STD-810F. With an operating altitude of up to 5000



meters, a wide operating ambient temperature of -40°C to +105°C, 36-160VDC input range, makes them very suitable for any safety critical application where a SELV output is mandatory. Examples are Bus Voltages of 72, 96, 110 VDC which need a safety barrier on the secondary side in rolling stocks, in transportation or in harsh industrial environments.

www.pduke.com

LED Driver with 4.5-75V Input Designed for Auto/Industrial/Med Apps

Taiwan Semiconductor announces the introduction of the TS19503 single channel, continuous conduction, hysteretic mode converter for driving single or multiple LEDs. Featuring 4.5-75V input and 2A output, the TS19503 offers up to 97% efficiency and 2% accuracy over a wide range of external conditions. AEC-Q100 qualification assures high reliability while the hysteretic (bang-bang) control technique provides high accuracy and reduced external parts count. Target automotive applications include high and low beam headlights; daytime running lights; turn indicators; position indicator lights; fog lights; ATV and four-wheel drive high-brightness lamps. The TS19503 is also well suited for DC input industrial and medical applications where SELV and line isolation considerations are a concern.

"The TS19503's constant current mode hysteretic control results in a very low parts count," reported Sam Wang, Vice President, TSC Products. "And our design calculator tool makes short work of implementing a working solution."

www.taiwansemi.com



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- Batteries in Power Electronics
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Deadlines

- 22.12.21 Receipt of synopses
- 02.03.22 Notification of provisional acceptance
- 01.06.22 Receipt of full typescript for final review



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