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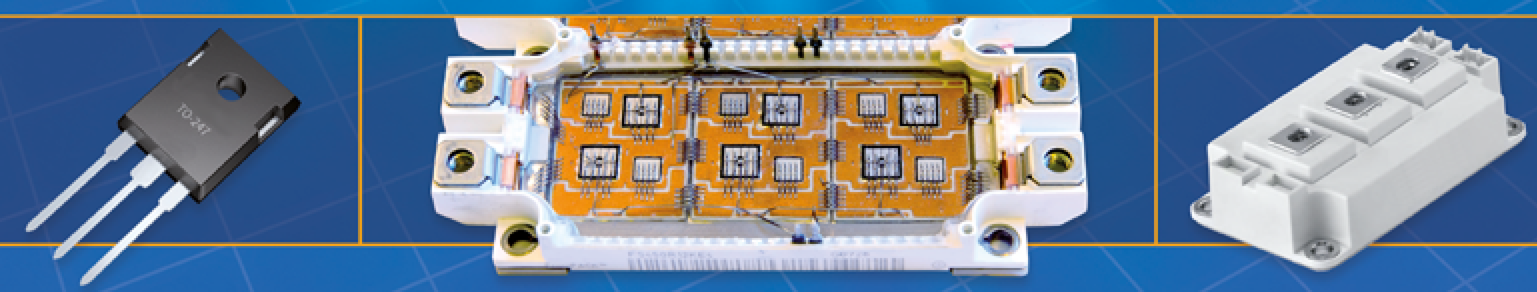
Bodo´s Power Systems®

Electronics in Motion and Conversion

January 2023



PULSED INDUCTANCE MEASUREMENT

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

Also suitable for 3-phase inductors

WIDE RANGE OF MODELS

7 models available with maximum test current from 100A to 10000A and maximum pulse energy from 1350J to 15000J

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

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

Technological leader in pulsed inductance measurement for 18 years

www.ed-k.de

Content

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PULSED INDUCTANCE MEASUREMENT

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

Publisher
Bodo Arlt, Dipl.-Ing.
editor@bodospower.com

Editor
Holger Moscheik
Phone + 49 4343 428 5017
holger@bodospower.com

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

Editor China
Min Xu
Phone: +86 156 18860853
xumin@i2imedia.net

US Support
Rusty Dodge
Phone +1 360 920 7825
rusty@eetech.com

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

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Only Good News, Please!

Happy New Year to all our readers, partners and friends. Bodo's team is looking forward to producing another 12 issues of the power electronics magazine of your choice. These will of course, like all their predecessors, be added directly to the archive on our website for all our e-book friends. On the same website, you will also find the latest industry news and our famous event calendar. I've heard a few times now that it is a welcome and helpful tool for planning events and trips throughout the year. We work hard to keep it as current as possible, so take advantage of this information so early in the year. Speaking of news: as an attentive reader of our magazine, you may have noticed over the past few years that we rarely include bad news in our updates. This is because general news in the newspapers is often bad and we don't want to publish this negative news from our industry. So, if you're looking for the latest bankruptcies, mass layoffs, and factory closures, you're sure to find them elsewhere. We will continue to focus on announcements of technical achievements, product releases, event news and innovations in power electronics. And we'll be on the lookout for good news, like global warming being stopped or peace becoming a reality. It's the beginning of the year, wishes and dreams are still allowed!

Other good news is that our recent Bodo's Wide Bandgap event was again a great success. Some numbers: We saw over 50 technical presentations, nearly 500 minutes of content. Bodo spoke with 51 speakers during the 12 live Q &A s on Zoom. Two-thirds of the attendees were from Europe, but one-third was from overseas, confirming that it was the right decision to schedule the event in the European afternoon time so that everyone could attend.

Ok, so one speaker from Asia said that it was quite late or early for him, depending on how you look at it. But he enjoyed the session, believe me! We are already looking forward to the next event, preferably in Munich. We will keep you updated in the magazine and on our digital channels.

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

My Green Power Tip for the Month:
This tip will probably soon be obsolete, but as long as there are cars with internal combustion engines: remember that it is not necessary to run the engine to defrost the windows. Sacrifice those five minutes and freezing fingers for the climate!

Happy New Year

Holger Moscheik

Events

IPC APEX 2023
San Diego, CA, USA January 21 – 26
www.ipcapexexpo.org

DesignCon 2023
Santa Clara, CA, USA
January 31 – February 2
www.designcon.com

3D-PEIM 2023
Miami, FL, USA February 1 – 3
www.3d-peim.org

embedded world 2023
Nuremberg, Germany March 14 – 16
www.embedded-world.de

APEC 2023
Orlando, FL, USA March 19 – 23
www.apec-conf.org

AMPER 2023
Brno, Czech Republic March 21 – 23
www.amper.cz

Smart Systems Integration 2023
Bruges, Belgium March 28 – 30
https://smartsystemsintegration.com

emv 2023
Stuttgart, Germany March 28 – 30
https://emv.mesago.com

electronica China 2023
Shanghai, China April 13 – 15
www.electronica-china.com

Product Distribution Center in Frankfurt

Texas Instruments announced plans to open a product distribution center (PDC) in Frankfurt, Germany, by the end of 2024. The PDC will expand the company's European footprint and enable faster deliveries to TI's growing customer base there.

"We are excited to expand our European presence in Frankfurt, as it offers a centralized location with proximity to key customers and our company's European headquarters in Freising, Germany," said Stefan Bruder, president of Texas Instruments Europe. "Frankfurt's key role as a logistics hub will mean faster deliveries to our European customers who are moving quickly to bring leading-edge products to the market." This Frankfurt location, near many of TI's industrial and automotive customers, will enable same-day delivery in central Germany and next-day delivery capabilities to most European-based customers. The Frankfurt site will pack and ship a broad range of TI technologies to support customers across Europe. "Expanding in Frankfurt is a logical extension of TI's presence in Europe and an important investment in our customers, providing them with even better service and support for decades to come," Bruder said.

www.ti.com

Joint Agreement to Develop Inverters for e-Axle Using SiC Power Modules

ROHM has signed a joint development agreement with Mazda Motor and Imasen Electric Industrial for inverters and SiC power modules to be used in the electric drive units of electric vehicles, including e-Axle. As the 'heart of the EV', e-Axle integrates a motor, reduction gearbox, and inverter into a single unit that plays a large part in determining the driving performance and power conversion efficiency of electric vehicles. SiC MOSFETs in particular are expected to improve efficiency even further.

ROHM will carry out joint inverter development for e-Axle by participating in a 'cooperative framework for the electric drive units development and production' with companies such as Imasen and led by Mazda. At the same time, ROHM will contribute to the creation of compact, high efficiency electrical units by developing and supplying advanced SiC power modules that provide improved performance. Through this collaboration, ROHM will develop even more competitive SiC MOSFETs and modules by working backwards from the finished vehicle to understand the performance and optimal drive method required of power semiconductors. Besides creating

value through mutual understanding between car and device manufacturers, the three companies also support technical innovation in the automotive field and contribute to a sustainable society by leveraging extensive knowledge, technologies, and products garnered on a global basis.

www.rohm.com

Funding Enables Mass Production of GaN Transistor Family

Cambridge GaN Devices (CGD) has raised $19m in Series B funding. The investment was led by Parkwalk Advisors and BGF, with participation from IQ Capital, CIC, Foresight Williams Technology and Martlet Capital. The investment will enable CGD to begin mass production of its range of GaN transistors for power applications.

CGD has already made remarkable progress, developing intellectual property and bringing to market its ICeGaN™ Gallium Nitride transistor family which addresses a $50bn global power semiconductor market. The company is positioned to disrupt multiple industries such as consumer and industrial power supplies, lighting, data centres and automotive HEV/EV. CGD's technology provides efficient, sustainable, and more cost-effective power solutions for electronic equipment.

As a result, CGD has gained global traction and attention at international conferences and in respected press. CGD is currently leading a $10m European-funded project developing GaN-based modules for low and high-power applications (GaNext); is participating in a UK supply chain initiative for PCB-embedded power systems with GaN devices (P3EP) and recently launched a project to develop highly reliable GaN power transistors and ICs to cut data centre

emissions (ICeData). CGD is also focused on key partnerships with their customers focused at the datacom and automotive solutions. The company has completed its brand development, moved to new offices, and now employs over 40 staff worldwide, with more planned to support the up scaling.

www.camgandevices.com

Collaboration on 8-Inch Gallium Nitride Power Semiconductor Manufacturing

EPC and Vanguard International Semiconductor Corporation (VIS) jointly announced a multi-year production agreement to produce gallium nitride-based power semiconductors. EPC will utilize VIS' 8-inch (200 mm) wafer fabrication capabilities, significantly increasing manufacturing capacities for EPC's GaN transistors and integrated circuits. Manufacturing will commence in early 2023.

The products manufactured at VIS, an Automotive IATF 16949 certified foundry, will meet the growing demand for GaN power devices in data centers, electric vehicles, solar inverters, robotics, and space systems. "EPC's GaN devices have superior performance, are easy to use, are extremely small, highly reliable, and very affordable. We are excited to partner with VIS to take advantage of their advanced, highly reliable, GaN platform to expand our capacity and meet our growing customers' demands," said Alex Lidow, CEO and co-founder of EPC.

"VIS' leading specialty IC manufacturing expertise, combined with EPC's product design capability and outstanding figure of merit (FOM) of GaN, will deliver greater energy efficiency for more eco-friendly high-performance computing and electric vehicle applications," said John Wei, COO of VIS. "We are thrilled to partner with EPC to bring this new-generation power device to new markets and applications, making contributions to environmental sustainability."

www.epc-co.com

Advanced Smart Electrical Outlet and Connector

VoltSafe announced a strategic partnership with Menlo Microsystems to co-develop an advanced electrical plug technology. Both companies are strong proponents of advancing how the world connects to electricity, and the combination of Menlo Micro's Ideal Switch technology with VoltSafe's smart electrical outlet and connector will enable the future of smart power connectivity.

Seeing deficiencies in existing relays and switches that caused the products they operated to be bigger, slower, less capable, or more expensive, Menlo Micro set out to create a better solution and developed Ideal Switch. The Ideal Switch is a device that delivers all the benefits of a mechanical relay and a semiconductor switch, with no compromises. The Ideal Switch is tiny, fast, reliable, withstands extreme temperatures, is ultra-low loss and can handle 1,000s of watts. Menlo Micro in March announced its $150 million USD Series C, bringing Menlo Micro's total cumulative funding to over $225 million USD. Vertical Venture Partners and Tony Fadell's Future Shape led the round. Menlo's Micro's confidence in VoltSafe's disruptive technology powering the future of how the world connects to electricity, paved the way for this early collaboration.

www.menlomicro.com

GaN ICs Fast-Charge from 1-50% in Only 7 Minutes

Navitas Semiconductor has announced its GaNFast power ICs have been selected for the 'in-box' 125 W charger of Motorola's latest flagship smartphone, the X30 Pro. A charge from 1% – 50% in just 7 minutes brings an ultra-fast charging experience to Motorola users. Jin CHEN, General Manager of Smartphone BU, Lenovo China commented on the launch of X30 Pro: "We hope to deliver a more comprehensive user experience in the flagship X30 Pro. By working hand-in-hand with Navitas and Aohai Technology, we are able to utilize GaN and speed up the charging capability of Motorola's smartphones to a new level. We look forward to collaborating further with Navitas and Aohai Technology, to break more records in charging speed, and offer a convenient and ultra-fast charging experience to our users." "We are excited that GaNFast technology empowers Motorola to achieve a more powerful charger. This time, Motorola, Navitas and Aohai Technology's collaboration reached a benchmark 125 W fast-charging solution on the new X30 Pro." said Charles (Yingjie) ZHA, VP and GM of Navitas China: "We are dedicated to offer an eco-friendly and ultra-fast charging experience for consumers. This tiny but powerful 125 W GaN charger demonstrates our continued effort to 'Electrify Our World™'. Navitas will continue to push the innovation of GaN technology to empower Motorola's charging roadmap."

www.navitassemi.com


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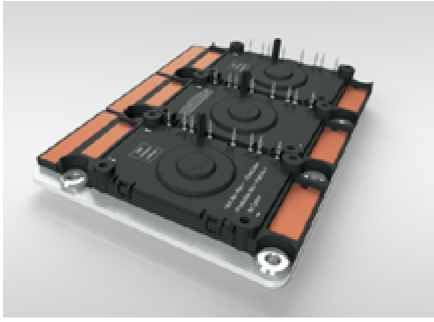
Modules for Silicon-Carbide Inverter Development

Semikron Danfoss announced a long-term agreement with Dana, a major Tier 1 manufacturer of propulsion solutions to power vehicles and mobile machines. The agreement is for the supply of silicon-carbide semiconductors for use in the company's Dana TM4 silicon-carbide inverters. The eMPack® platform from Semikron Danfoss is optimized for silicon carbide (SiC) technology, and the fully sintered "Direct Pressed Die" (DPD) technology, which allows for extremely compact, scalable and reliable inverters, was one of the crucial factors that clinched the deal between Dana and Semikron Danfoss.

"Semikron Danfoss is proud to be selected by Dana to deliver high performance SiC-based eMPack® traction modules for their future inverter platforms. Our modular design, capable of utilizing SiC devices from multiple chip sources, is the ideal module platform for Dana's broad inverter portfolio", said Siegbert Haumann, Senior Vice President, Semikron Danfoss Automotive Division.



Targeted for use across the light-vehicle, commercial-vehicle, and off-highway mobility markets, Dana's silicon-carbide inverter designs will enable higher system efficiency and power density in a compact package for medium- and high-voltage inverter applications, resulting in the potential for increased range.

"This long-term supply agreement with Semikron Danfoss gives us a strong strategic advantage as we expand the use of silicon-carbide technology and support our customers with innovative, efficient, and powerful solutions," said Christophe Dominiak, chief technology officer, Dana Incorporated.

www.semikron-danfoss.com

SiC & GaN User Forum: Potential of Wide Bandgap Semiconductors in Power Electronic Applications

The hybrid 'SiC & GaN User Forum: Potential of Wide Bandgap Semiconductors in Power Electronic Applications' from the ECPE will be held on March 28-29, 2023, in Erding/Munich, Germany. The technical chair is Prof. Andreas Lindemann, Otto-von-Guericke-University, Magdeburg, Dr. Peter Friedrichs, Infineon Technologies, and Prof. Leo Lorenz and Thomas Harder, ECPE. The programme will start with an overview on the status and trends in WBG Power Electronics. Then, the 1st day is dedicated to the use of GaN HEMTs in different systems and applications. Recent developments e.g. on bidirectional HEMTs, multi-channel tri-gate devices and vertical GaN devices will also be presented and discussed. The 2nd workshop day will concentrate on SiC device applications. Further, an outlook on promising ultra wide bandgap (UWBG) materials and devices will be given. The workshop will be closed with a panel discussion addressing the topics of WBG device maturity, robustness and reliability. International renowned experts are being invited to give an overview and to in depth explain their research and development work in technical presentations. Besides, the ECPE Wide Bandgap User Forum offers a platform for all participants to share experience and ideas. Registration Deadline is the 22nd of March.

www.ecpe.org

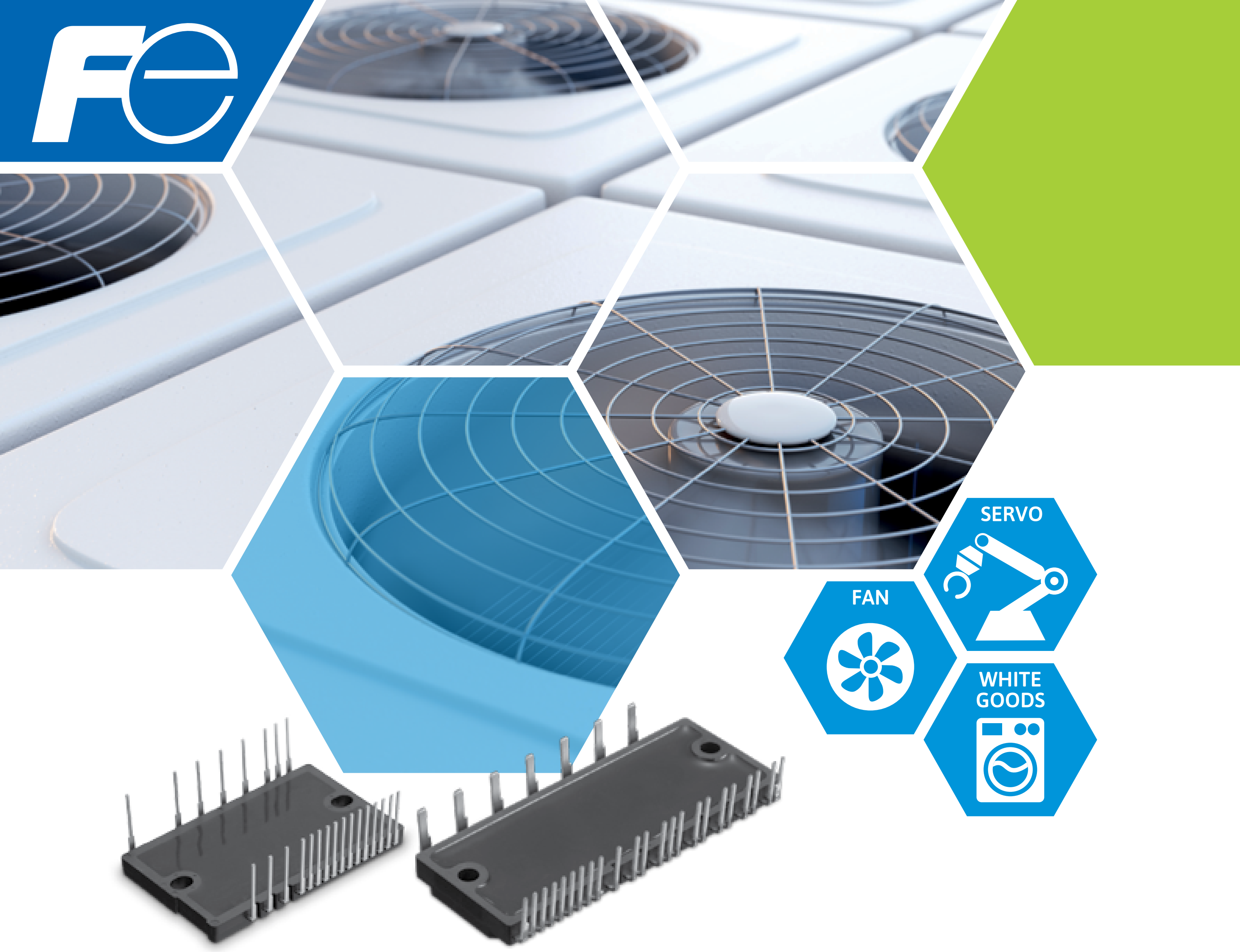
Partners to Automate and Speed Up EMC Tests

Electric vehicles contain many electronic components that emit radio-frequency interference which may have a negative impact on the vehicle performance and driving experience. To ease and speed up the development process, AVL and Rohde & Schwarz present an solution for automated electromagnetic compatibility (EMC) data analysis of an electric drivetrain under real driving conditions. The electrification of vehicles leads to new EMC challenges because of higher switching frequencies of semi-conductors and higher emissions due to high voltages and currents. EMS (Electromagnetic Susceptibility) and EMI (Electromagnetic Interference) testing of components and vehicles addresses these challenges. To meet time to market requirements, test automation is key. Additionally, the tests must be as realistic as possible, so there is a trend from static EMC testing of vehicles to dynamic testing where the drivetrain is active, varying in speed as well as torque during the execution of the EMC test.

"Many customers have been wanting for years to see Rohde & Schwarz EMC analyzers connected to the AVL EMC test automation system. Together, we have finally accomplished this, and are pleased to offer this new solution, improving and accelerating EMC validation of e-drives and vehicles," states Alban Hemery, Department Manager for E-Motor Test Systems and EMC Applications at AVL List GmbH.

"As market leader in EMC instrumentation, Rohde & Schwarz has a long and productive history of collaboration with AVL to develop leading-edge test systems for the automotive industry. The enhancement of R&S ELEKTRA to be compatible with AVL's PUMA 2 is another significant step speeding up EMC test times under real driving conditions, particularly for electric drivetrains," adds Juergen Meyer, Vice President Market Segment Automotive at Rohde & Schwarz.

www.rohde-schwarz.com



Small-IPM Series – 2nd Generation

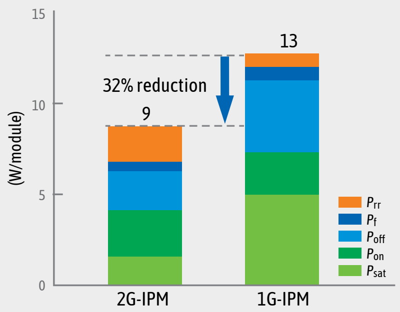
Ideal for Air Conditioners, Inverters and Servo Systems

MAIN FEATURES

- Reduction of losses and improvement of energy efficiency by utilizing 7th generation IGBT technology
- Built-in gate driver IC for optimum switching conditions
- Expansion of permissible operating area by improving the accuracy of overcurrent and overheating protection functions
- Utilizes an ultra-small DIP package with high heat dissipation aluminium insulating substrate

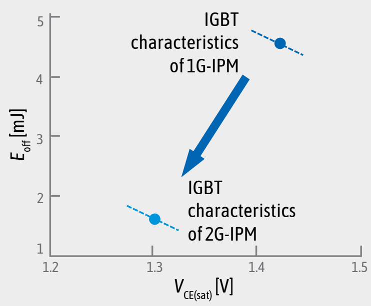
An IPM is a module which include three-phase inverter bridge circuit, control circuit and protection circuits.

Comparison with previous generation



$I_{O\,(RMS)}$ = 3 A, V_{DC} = 325 V, f_O = 60 Hz, f_c = 5 kHz, λ = 1.0, 3 ph-mod, T_c = 100 °C

Estimated loss of a 10 hp PAC at intermediate load 650V / 50 A rating



$V_{CE(sat)}$ — E_{off} trade-off

Investment Boosts Existing Power Management Expertise

Nexperia announced a broadening to its portfolio of power management products to include energy harvesting solutions. Energy can be harvested from light, vibrations, radio waves or temperature gradients and can therefore be used to replace batteries in low-power applications like smart wearables and autonomous wireless sensor nodes.

The expansion of Nexperia's expertise comes through the acquisition of Netherlands-based Nowi, founded in 2016. Nowi's PMICs combine small PCB footprint with low BOM cost and the best average harvesting performance. The manufacturing capacity and capability of Nexperia as well as its global infrastructure will ensure that together, Nowi will be able to speed the production of these solutions enabling higher volume production and shipping by the end of 2022 and early 2023.

"Nowi represents a strategically important investment because energy harvesting is the perfect complement to Nexperia's existing power management capabilities," says Dan Jensen, General Manager Business Group Analog & Logic ICs at Nexperia. "This decision means Nexperia can now offer customers a sustainable alternative to battery power for their products, that will be available in

the market quickly. The team at Nowi has built a strong foundation on which we are only looking to build and facilitate the ability to scale – both from the production side, but also the business and the team. We are excited to be bringing the Nowi team into the Nexperia family."

www.nexperia.com

Power Management System for BHP's Jansen Potash Project

ABB has been selected by BHP to deliver a power management system for the Jansen Potash Project in Canada, which will provide nutrient-rich potash fertilizer to enable more sustainable farming globally. The global resource company is progressing the US $5.7 billion Jansen Stage 1 Potash Project which is expected to achieve first production in late 2026.

The order includes ABB Ability™ System 800xA Power Control Library, a digital application to monitor industrial electrical systems. It will help BHP on its journey towards an automated, electrified and digitalized site where engineers can monitor and quickly troubleshoot disturbances. The system will cover the electrical substation equipment remotely, reducing the time taken for fault diagnosis and problem solving.

BHP's 100 percent-owned Jansen Potash Project in Saskatchewan, Canada, is planned to be the largest potash producing mine in the world with an initial Jansen Stage 1 capacity of 4.5 million tons per annum (Mtpa) and potential for 16 to 17 Mtpa through future development. Potash, a potassium-rich salt used as a fertilizer to improve the quality and yield of agricultural crops, is an essential plant nutrient and is increasingly vital due to land scarcity and a growing world population. ABB will ensure high levels of availability and efficiency of the energy supply to the process. BHP will also have access to data for the electrical substation and electrical assets and the bank of information available will build over time, allowing trends to be identified and actions taken.

www.abb.com

Partnership Contributes to the Technical Innovation of New Energy Vehicles

Shenzhen BASiC Semiconductor and ROHM have entered into a strategic partnership agreement on SiC power devices for automotive applications. A signing ceremony was held at ROHM's head-

quarters in Kyoto to commemorate the occasion. The signing ceremony was concluded by Weiwei He (right), General Manager of Shenzhen BASiC Semiconductor Ltd. and Isao Matsumoto (left), President and CEO of ROHM Co., Ltd. Under this agreement, the two companies will leverage their respective strengths to innovate and improve the performance of SiC power devices and develop higher performing, more efficient and reliable SiC solutions for new energy vehicles.

The first step involves supplying onboard power modules that leverage the combined technologies to several major automakers for use in electric vehicle powertrains. And going forward, both ROHM and BASiC Semiconductor will contribute to technological innovation in the automotive sector by accelerating the development of innovative power solutions centered on SiC.

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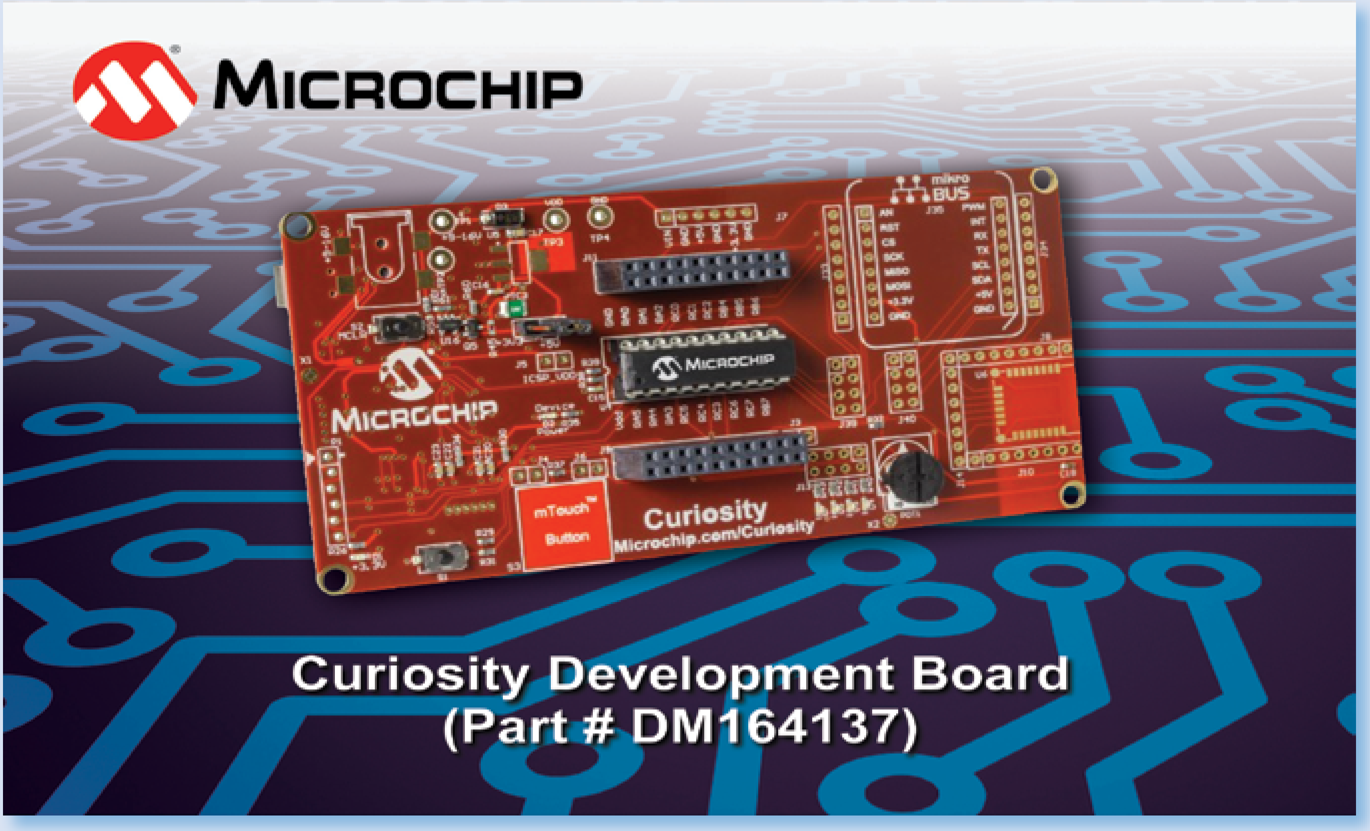
Win a Curiosity Development Board

Win a Microchip Curiosity Development Board (DM164137) from Bodo's Power and if you don't win, receive a 15% off coupon for this board, plus free shipping.



Microchip's Curiosity Development Board offers a cost-effective, fully integrated microcontroller development platform targeted at first-time users, makers and those seeking a feature-rich rapid prototyping board. Designed from the ground up to take full advantage of Microchip's MPLAB® X and MPLAB Xpress Integrated Development Environments, the Curiosity platform includes an integrated programmer/debugger and requires no additional hardware to get started. The Curiosity Development Board is designed to support 8-, 14- and 20-pin 8-bit PIC MCUs with low-voltage programming capability.

Out of the box, this board offers several options for user interface—including physical switches, mTouch® capacitive sensing and on-board potentiometers. A full complement of accessory boards is available via the MikroElectronika mikroBUS™ interface footprint.

The Curiosity Development Board can be operated as an all-in-one development platform, or you can customize it to suit your individual needs.

For your chance to win a Curiosity Development Board or receive a 15% off coupon for this board, plus free shipping, visit https://page.microchip.com/Bodo-Curiosity.html and enter your details in the online entry form.

www.microchip.com

Pulse Current Sources for High Current Wafer Tests up to 3000A

With its Power Choke Tester DPG10/20 series, ed-k is the technical leader in pulsed inductance measurement with rated currents of up to 10 kA. Since pulse current sources in the kA range are also required for the dynamic wafer testing of IGBTs, ed-k has developed new pulse current sources for this purpose in cooperation with a German semiconductor manufacturer.

However, there are further interesting innovations in the DPG10/20 series, e.g. for use in mass production and for measurements in the nH range.

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

As far back as 2002, ed-k developed the world's first commercially available inductance meter that works according to the pulse measurement principle. That was followed a short while later by the first model of the well-known Power Choke Tester DPG10/20 series, which is a fully integrated, extremely compact and simple to use measuring system with an enormously wide range of applications for all inductive power components. The device is operated using powerful PC software with a very simple to use graphic user interface. The DPG10/20 series has been continuously developed and successively supplemented by what is now a total of 9 further models for smaller currents down to the mA range and larger currents up to 10 kA.

ed-k's Power Choke Tester DPG10/20 series has long since established itself worldwide as the quasi-standard for the development, production and quality control of inductive power components.

Now, based on the pulse current sources used in the DPG10 series, ed-k has developed new pulse current sources up to 3 kA for the dynamic wafer testing of IGBTs, as previously available test systems could not cover this current range.

Two fundamental innovations in the Power Choke Tester DPG10/20 series will be presented in the second part of this article: an additional application, which has been optimised for routine testing in mass production, and new test adapters that enable the measurement of very small inductance values as low as 50 nH.

Measuring principle of the Power Choke Tester DPG10/20 series
In the pulse measurement principle of the DPG10/20 series, a square-wave voltage pulse is applied to the test specimen. The amplitude is adjustable and is conveniently selected so that it corresponds approximately to the voltage at the inductor in the real application. A current curve is then established in the inductor, whose slew rate di/dt is dependent on the current-dependent inductance L(i). When the preset maximum current or a preset pulse width is reached, the measuring pulse is switched off again.

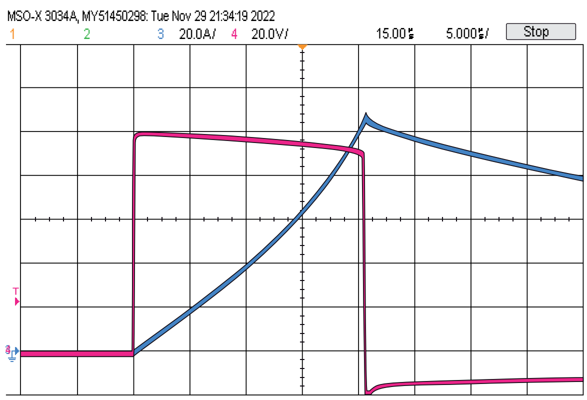


Figure 1: Measurement pulse of the Power Choke Tester DPG10 CH3: 20A/div, CH4: 50V/div

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:

- Differential inductance $L_{diff}(i)$ and $L_{diff}(\int Udt)$
- Amplitude inductance $L_{amp}(i)$ and $L_{amp}(\int Udt)$
- Flux linkage ψ(i)
- Magnetic co-energy $W_{co}(i)$
- Flux density B(i), if the core cross-section and number of turns are known
- Also suitable for 3-phase chokes with the optional 3-phase Extension Unit

Remark: The amplitude inductance $L_{amp}(i)$ is often also referred to as the secant inductance $L_{sec}(i)$.

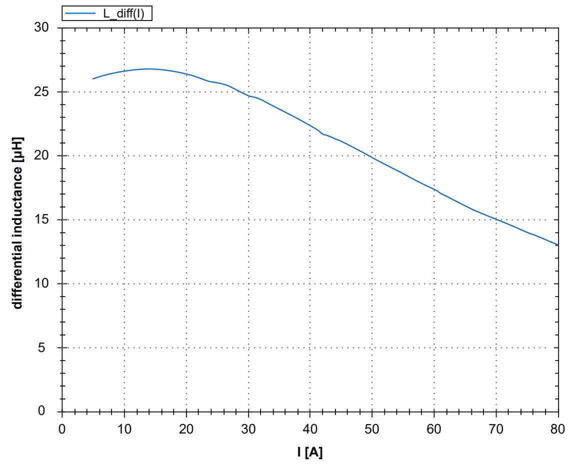


Figure 2: Measurement diagram $L_{diff}(i)$

The behaviour of all core materials is strongly dependent on frequency and amplitude. Since the measuring pulse has the same rectangular curve shape as in most power electronics applications and the same amplitude and frequency or pulse width as in the real application, the most realistic measurement results are obtained. Other measurement methods such as the small-signal measurement of LCR meters and the pulse measurement method with SCR use measurement signals that have nothing to do with the real conditions. Therefore, the results are usually not very meaningful.


Johannes Soldan, Stefanie Hagemann, Daniel Rückert, Steffen Knapp, GVA experts for development
gva-power.de
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POWER ELECTRONICS EXPERTS

The pulse voltage source takes the pulse energy from a capacitor bank. If its energy content is significantly higher than the energy withdrawn during the pulse, the voltage of the measuring pulse is roughly constant. Due to the principle, there is no upper limit for the capacitance of the capacitor bank, regardless of the type of test specimen. That is one of the reasons for the extremely wide application range of the Power Choke Tester DPG10/20 series for virtually all inductive power components, from small PCB-mounted inductors to reactors in the MVA range weighing several tonnes.

New device series of PCS10 pulse voltage sources

One of the core components of the pulse inductance meters from ed-k is a powerful pulse voltage source, which has to be able to supply currents of up to 18 kA depending on the model. The dynamic wafer testing of IGBTs also requires powerful pulse voltage sources for ramp-shaped currents up to several kA. Previously available test systems for dynamic wafer testing cannot cover this current range.

For this reason, a world's leading German manufacturer of power semiconductors has developed its own test system. It turned to ed-k for the necessary high-power pulse voltage source. Initially, the idea was to simply "misuse" a Power Choke Tester DPG10-3000B/E as a pulse voltage source. However, this simple solution was not satisfactory for the requirements in series production with test cycle times of < 400 ms.

Therefore, in cooperation with this semiconductor manufacturer, ed-k developed such a pulse voltage source for currents up to 3 kA based on the Power Choke Tester DPG10 series. It meets the specific requirements of dynamic wafer testing, such as short cycle times and fibre optic trigger outputs to activate the drivers for the IGBT chips. This ultimately resulted in the new PCS10 device series.

Model	PCS10-1000B	PCS10-3000B
Max. pulse current	1000A	3000A
Pulse voltage	10 – 400V	
Pulse width	1µs – 260ms	
Max. pulse energy	1250J	2500J
Pulse repetition rate	up to 5Hz	
Average pulse power	150W	
Load	resistive or inductive	
Control interface	USB and RS232	
Trigger outputs	Fiber optic and TTL	

Table 1: Technical data of the PCS10 series

Dynamic wafer test

In dynamic wafer testing, the RBSOA (reverse bias safe operating area) and the SCSOA1 / SCSOA2 (short circuit safe operating area) are measured according to the IEC60747-9 standard. The dynamic wafer test can detect defects in the chip that would not be detectable with a static test and can lead to failure during operation (e.g. latch-up).

To check the RBSOA, the clamped inductive load test is executed. Here, the IGBT chip is switched on with an inductive load of a few µH. The voltage of the pulse source does not need to be very high and is usually in the range of 50-200 V. A linearly increasing current then results in the load and in the IGBT. The IGBT is switched off once the desired current level is reached. The inductive load then drives the current further, so that the voltage at the IGBT rises sharply. The collector voltage is limited by a clamping circuit to a value below the breakdown voltage to prevent immediate destruction of the IGBT due to overvoltage. The IGBT chip must therefore be able to withstand both the full current and the clamping voltage for a short time during the shutdown process without being damaged.

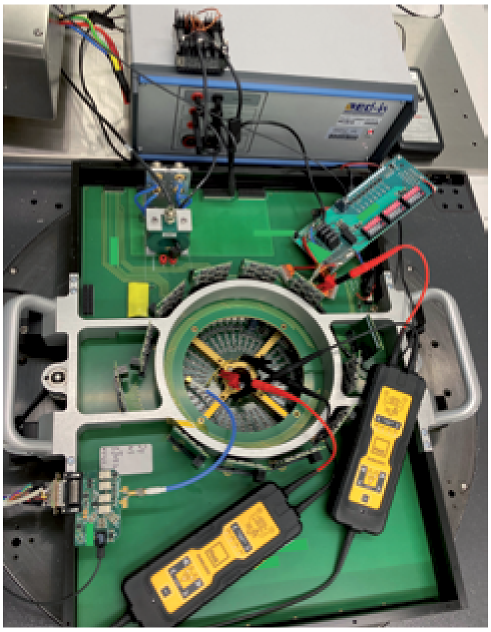

Figure 3: Test system for the dynamic wafer test

If the chip has a defect in its crystal structure, this usually leads to an explosion during the clamped inductive load test. The extent of the destruction on the wafer and the contact needles depends on the energy or current. Therefore, a sensible strategy is to first perform the test with a small current to minimise the destruction in the event of a failure and only then to repeat it with the full specified current.

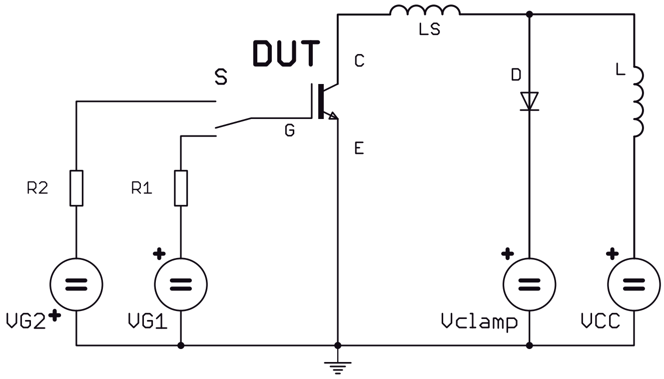

Figure 4: Simplified diagram of the RBSOA test according to IEC60747-9

In the SCSOA1 test, the switch-on is tested for a short circuit. This test is performed with a higher voltage, e.g. 50% of the maximum collector-to-emitter voltage V_{cemax}. The current in the IGBT chip then increases very quickly until it is limited by the desaturation

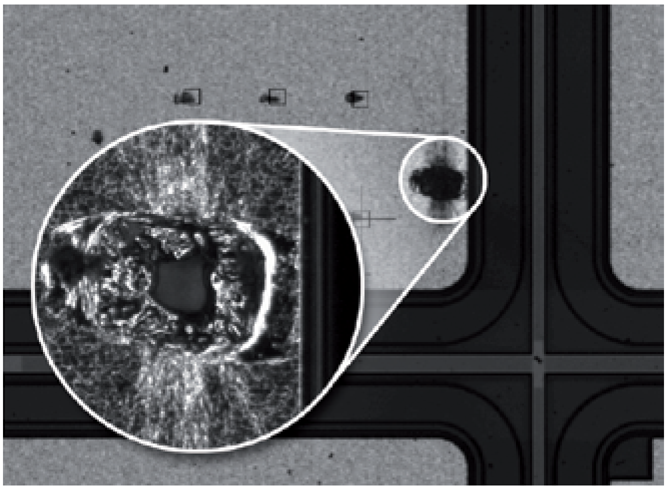

Figure 5: Destruction of the chip after the clamped inductive load test due to a defect in the crystal structure

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of the chip. In large IGBT chips this can be up to 3 kA. At the same time, the collector voltage remains at the full value of the voltage source. The power loss is extremely high and is in the MW range. Depending on the specification, the IGBT chip must be able to withstand this for a few µs without being damaged. Subsequently, the IGBT is switched off again.

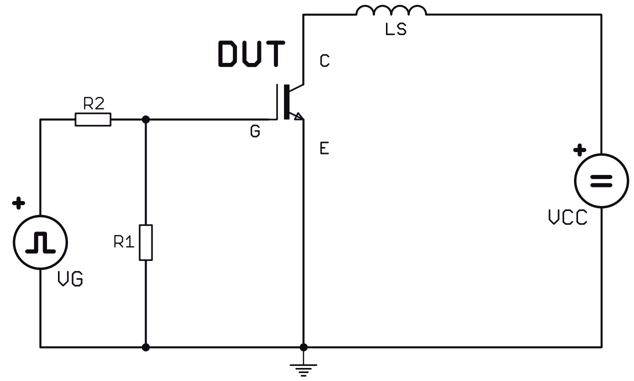

Figure 6: Simplified diagram of the SCSOA1 test according to IEC60747-9

The SCSOA2 test is similar. Here, however, the load is short-circuited with the IGBT switched on.

Further developments of the DPG10/20 series

Use of the DPG10/20 series in mass production

Until now, the Power Choke Tester DPG10/20 series has been delivered with a very powerful software that offers extensive measurement options.

This software is ideally suited for laboratory operation and for the routine testing of small series with manufacturing batches of up to several hundred items. This software was less suitable for the routine testing of very large quantities, as the measured data were saved in files in the XML format. With very large numbers of items these files become too big and can only be handled with difficulty.

However, it has also been possible up to now to use the DPG10/20 series in mass production. With the help of a supplied DLL, the devices can be controlled relatively easily by proprietary applications and integrated into customer-specific automated test environments (ATE). For control with proprietary applications, there is extensive technical support such as example programs for .NET, CS and C+.

Control by means of LabVIEW is also possible. VIs and corresponding technical support are also provided for this purpose.

Many major customers have already chosen the option of integrating the devices into their own test environments with the help of the DLL provided. For example, a well-known international manufacturer from the solar industry already uses more than 75 devices of the type DPG10-1000B for 100% routine testing of large quantities.

For the integration in the customer's own ATE, however, a certain amount of programming effort and the corresponding skills are required on the part of the customer. For this reason, ed-k has extended the software package for the Power Choke Tester DPG10 series by a plug-and-play solution for mass production. In addition to the already familiar application for laboratory and small series use, there is now a second application that has been specially designed for mass production.

The most important innovations in the production application are the storage of measured data in a database instead of in files as well as a completely new user interface that has been optimised for use in mass production in a harsh production environment.

The large amounts of data generated during mass production can only be stored sensibly in a database. Since many companies already use databases in production, the productive application can deal with different databases. This allows companies with several production sites to access the same database at all locations.

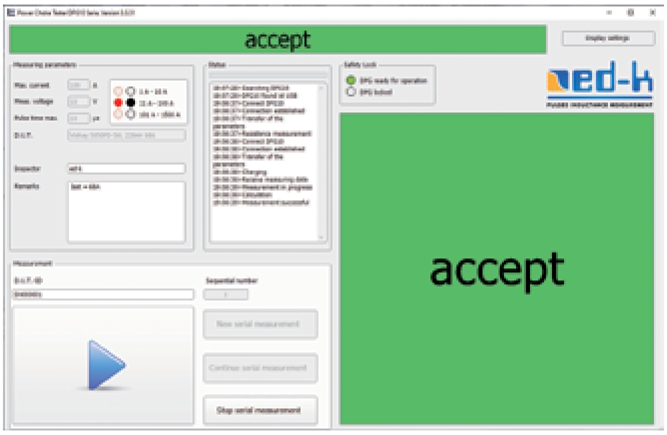

Figure 7: Graphical user interface of the new DPG10 application for mass production

The user interface of the productive application is limited exclusively to the operating and display elements necessary for routine testing, so that operation by unskilled personnel is also not a problem. Of course, an automatic PASS/FAIL test is carried out according to the specification of corresponding limit value curves. The display elements of the user interface are configurable. For example, a large coloured display area for PASS (green) or FAIL (red) is already clearly visible on the monitor from several metres away, so that the defective part can be sorted out. Alternatively, however, the measured inductance curve can also be displayed.

For high efficiency or short test times, the use of a barcode scanner is recommended. This means that, in addition to contacting the device under test, the test personnel only need to scan the barcode. Everything else runs automatically. With automatic handling and contacting of the DUT via a specimen-specific adapter, a fully automatic test is even possible.

After the redesign of the Power Choke Tester DPG10 series last year, which enables significantly shorter measuring times, cycle times as short as 2 seconds can be achieved in fully automatic testing.

However, the familiar application for laboratory and small series testing has also been significantly further developed. The application is now available in 32-bit and 64-bit versions. It can store the measured data both in the well-known manner as xml files and in a database. An export from the database and conversion into xml format is also possible, so that compatibility with older devices and measured data is guaranteed.

Measurement of low-inductance components down to 50 nH

The measurement of low-inductance components < 1 µH is basically problematic, regardless of the measuring device and measurement principle used. In the pulse measurement principle of the Power Choke Tester DPG10 series, it is above all the parasitic inductances, the inductive coupling between the force leads and the sense leads, as well as the maximum sampling rate that are decisive.

Together with the inductance of the test specimen, the parasitic inductance of the test leads as well as the device's internal parasitic inductance form an inductive voltage divider. If these parasitic inductances are larger or even much larger than the inductance of the test specimen, then only a small part of the voltage of the measuring pulse is dropped across the test specimen. Most of it is dropped across the parasitic inductances. This worsens the measuring accuracy, even if a 4-wire measurement is always used. In the 4-wire measurement, the voltage is tapped directly on the test specimen via separate sense leads.

To prevent the display of incorrect or inaccurate measurement results, measurements must be discarded if too much of the pulse voltage drops across the parasitic inductances. In order to be able to measure the smallest possible inductance values, the parasitic inductances must therefore be minimised.

The test leads play a significant role in the parasitic inductances. The optimized test leads made of highly flexible litz wire with a 6 mm² copper cross-section and a length of 0.6 m from the standard scope of delivery of the DPG10 series already has an inductance of more than 700 nH. In conjunction with further parasitic inductances for the alligator clips on the test specimen and the device's internal inductances, this limits the measurement to values of 500 nH at the most.

In order to extend the area of use of the DPG10 series down to 50 nH, ed-k has developed a set of 3 different test adapters that can be plugged directly into the sockets on the front panel of the devices without the use of test leads. The influence of the test leads can thus be completely eliminated. These test adapters are optimised for minimum parasitic inductances. In conjunction with the optimum internal design of the DPG10 series and the associated extremely low parasitic inductances, measurement can be performed in some case down to less than 50 nH!

Figure 8: Test adapter MAB1/2/3 for the Power Choke Tester DPG10 series

The test adapters are particularly suitable for SMD components and through-hole PCB-mounted components. A separate test adapter is required for each current range.

The measurement of low inductance values is also limited by the minimum possible pulse width, which is mainly limited by the maximum sampling rate, because the lower the inductance, the greater the slew rate of the current and thus the faster the preset current limit is reached. The A/D converters of the DPG10 series, an ed-k proprietary development, enable both very short measuring pulses due to a high maximum sampling rate and very long pulses due to an arbitrarily reducible sampling rate. Thus, an extremely wide pulse range from 3 µs up to 70 ms can be covered.

The maximum pulse width is not determined by technical limits, but has been limited to 70 ms due to safety considerations for the user. However, this is sufficient even for chokes that are used in a frequency range of <5 Hz.

New models in the DPG10 series

In the course of the continuous further development of the DPG10 series, two new models were developed with a maximum measurement current of up to 2000 A. The DPG10-2000B and DPG10-2000B/E models replace the DPG10-1500B and DPG10-1500B/E models, which will still be available for the time being. The current measurement ranges are 20 A, 200 A and 2000 A with the usual gradation 1:10, as with the other models. This results in better accuracy in the widest measuring range compared to the 1500 A models. The other technical data are the same as those for the 1500 A models.

Cover Artwork: Leonrosenbaum, CC BY-SA 3.0

About the author

Dipl.-Ing. Hubert Kreis is the owner of ed-k. He studied electrical engineering at the Technical University of Stuttgart and since 1994 has worked for various companies in the development of switch mode power supplies, electrical drive systems for heavy vehicles and power electronics for aviation equipment.

In 2002 he founded ed-k that specialises in inductance meters using the pulse measuring method with extremely compact IGBT high-power pulse voltage sources, and has helped this measuring principle to achieve a breakthrough worldwide.

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Power Modules for Onboard Chargers

Electric vehicles (EVs) are rapidly becoming state of the art in passenger cars, substituting combustion engine vehicles. Initially, one of the main challenges was the maximum distance covered by EVs in a single charge. Now, modern EVs can cover distances between 400 to 600 kms in a single charge due to increased Li-ion battery capacity, elevated nominal battery voltage of 800 V, and wide bandgap semiconductors.

By Koray Yilmaz and Christoph Schäfer, Infineon Technologies

To accommodate the full potential of this increased battery capacity, high speed charging becomes inevitable. For AC charging in passenger cars, onboard chargers (OBCs) are required. Earlier, the most common power rating of OBCs was in the range of 3.6 kW to 7.2 kW. However, with an increase in the battery capacity, the popularity of OBCs with rated powers of 11 kW and 22 kW will also increase.

Increased power rating and production volumes pose some challenges for modern OBC designs. For instance, despite the fact that the power rating of OBCs increases, the available installation space for the OBC stays nearly unchanged due to the limited space in EV. Therefore, an OBC with 11 kW or higher power rating will require a higher power density (W/l) compared to former OBC solutions. Additionally, as the power density of an OBC increases, the cooling of semiconductors in the OBC also becomes more crucial. This makes an optimized thermal connection between the semiconductors to the heatsink, essential.

Another challenge that modern OBCs need to address is fast and robust manufacturing. To meet the increasing production demands, OBCs need to be designed such that their production can be realized through automation. Additionally, to reduce costs at system level a vertical integration of components, for example, in the form of power semiconductor modules is also required. In short, to meet the increasing demand for EVs equipped with OBCs of 11 kW or higher charging power, design and manufacturing processes need to be optimized.

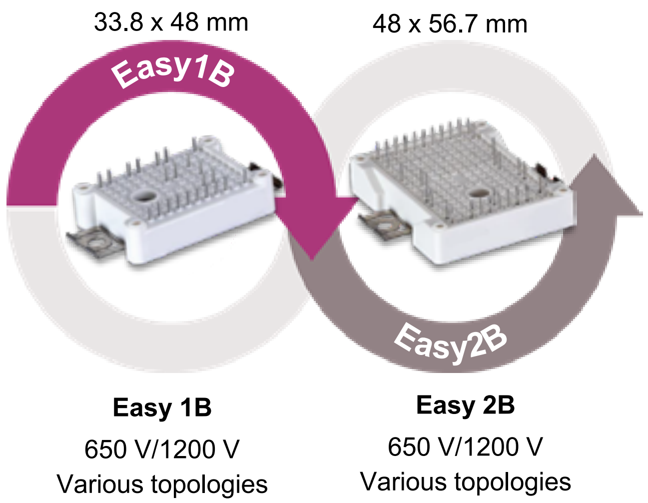

Figure 1: EasyPACK family with AQG324 qualification for OBCs

Here, EasyPACK™ modules offer the right-fit solution. As one of the industrial module standards set by Infineon Technologies, EasyPACK modules are well known for usage in applications such as EV chargers, general purpose drives, solar inverters, air conditioners, and many more. The two sizes of EasyPACK modules with AQG324 qualification, as shown in figure 1, provide the optimal area required for the semiconductors to realize a compact OBC solution.

A typical OBC consists mainly of a power factor correction (PFC) stage, and the primary and secondary sides of a DC/DC converter. For example, a 22 kW OBC solution can be easily achieved by using an EasyPACK 2B and an EasyPACK1 B. The EasyPACK 2B can utilize, for example, 12 pieces of 33 mOhm 1200 V CoolSiC™ M1H MOSFETs, allowing the PFC stage and the primary side of the DC/DC to be realized, as shown in figure 2 (a). Additionally, a negative temperature coefficient (NTC) resistance can be integrated in the module to monitor its internal temperature. On the secondary side of the DC/DC converter, the EasyPACK 1B can accommodate four pieces of 33 mOhm 1200 V CoolSiC M1H MOSFETs. However, EasyPACK 1B offers enough area to house the primary side of a high voltage to low voltage (HV/LV) DC/DC converter as well as an NTC, as shown in figure 2 (b). Using an EasyPACK 2B and an EasyPACK 1B the area required for semiconductor switches of a 22 kW OBC on the heat sink can be reduced to 43.4 cm². This design not only enables a very high power density, but also reduces the heat sink area providing more design flexibility.

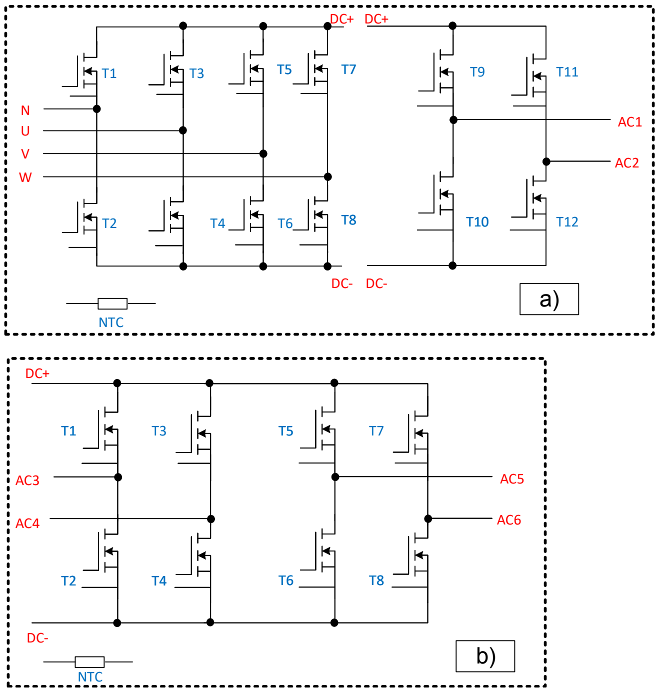

Figure 2: Common topology of OBC consisting of PFC (a) The primary side of DC/DC converter (b) The secondary side of DC/DC converter with integrated primary side of HV/LV DC/DC converter

The semiconductors in EasyPACK modules are placed on a direct-bonded copper (DBC) substrate. The layers of the DBC are shown in figure 3. On the top copper layer, the semiconductors are connected via soldering and wire bonding. The ceramic material between the top and bottom layer (can be either Al_2O_3, AlN, or Si_3N_4) isolates the high potential on the semiconductors from the ground. This eliminates the necessity of an additional isolation layer for the power semiconductors, which is an additional leverage for reducing the bill of materials and processing steps in production. One additional benefit of the DBC substrate, thanks to the ceramic layer, is stable isolation properties over its lifetime.

Another characteristic of EasyPACK is its very good thermal performance. EasyPACK modules are screwed directly onto the heat sink (see figure 5). This construction of the EasyPACK modules allows them to be fixed to the heat sink with a very low cavity. The resulting thickness of the thermal interface material (TIM) layer between the bottom side of the DBC and the heatsink is less than 100 µm. Such a thin TIM layer is sufficient to fill up the cavity and assure the connection of semiconductors with very low thermal resistance to the heat sink. For instance, a 80 mOhm 1200 V CoolSIC™ M1H in EasyPACK can achieve power losses of up to 30 W without exceeding the $T_{vj,max}$.

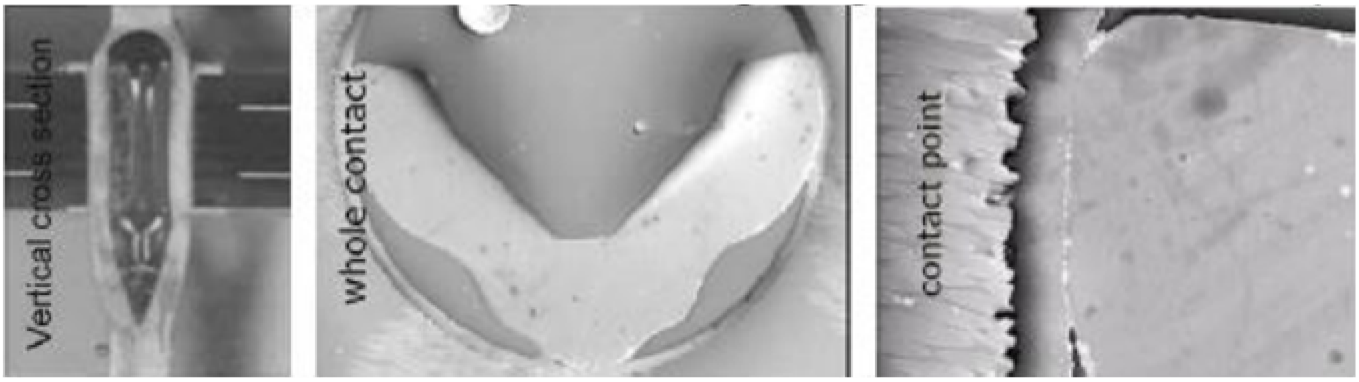

Figure 3: Cross sections of the PressFIT contact zones [2]

The connection of EasyPACK modules to the printed circuit board (PCB) is realized by PressFIT pins. The PressFIT pin has a press zone with galvanized tin that forms a cold-welding contact with FR4 PCBs. A cross section of welded parts is shown in figure 4. This interconnection provides consistent and continuous low electrical contact resistance (as low as 0.05 mOhm [1]). The cold-welded PressFIT contacts offer a very low failure-in-time (FIT) rate that according to [2] is a factor of six lower than that of automated soldered contacts.

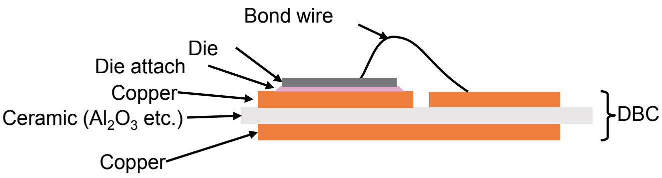

Figure 4: The layers of a DBC in an EasyPACK

Another benefit of PressFIT pins is the reduction in production complexity compared to selective soldering. Due to the height of the passive components and modules that need to be connected to the heat sink, the modules are located on the opposite side of the contact pins of the through-hole components. As the pins are pressed, only the side of the PCB, on which the contacts of through-hole components, such as capacitors, connectors and transformers are placed, needs to be selective soldered. Using the PressFIT pins to contact the modules to PCB, therefore, reduces processing time and handling complexity; thereby reducing production costs.

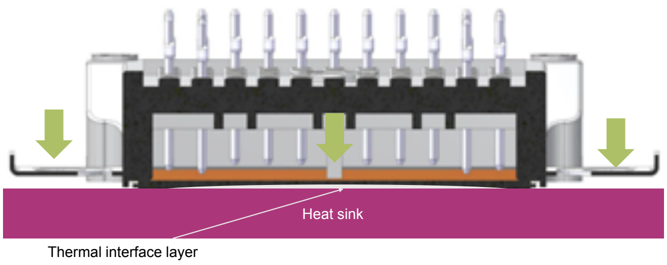

Figure 5: The construction of EasyPACK allows a low cavity between module and heat sink

Furthermore, the screwed EasyPACK in combination with PressFIT pins eliminates nearly all mechanical and assembly process related tolerances, and reduces the mechanical stress on the PCB.

Conclusion

The growing demand for OBCs with higher power ratings, such as 11 kW and 22 kW, necessitates higher vertical integration and easier manufacturing capability to increase productivity and achieve better economies of scale. These requirements can be easily fulfilled by using integrated power modules such as EasyPACK. For example, it is possible to concentrate power semiconductors in a 800 V 22 kW OBC within 43.4 cm² area using a single EasyPACK 2B for the PFC stage and primary side of the DC/DC, and a single EasyPACK 1B for the secondary side of the DC/DC. The utilization of the EasyPACK 1B for the secondary DC/DC stage can be further extended by integrating a H-bridge as primary side of a HV/LV DC/DC converter to bring the power density for combined systems to an even higher level.

High power density, integrated isolation, fast and robust manufacturing capability, and lower FIT rate due to PressFIT pins makes the existing EasyPACK module family with AQG324 qualification an excellent solution to meet the demands of OBCs with 11 kW and above power rating.

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[1] AN-Automotive EasyPACK™-Assembly, revision 1.0, 7 Sept. 2021
[2] Siemens norm SN 29500-5 / Edition 2004–06

About the Authors

Koray Yilmaz has a power electronics (M.Sc.) and mechanical engineering (Ph.D.) background. As a technical marketing manager, he is responsible for the definition and application of EasyPACK modules in EV auxiliaries.

Christoph Schäfer has studied electrical engineering (Dipl.-Ing.) and has more than ten years of automotive tier1 experience. As a product marketing manager, he is responsible for developing the product strategy for EV auxiliary applications with focus on EasyPACK modules.

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Bosch Uses Simulation to Optimize Inverters for Electric Cars

The global transition toward electric cars is getting a boost from industry suppliers like Robert Bosch, which provides electrical components and systems to car manufacturers. The Bosch team optimizes three-phase inverters and their DC link capacitors with a simulation-powered design process, which enables them to identify potentially destructive "hot spots" early in the development cycle.

By Alan Petrillo, Content Writer, COMSOL

Just as tourists in Paris are drawn to the Louvre, visitors to Stuttgart, Germany, also flock to museums displaying the great works of the city. Stuttgart may not boast of Degas or Monet, but its prominent names are perhaps even more famous than Paris' painters: Mercedes–Benz and Porsche. Each of these iconic automakers maintains a museum in the southwestern German city they call home. Their gleaming galleries feature many historic and influential cars, almost all of them powered by petroleum-fueled internal combustion (IC) engines. Looking ahead, Stuttgart will likely continue to be the heart of the German auto industry, but how long will the IC engine remain the heart of the automobile?

Even the most successful manufacturers must adapt to changing conditions. The German automotive sector, along with its global counterparts, is doing so by developing elektrische autos. Electric cars are an important focus of Robert Bosch — another leading automotive company founded in Stuttgart. Today, Bosch supplies electric powertrains, systems, and components to automakers worldwide.

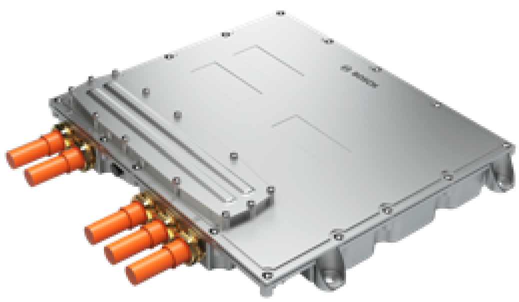

Figure 1: A Bosch three-phase inverter for automotive drivetrains.

As the automotive industry races toward an electrified future, Bosch is accelerating its R&D into the essential building blocks of electric drivetrains. One of these components is the inverter, which changes direct current (DC) from the car's batteries into alternating current (AC) to power its drive motor (Figure 1). The inverter's ability to provide a smooth flow of current depends on its integral DC link capacitor (Figure 2). "The capacitor is one of the most expensive components of the inverter. Its performance has a direct impact on the performance and reliability of the inverter, which is fundamental to the operation of the drivetrain," explains Martin Kessler, Bosch senior expert for automotive electronics.

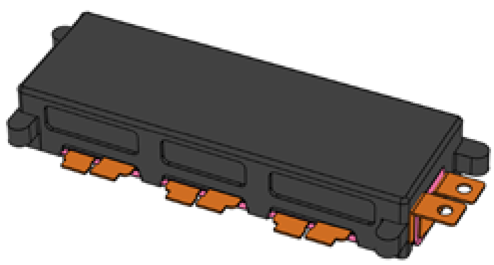

Figure 2: A typical DC link capacitor, with a battery interface on the right and transistor connectors on the front.

and their capacitors must undergo continuous improvement and optimization. Martin Kessler and his team rely on multiphysics simulation to test and refine Bosch's DC link capacitors. Their simulation-enabled predictive analysis complements and optimizes the live prototyping of new designs. "It is simply not possible to predict potential problems with testing alone; we need both simulation and prototyping working hand in hand," says Kessler.

The Emerging Era of the Electric Automobile

"Drivers, start your engines!" As if heeding the call to begin a worldwide race, people everywhere begin their days by firing up a rumbling IC engine. But this familiar sound can seem ominous, especially as the environmental impact of vehicle emissions grows more apparent. To lessen these emissions and their contribution to global climate change, the automobile industry is ramping up the production of electric-powered cars and trucks. Many of the electric vehicles available today have familiar brand names, but under the hood, these cars often rely on the technology and expertise of outside suppliers.

It is worth noting just how significant a shift this is for a major global industry. Leading automakers are some of the world's largest employers, and a vast share of their workers, R&D, and production capacity is dedicated to producing IC engines. The centrality of internal combustion to these companies can be found in their names, from General Motors to Bayerische Motoren Werke (better known as BMW). Why would companies known for their engines turn to outsiders to make their cars go? Perhaps it is because, in a sense, electrification is forcing the industry to learn how to produce an entirely different type of machine.

Anatomy of an Electric Drivetrain

To make a fully electric car, it is not enough to replace the engine with an electric motor and the gas tank with a battery. Such familiar devices are only parts of a larger system, which helps deliver smooth, reliable performance by adjusting to the constantly varying conditions under which every vehicle must operate (Figure 3).

Indispensable Inverter, Crucial Capacitor

The role of the inverter in an automotive drivetrain is simple in concept, but complex in practice. The inverter must satisfy the AC demands of the motor with the DC provided by the battery, but it must also adjust to ongoing fluctuations in load, charge, temperature, and other factors that can affect the behavior of each part of the system. All of this must occur within tight cost and spatial constraints, and the component must sustain this performance for years to come.

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www.infineon.com/gate-driver-ics-6ed2742s01q

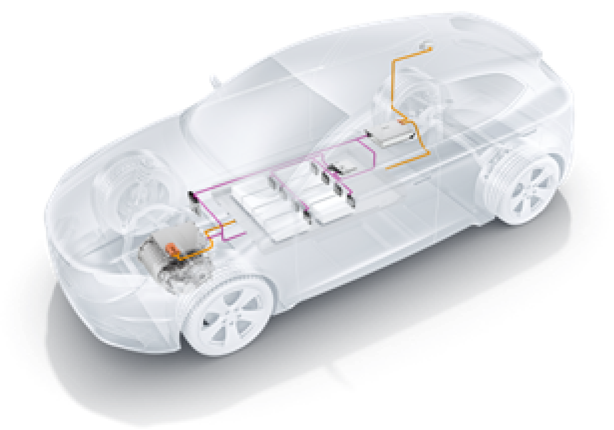

Figure 3: A Bosch schematic that helps explain the operation of a generic electric drivetrain. The amber line traces the path of drive current through the system, from the right to the left side of the picture. The path begins with a charger-converter, which accepts power from an external connection to the AC electrical grid. The charger-converter supplies DC to the battery, shown at the center of the car. The battery provides DC to a three-phase inverter, shown at the front of the car, mounted above the drive motor assembly. The inverter converts DC into three-phase AC to power the car's drive motor.

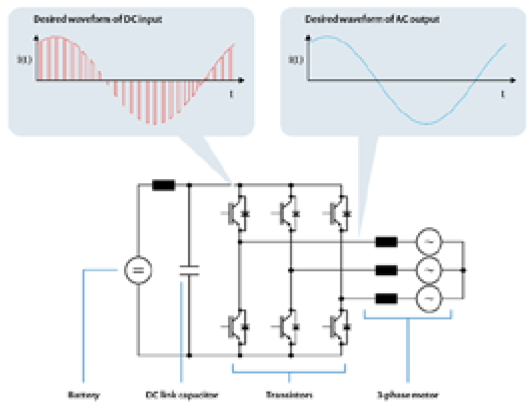

Figure 4: A diagram of a Bosch three-phase inverter's core circuitry. The battery provides DC, which is converted to a three-phase AC by the action of three sets of transistors. By switching on and off in a precise sequence, the transistors produce alternating current in three distinct phases, causing the car's drive motor to rotate. To make the motor's performance as smooth as possible, the DC link capacitor helps manage the input current that is fed to the transistors.

To understand the inverter's function, consider what a three-phase AC motor needs in order to operate. If connected to DC, the motor simply will not rotate. Instead, it must be provided with alternating current with three distinct but complementary waveforms, enabling the motor's three-part field coil to magnetically attract the segments of its rotor in a sequential pattern. "To control the activity of the motor, we must control the amplitude and frequency of the inverter's current output," explains Kessler. "The speed of the motor is proportional to frequency, while amplitude helps determine its torque."

"The desired current waveform through the transistors has a relatively steep gradient. The only way to achieve switch-mode current with this high gradient is to have very low inductance in the source path," Kessler says. Inductance is the particular force opposing changes in current flow. Every slight change in current will be limited by an induced counteracting voltage, which will disrupt the desired waveform — and the smooth rotation of the motor.

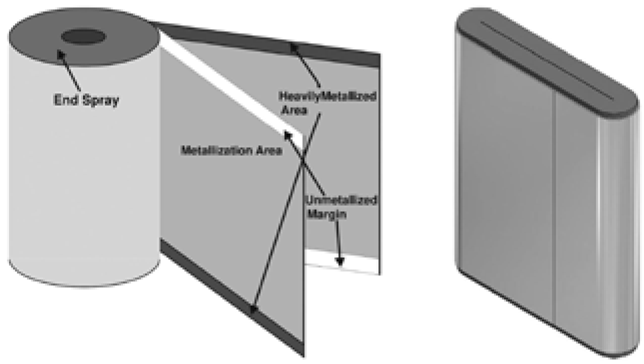

Figure 5: DC link capacitors are made from metallized polypropylene film, which is wound into an elongated canister shape.

To reduce the inductance in the source path of the transistors, a capacitor is placed in parallel across the input lead from the battery, which is called the DC link. The DC link capacitor (Figure 5) is placed in direct proximity to the transistors and provides the desired current waveforms through the transistors. The low impedance of the capacitor minimizes any remaining ripple voltage on the battery side.

A typical capacitor consists of two electrodes separated by an insulating gap, which may simply be airspace or some kind of material. In this application, Bosch uses capacitors made with metallized polypropylene film. A thin coating of metal (forming the electrodes) is sprayed on each side of the film, which provides the necessary dielectric gap. The metallized film is then wound tightly into a canister shape. As with the inverter itself, the capacitor's conceptual simplicity conceals a multifaceted engineering design problem.

Challenges with DC Link Capacitor Design for Vehicle Inverters
Capacitors are widely available components that are installed in countless electronic devices. For the past seven years, Martin Kessler has been responsible for DC link capacitor design at Bosch. He has been with the company since 1989 and has worked on electric car technology since 2010. That such an experienced engineer is dedicated to this one component shows its importance — and its complexity.

"Why can we not just pick up a capacitor from the marketplace?" asks Kessler, rhetorically. "There are multiple interdependent factors at work. First, we have high demands for performance and reliability. Second, there are very tight spatial requirements. Third, we face difficult thermal constraints, as the polypropylene film in a capacitor can only withstand temperatures up to around 105°C. This issue is compounded by the interaction of electromagnetic and thermal activity throughout the inverter. And finally, the capacitor is relatively expensive," Kessler explains.

Simulation (Not Luck) Helps Solve the Black Box Problem
To meet the design challenges of a DC link capacitor, Kessler developed a process that combines experimental testing with multiphysics simulation. As an example of why simulation-based analysis is a necessary part of his work, he cites the difficulty of finding and measuring potential hot spots, where high heat and coupled effects can cause failures. "We try to locate hot spots by placing a lot of thermocouples inside prototypes and measuring temperatures at various load points," Kessler says. "But my mantra is that you will never find a hot spot like this without a lot of luck! You will need to be lucky to place the thermocouple in the right position," he laughs.

"A simple 2D model of a capacitor is also insufficient," Kessler continues. "The inverter is a distributed system with internal resonances and a complex loss distribution. Our coupled EM and thermal analysis must account for skin effects and proximity effects. We

cannot calculate an absolute value for peak temperatures without a 3D finite element approach, which also enables us to model the spatial distribution of coupled EM and thermal effects. This is an ideal task for the COMSOL Multiphysics® software,» Kessler says. (Figures 6–7)

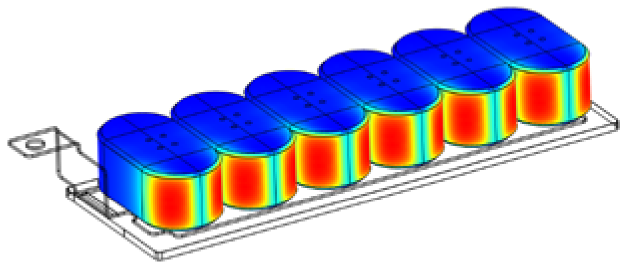

Figure 6: 3D model image showing simulation of EM effects inside a DC link capacitor design.

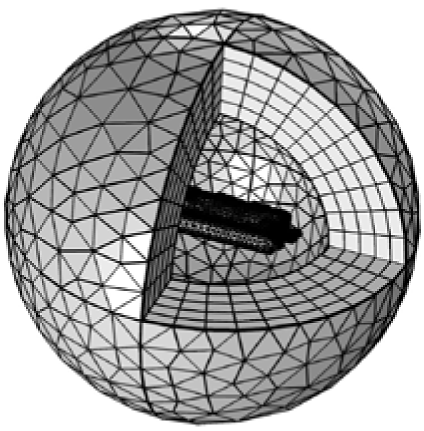

Figure 7: A model of the electromagnetic field generated by the capacitor, which aids the calculation of loss distribution in the unit.

Kessler's design process validates simulation models against measured results, where possible, and then uses the validated models to pinpoint potential problems (Figure 8). "By helping us locate hot spots in the model, the simulation helps us avoid issues that would have appeared late in the development process, or even after production had started," says Kessler. "Instead, we can get specific results and make adjustments early in the process."

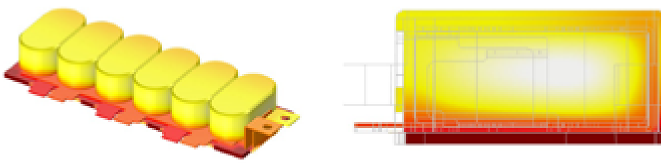

Figure 8: A 3D model showing simulation of thermal effects inside a DC link capacitor design, and a cutaway view showing the hotspot location in the capacitor.

"We perform EM modeling and validation of every new design. We compare the calculated equivalent series resistance (ESR) curve with the ESR curve as measured from a prototype (Figure 9). If these curves are aligned, we can set up boundary conditions for stationary and transient heat calculations," says Kessler. "We can compare the temperature curves from our thermocouples with the results of probes in the COMSOL Multiphysics® model. If they match, we can then simulate all the critical points where we must keep temperatures within limits." The curve data is put into the COMSOL Multiphysics® software via the LiveLink™ for MATLAB® i nterfacing product.

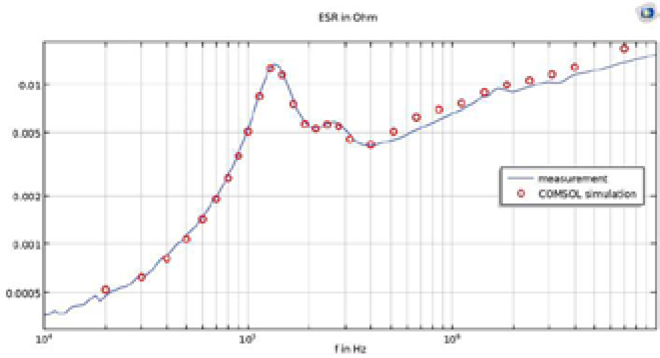

Figure 9: A plot of the ESR curve, as calculated in the simulation, compared with ESR values derived from measurement of a live prototype. Alignment of these curves helps validate the model for further analysis.

"Before we can do this, we have to think about which factors should be incorporated into the model," says Kessler. "Some of the variables we receive from the OEM, such as maximum DC link voltage, are not very relevant to our simulation," he continues. "But the current, switching frequency, e-machine values, and modulation schemes all help define a current spectrum. We need to calculate the current spectrum for all three phases of our output in order to establish power losses. Once we have this, we can do the harmonic analysis with COMSOL Multiphysics® for the frequencies of the current spectrum. Then we sum up our losses for every harmonic,» Kessler explains.

Other important values include the boundary conditions, which help Kessler and his team determine coupled effects. "We calculate parasitic inductance of the capacitor with the AC/DC Module," Kessler says. "We also find the complete AC loss distribution through the capacitor windings or internal busbar. Then we can couple the results and determine a temperature-dependent resistivity of the cover parts with the Heat Transfer Module," he says. "This enables us to establish the maximum element hot spot temperature resulting from the EM activity."

Findings from their analyses can then lead to design changes. Kessler explains that each new capacitor design typically undergoes three rounds of testing. "With simulation, the improvement curve gradient is much steeper from one phase to the next. Our knowledge grows quickly, and this is reflected in the final product." The latest generation of Bosch inverters promises 6% greater range and a 200% jump in power density compared to previous designs.

Electrification Shifts into High Gear

As automakers convert more of their product lines to electric propulsion, Martin Kessler believes that the need for rapid, cost-conscious R&D will also increase. "Electric mobility is growing up now," he says. "We expect that the OEMs will come to us with more varied needs, for inverters in different power classes and that meet tighter spatial constraints," says Kessler. "I do think that the number of products that require new capacitor designs will keep expanding. With our simulation-driven development methods, we are confident that we can keep up with this growth."

In the years to come, perhaps visitors to Stuttgart's car museums will stop to admire the historic motors and inverters that powered the industry into a new electric age.

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High-Voltage Battery Disconnect Switch

This article is a short introduction to a high-voltage battery disconnect switch, where transistors have replaced the old-fashioned relays. It briefly explains why clients should choose this solution from VisIC Technologies, a provider of innovative Gallium Nitride Transistors.

By Bernd Schmoelzer, Field Application Engineer, VisIC Technologies

Electric cars currently on the market use 400 and 800 V batteries with nominal currents above 200 amperes, which could be lethal for living beings if this high voltage and current were connected to the chassis or any conductive part of the car. To prevent such a scenario, manufacturers use high voltage and high current direct-current contactor relays, disconnecting the battery plus and minus rail from the high-voltage-board net shown in Figure 1.

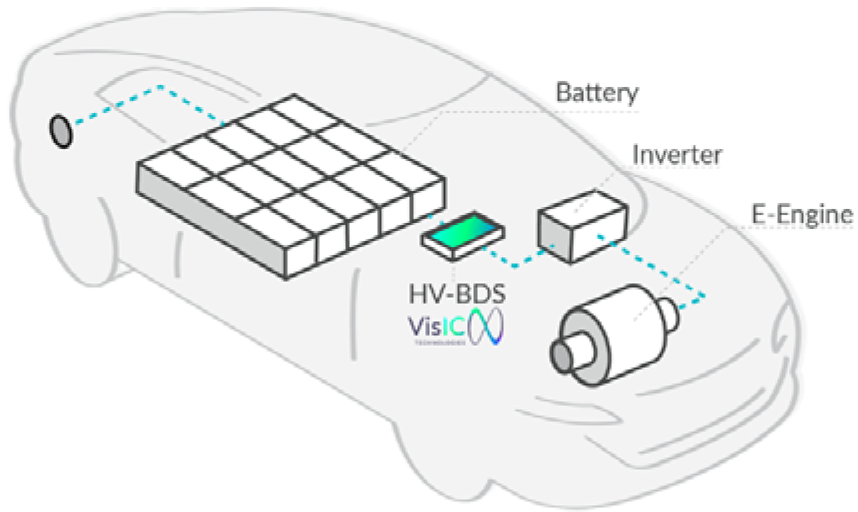

Figure 1: Battery disconnect switch

The pre-charge circuit is needed if relays are used for charging the direct current (DC) link capacitor parallel to the inverter, which has an inrush current depending on its size, voltage, and time transients. This circuit closes first and opens after the DC link voltage is nearly reached. If semiconductors are used instead, this pre-charge is not needed anymore.

Relays are electromechanical devices with certain challenges in their application. One major challenge is the arcing between two switch contacts, an electric discharge caused by the voltage across them and sustained by the current running through them. Arcing leads to a shortened lifetime or worst case to destruction if the contacts are welded together. Relay providers have several solutions to overcome this problem, such as a capacitor across the load, gas filled chambers, etc. The temperature range from HV DC relays is often limited to -40°C to 85°C and the switching speed is in the range of several tens of milliseconds.

Alternative to relays is bi-directional solid state semiconductor switches, described below. It focuses on the main contractor, aware that auxiliary circuits also need these switches.

Implementing semiconductors as relay replacement is done in such a way that two transistors are placed in anti-series to block the current in both directions (see Figure 2 below), with a n-channel MOSFET. Alternatively, every other type of FET could be generally used. VisIC core competence is in wide bandgap Gallium Nitride (GaN) FETs in a Direct Drive Configuration, hence the reason for proposing them for the HV-BDS.

What are the requirements for the FETs used in the BDS? During normal operation the switch is constantly on, therefore RDS_{on} is a dominant parameter, defining the conduction losses ($P_{con}=I^2*RDS_{on}$). A desired minimum can be achieved by the technology itself and by parallelization of multiple dies. Parallelization is critical for proper current sharing, which must be guaranteed. It depends strongly, among other parameters, on a flawlessly printed circuit layout with symmetrical stray inductances. Depletion mode GaN FETs provides high electron mobility of approx. 1500 $cm^2/V*s$ from the 2-dimensional electron gas (2DEG) combined with superior reliability.

Why are GaN devices a suitable candidate for a HV-BDS? Baliga (2016) said: "...the predicted specific on-resistance of 0.4mohm/cm² is 180 times smaller than the ideal specific on-resistance for a conventional silicon device". Commercial devices are currently not

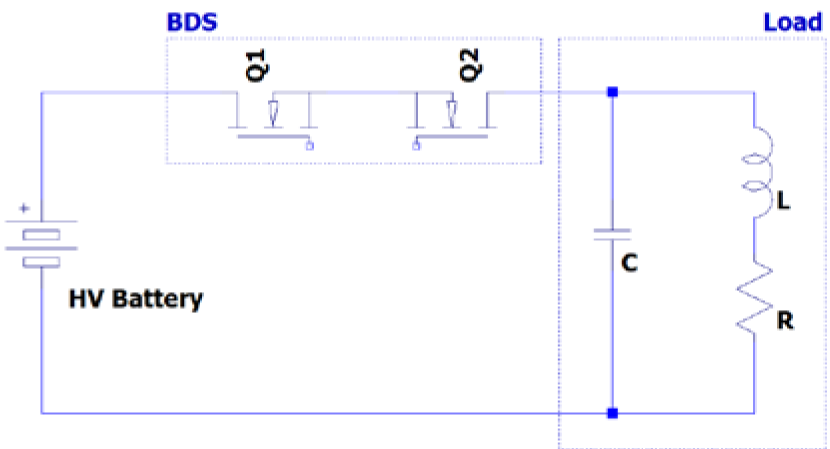

Figure 2: Block schematic

at this prediction, but even if the resistance is double, it would be 90 times smaller than a silicon switch. Due to that, GaN transistors can be made either much smaller for the same RDS_{on} or have much less resistance for the same size and are a perfect fit for battery disconnect switches. VisIC's direct drive configuration, set out in Figure 3, shows how to control the GaN device, producing multiple benefits compared to other solutions on the market, e.g., no reverse recovery losses, increased reliability, etc.

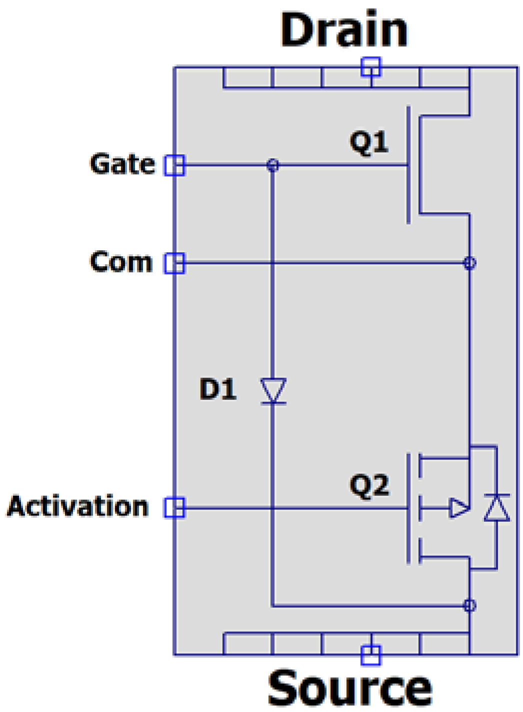

Figure 3: Direct Drive GaN

What are the challenges facing Gallium Nitride in this application? Lateral GaN FETs do not have any avalanche breakdown tolerance (Baliga). VisIC switches have therefore a high enough breakdown voltage margin. The 650 V rated devices have a static blocking voltage above 1600 V providing robustness to surge and overvoltage tested by Q. Song et.al. (2022) at Virginia Tech. The dynamic breakdown voltage is even more than 2 kV. In a short circuit event, the device must withstand the high currents running through the channel. Song showed that the 22 mOhm device from VisIC can handle repetitive 358A for 5 microseconds. Beside this technological solution, a discrete approach can be implemented protecting the FET in a short circuit event within 100 ns. The detailed explanation can be found in the Short Circuit Protection Application Note APN-01650-0003 Rev1.0.

References:

1. Baliga (2016): Gallium Nitride and Silicon Carbide Power Devices, World Scientific
2. VisIC Technologies Short Circuit Protection Application Note APN-01650-0003 Rev1.0
3. Q. Song et al., "Evaluation of 650V, 100A Direct-Drive GaN Power Switch for Electric Vehicle Powertrain Applications," 2021 IEEE 8th Workshop on Wide Bandgap Power Devices and Applications (WiPDA), 2021, pp. 28-33, doi: 10.1109/WiPDA49284.2021.9645143.

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How to Optimize Switching Power Supply Layout by Minimizing Hot Loop PCB ESRs and ESLs

Question: Can you optimize the efficiency of a switching power supply?
Answer: Sure - minimizing hot loop PCB ESRs and ESLs is an important method for optimizing efficiency.

By Jingjing Sun, Product Applications Senior Engineer, Ling Jiang, Product Applications Manager, and Henry Zhang, Product Applications Senior Director, Analog Devices

Introduction

For power converters, a hot loop PCB layout with minimum parasitic parameters can improve the power efficiency, lower the voltage ringing, and reduce the electromagnetic interference (EMI). This article discusses the optimization of hot loop layout design by minimizing the PCB equivalent series resistances (ESRs) and equivalent series inductances (ESLs). This article investigates and compares impact factors including decoupling capacitor positions, power FET sizes and positions, and via placements. Experiments are conducted to verify the analysis, and effective methods of minimizing the PCB ESRs and ESLs are summarized.

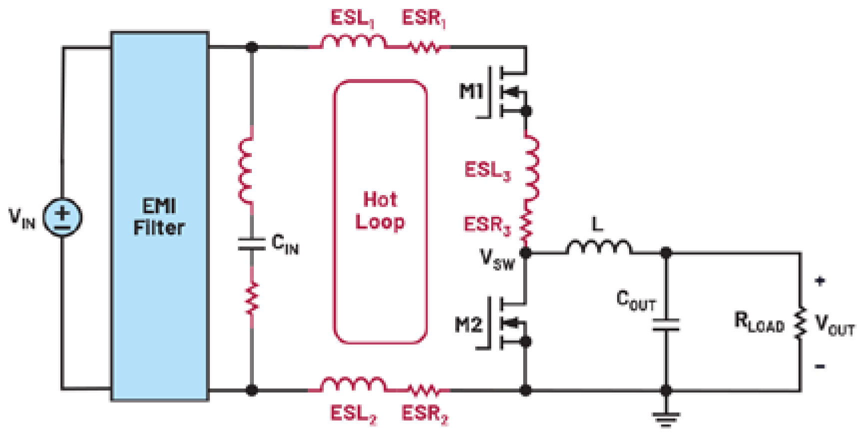

Figure 1: A buck converter with hot loop ESRs and ESLs.

Hot Loop and PCB Layout Parasitic Parameters

The hot loop of a switching-mode power converter is defined as the critical high frequency (HF) AC current loop formed by the HF capacitor and adjacent power FETs. It is the most critical part of the power stage PCB layout because it contains high dv/dt and di/dt noisy content. A poorly designed hot loop layout suffers from a high level of PCB parasitic parameters, including the ESL, ESR, and equivalent parallel capacitance (EPC), which have a significant impact on the power converter's efficiency, switching performance, and EMI performance.

Figure 1 shows a synchronous buck step-down DC-to-DC converter schematic. The hot loop is formed by MOSFETs M1 and M2 and the decoupling capacitor C_{IN}. The switching actions of M1 and M2 cause HF di/dt and dv/dt noise. C_{IN} provides a low impedance path to bypass the HF noisy content. However, parasitic impedance (ESRs, ESLs) exists within the components' packages and along the hot loop PCB traces. The high di/dt noise through ESLs causes HF ringing, furthermore, resulting in EMI. The energy stored in ESL is dissipated on ESRs, leading to extra power loss. Therefore, the hot loop PCB ESRs and ESLs should be minimized to reduce the HF ringing and improve efficiency.

An accurate extraction of the hot loop ESRs and ESLs helps predict the switching performance and improve the hot loop design. Both components' package and PCB traces contribute to the total loop parasitic parameters. This work mainly focuses on the PCB layout design. There are tools for users to extract the PCB parasitic parameters, such as Ansys Q3D, FastHenry/FastCap, StarRC, etc. Commercial tools like Ansys Q3D provide accurate simulation but are usually expensive. FastHenry/FastCap is a free tool based on partial element equivalent circuits (PEEC) numerical modeling1 and can provide flexible simulation through programming to explore different layout designs, though additional coding is required. The effectiveness and accuracy of the parasitic parameter extraction in FastHenry/FastCap have been verified and compared to Ansys Q3D with consistent results.2,3 In this article, FastHenry is used as a cost-efficient tool to extract PCB ESRs and ESLs.

Hot Loop PCB ESR and ESL vs. Decoupling Capacitor Position

In this section, the impacts of C_{IN} position are investigated based on ADI's LTM4638 μModule® regulator demo board DC2665A-B. The LTM4638 is an integrated 20 V_{IN}, 15 A step-down buck converter module in a tiny 6.25 mm × 6.25 mm × 5.02 mm BGA package. It offers high power density, fast transient response, and high efficiency. The module integrates a small HF ceramic C_{IN} inside, though it is not sufficient yet, limited by the module package size. Figures 2 to 4 illustrate three different hot loops on the demo board with additional external C_{IN}. The first one is the vertical Hot Loop 1 (Figure 2), where C_{IN1} is placed on the bottom layer just beneath the μModule regulator. The μModule VIN and GND BGA pins are connected to CIN1 directly through the vias. These connections provide the shortest hot loop path on the demo board. The second hot loop is the vertical Hot Loop 2 (Figure 3), where C_{IN2} is still placed on the bottom layer, but moved to the side area of the μModule regulator. As a result, an extra PCB trace is added to the hot loop and larger ESL and ESR are expected compared to vertical Hot Loop 1. The third hot loop option is the horizontal hot loop (Figure 4), where CIN3 is placed on the top layer close to the μModule regulator. The μModule VIN and GND pins are connected to CIN3 through the top layer copper without going through vias. Nevertheless, the V_{IN} copper width on the top layer is limited by the other pinout, resulting in an increased loop impedance compared to that of vertical Hot Loop 1. Table 1 compares the extracted PCB ESRs and ESLs of the hot loops by FastHenry. As expected, the vertical Hot Loop 1 has the lowest PCB ESR and ESL.

To experimentally verify the ESRs and ESLs in different hot loops, the demo board efficiency and V_{IN} AC ripple at 12 V to 1 V CCM operation are tested. Theoretically, a lower ESR leads to higher efficiency, and smaller ESL results in higher V_{SW} ringing frequency and lower VIN ripple magnitude. Figure 5a shows the measured efficiency. The vertical Hot Loop 1 gives the highest efficiency that corresponds to the lowest ESR. The loss difference between the horizontal hot loop and vertical Hot Loop 1 is also calculated based on the extracted ESRs, which is consistent with the testing result as shown in Figure 5b. The VIN HF ripple waveforms in Figure 5c are tested crossing C_{IN}. The horizontal hot loop has a higher V_{IN} ripple magnitude and a lower ringing frequency, thus validating the higher loop ESL compared to the vertical Hot Loop 1. Also, because of the higher loop ESR, the V_{IN} ripple in the horizontal hot loop damps

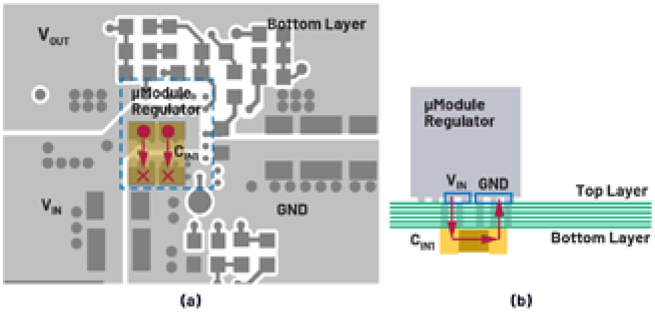

Figure 2: Vertical Hot Loop 1: (a) top view and (b) side view.

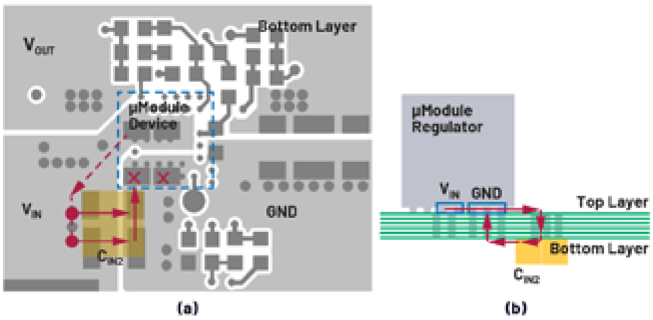

Figure 3: Vertical Hot Loop 2: (a) top view and (b) side view.

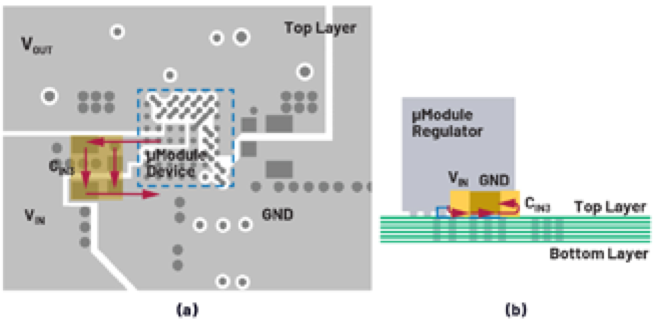

Figure 4: Horizontal hot loop: (a) top view and (b) side view.

faster than in the vertical Hot Loop 1. Furthermore, a lower VIN ripple reduces EMI and allows a smaller EMI filter size.

Hot Loop PCB ESR and ESL vs. MOSFETs Size and Position

For a discrete design, the placement and package size of power FETs also have a significant impact on hot loop ESRs and ESLs. A typical half-bridge hot loop with power FETs M1 and M2 and a decoupling capacitor CIN is modeled and investigated in this section. As illustrated in Figure 6, popular power FET package sizes and placement positions are compared. Table 2 shows the extracted ESRs and ESLs in each case.

Cases (a) to (c) present three popular power FET placements with 5 mm × 6 mm MOSFETs. The physical length of the hot loop determines the parasitic impedance. Hence, both 90˚ shape placement in Case (b) and 180˚ shape device placement in Case (c) result in 60% ESR reduction and 80% ESL reduction because of the shorter loop paths compared to those in Case (a). Since a 90˚ shape placement shows the benefit, several more cases are investigated based on Case (b) to further reduce the loop ESR and ESL. In Case (d), a 5 mm × 6 mm MOSFET is replaced with two 3.3 mm × 3.3 mm MOSFETs in parallel. The loop length is further shortened thanks to the

Hot Loop	ESR ($ESR_1 + ESR_2$) at 600 kHz (mΩ)	ESL ($ESL_1 + ESL_2$) at 200 MHz (nH)
Vertical Hot Loop 1	0.7	0.54
Vertical Hot Loop 2	2.5	1.17
Horizontal Hot Loop	3.3	0.84

Table 1: Extracted PCB ESRs and ESLs in Different Hot Loops by Using FastHenry

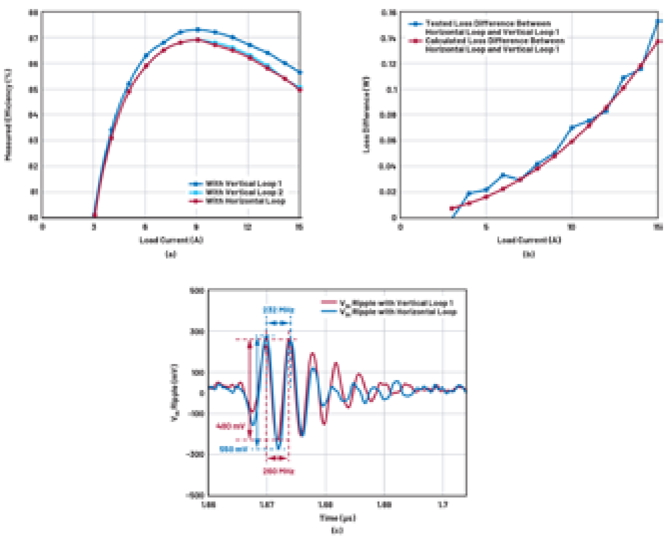

Figure 5: Demo board testing results: (a) efficiency, (b) loss difference between horizontal loop and vertical Loop 1, and (c) VIN ripple during M1 turn-on at 15 A output.

	ESR_1 (mΩ) at 2 MHz	ESR_2 (mΩ) at 2 MHz	ESR_3 (mΩ) at 2 MHz	ESR_{TOTAL} (mΩ) at 2 MHz	ESR Change Rate vs. (a)	ESL_1 (nH) at 200 MHz	ESL_2 (nH) at 200 MHz	ESL_3 (nH) at 200 MHz	ESL_{TOTAL} (nH) at 200 MHz	ESL Change Rate vs. (a)
(a)	0.59	2.65	0.45	3.69	N/A	0.42	2.80	0.23	3.45	N/A
(b)	0.59	0.3	0.38	1.27	–66%	0.42	0.09	0.17	0.67	–81%
(c)	0.24	0.27	0.83	1.35	–63%	0.07	0.07	0.52	0.66	–81%
(d)	0.44	0.3	0.28	1.01	–73%	0.25	0.09	0.08	0.42	–88%
(e)	0.44	0.27	0.26	0.97	–74%	0.21	0.08	0.07	0.36	–90%
(f)	0.31	0.27	0.13	0.7	–81%	0.12	0.07	0.02	0.21	–94%

Table 2: Extracted Hot Loop PCB ESR and ESL with Various Device Shapes and Positions in FastHenry

smaller MOSFETs footprint, leading to 7% reduction of the loop impedance. In Case (e), when a ground layer is placed under the hot loop layer, the hot loop ESR and ESL are further decreased by 2% compared to Case (d). The reason is that eddy current is generated on the ground layer, which induces the opposite magnetic field and equivalently reduces the loop impedance. In Case (f), another hot loop layer is constructed as the bottom layer. If two paralleled MOSFETs are symmetrically placed on the top layer and bottom

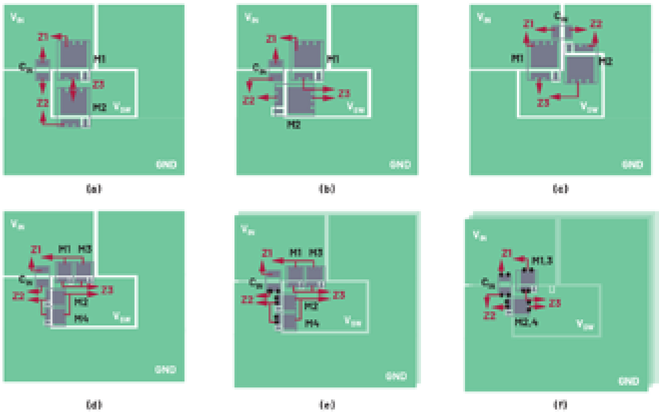

Figure 6: Hot loop PCB models: (a) 5 mm × 6 mm MOSFETs in straight placement; (b) 5 mm × 6 mm MOSFETs in 90˚ shape placement; (c) 5 mm × 6 mm MOSFETs in 180˚ shape placement; (d) two-parallel 3.3 mm × 3.3 mm MOSFETs in 90˚ shape placement; (e) two-parallel 3.3 mm × 3.3 mm MOSFETs in 90˚ shape placement with ground layer; (f) symmetrical 3.3 mm × 3.3 mm MOSFETs on top and bottom layers in 90˚ shape placement.

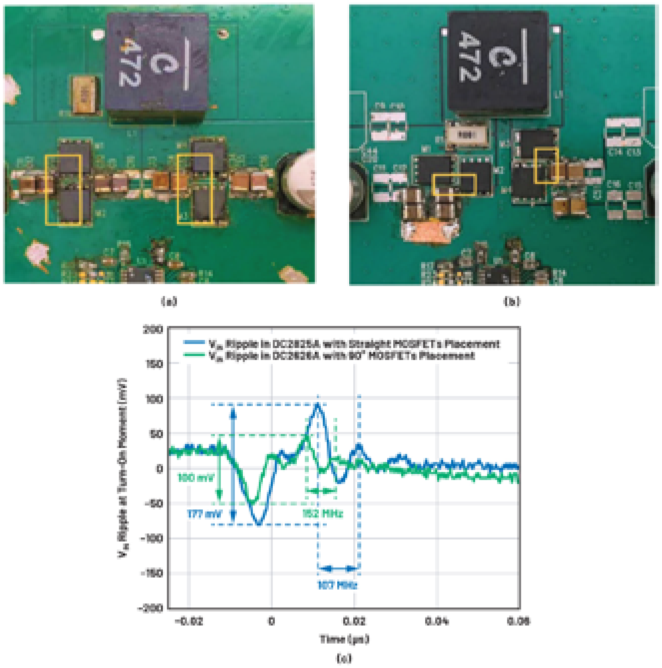

Figure 7: (a) LT8390/DC2825A hot loop with straight MOSFETs placement; (b) LT8392/DC2626A hot loop with 90˚ MOSFETs placement; (c) VIN ripple waveforms at M1 turn-on.

layer and connected through vias, the hot loop PCB ESR and ESL reduction are more obvious because of the paralleled impedance. Therefore, smaller sized devices with symmetrical 90˚ shape or 180˚ shape placement on top and bottom layers lead to the lowest PCB ESR and ESL.

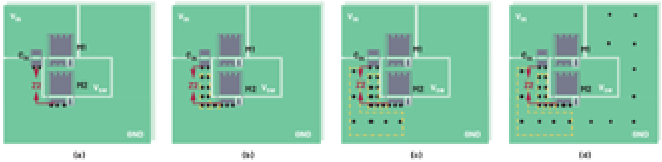

Figure 8: Hot loop PCB models with (a) five GND vias placed close to CIN and M2; (b) 14 GND vias placed between CIN and M2; (c) 6 more vias placed on GND based on (b); (d) nine more vias placed on GND area based on (c).

To experimentally verify the impact of the MOSFETs placement, ADI's high efficiency, 4-switch synchronous buck-boost controller demo boards LT8390/DC2825A and LT8392/DC2626A are used.4 As shown in Figure 7a and Figure 7b, the DC2825A has a straight MOSFETs placement and the DC2626A has a 90˚ shape MOSFETs placement. To make a fair comparison, the two demo boards are configured with the same MOSFETs and decoupling capacitors, and tested at 36 V to 12 V/10 A, 300 kHz step-down operation. Figure 7c shows the tested VIN AC ripple during M1 turn-on moment. With the 90˚ shape MOSFETs placement, the VIN ripple has lower magnitude and higher resonant frequency, hence validating the smaller PCB ESL due to a shorter hot loop path. On the contrary, because of the longer hot loop and higher ESL, the straight MOSFETs placement results in much higher VIN ripple magnitude and slower resonant frequency. A higher input voltage ripple also causes a more severe EMI emission according to the EMI test results in the study of Cho and Szokusha.4

Case	ESR_2 (mΩ) at 2 MHz	ESR Change Rate vs. Initial Case	ESL_2 (nH)at 200 MHz	ESL Change Rate vs. Initial Case
Initial Case Without Vias	2.67	N/A	1.19	N/A
(a)	1.73	–35.2%	0.84	–29.8%
(b)	1.68	–37.1%	0.82	–30.8%
(c)	1.67	–37.5%	0.82	–31%
(d)	1.65	–38.2%	0.82	–31.4%

Table 3: Extracted Hot Loop PCB ESR2 and ESL2 with Different Via Placements

Hot Loop PCB ESR and ESL vs. Via Placement

The vias placement in the hot loop also has a critical impact on the loop ESR and ESL. As shown in Figure 8, the hot loop with a two-layer PCB structure and straight power FETs placement is modeled. The FETs are placed on the top layer and the second layer is a ground plane. The parasitic impedance Z2 between CIN GND pad and M2 source pad is part of the hot loop and is studied as an example. Z2 is extracted from FastHenry. Table 3 summarizes and compares the simulated ESR2 and ESL2 with different via placements.

In general, adding more vias reduces the PCB parasitic impedance. However, the reduction of ESR2 and ESL2 is not linearly proportional to the number of vias. The vias close to the terminal pads give the most obvious reduction in PCB ESR and ESL. Therefore, for hot loop layout design, several critical vias must be placed close to the pads of CIN and MOSFETs to minimize the HF loop impedance.

Conclusion

The reduction of a hot loop's parasitic parameters can help improve the power efficiency, lower voltage ringing, and reduce the EMI. To minimize the PCB parasitic parameters, hot loop layout designs with different decoupling capacitor positions, MOSFET sizes and positions, and via placements were studied and compared. A shorter hot loop path, smaller sized MOSFETs, symmetrical 90˚ shape and 180˚ shape MOSFETs placements, and vias close to the key components contribute to the lowest hot loop PCB ESR and ESL.

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www.analog.com

High-Power, Low-Ohmic Current Sense Resistors

Sense Resistor Basics

Measuring the electrical current flowing through a circuit can be done using a variety of techniques. One of the simplest and most common way is to use a dedicated sensing resistor.

By Travis Moench, Senior Business Director, ROHM Semiconductor

Such a resistor can be employed in two ways, as shown in the figure below. On the left is a shunt configuration, where the majority of current flows through the sensing resistor and a known ratio flows through an ammeter. The total circuit current can be calculated since this ratio is a function of the known ammeter resistance compared to the known shunt resistance. The configuration on the right depicts a series sensing topology, where all of the current flows through a relatively low resistance sensing resistor, and a high impedance meter measures the voltage across it. The total circuit current is readily calculated using Ohm's law.

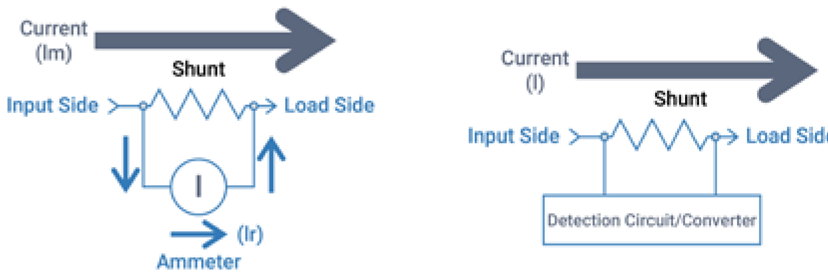


Figure 1: Shunt and series configurations for sense resistors

In both of these sense resistor topologies, it should be clear that the resistor will dissipate some amount of power in the form of heat. This power loss can be minimized by making the sense resistor as small as possible, the tradeoff being higher noise in the measurement circuitry. This balance between measurement accuracy and power dissipation must be carefully balanced to achieve satisfactory design performance.

Sense resistors must also be carefully selected based on the second-order effects at high temperatures. The resistance of the device itself increases with temperature, and this non-ideality must be accounted for in the measurements if the resistor cannot be adequately cooled. Similarly, as the sense resistor heats up, the total power it can safely dissipate must be derated after a particular temperature is reached. Careful selection of resistor construction, package geometry, and PCB layout can be used to mitigate this effect.

Sense Resistor Applications

Sense resistors are used in a myriad of applications ranging from low-current wearables to high-power electric vehicles. Regardless of the application however, the same general principles apply. The resistor must be sized to provide the appropriate magnitude and range of sensing, and the thermal considerations for the resulting power dissipation must be thoroughly addressed. In the figure below, two common applications are shown, one for a relatively high current multi-phase motor driver, and the other for a low current battery monitor.

In the motor drive circuit on the left, the sense resistor is used to monitor the current sunk through each phase of the motor windings by the low side transistors. A differential amplifier is used to measure the sense voltage and feed it into an analog to digital converter (ADC) in a controller IC. The controller IC uses this voltage feedback to calculate the magnitude and phase of the motor current and in turn, control the timing of the transistor drivers.

In the battery monitor circuit on the right, the current flowing into and out of a lithium battery bank is being measured via an ADC on a dedicated battery management IC. This is typically used to control the charging of the battery, which must be carried out following a very specific current profile. In addition, this same resistor can be used to measure total charge leaving the battery to provide a fuel gauge read-out to an upstream user interface.

Types of High-Power Sense Resistors

Sense resistors are manufactured in two different ways. The first is based on the traditional thick-film resistor structure shown below, where a resistive paste is screen

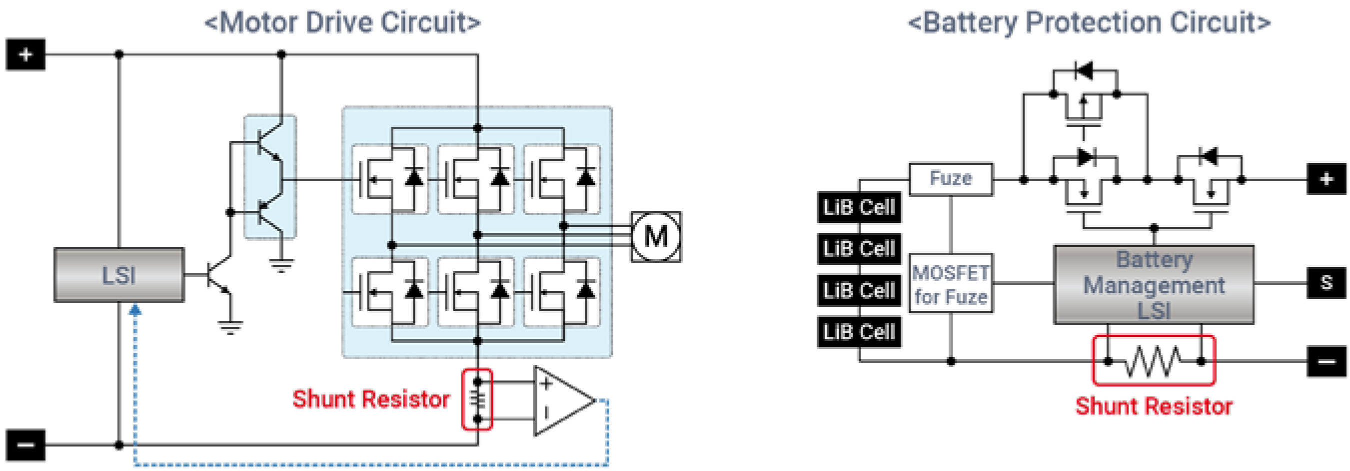


Figure 2: Shunt resistors for motor drive and battery monitoring applications

printed onto a ceramic substrate. After firing, the resistive area is laser trimmed to a specific value, and then coated and contacted to achieve the final surface mount device as shown in Figure 3.

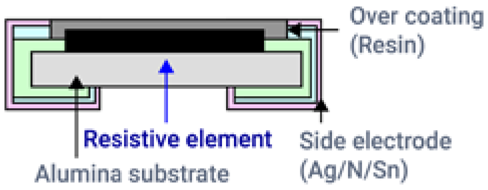


Figure 3: Thick film resistor construction

The second method utilizes a metal alloy as the resistive structure which is welded directly to the contact electrodes. The alloy formula is critical to determining the resistance and its thermal characteristics. This offers excellent power and thermal performance, but can be more costly to construct. An example is shown in the figure 4.

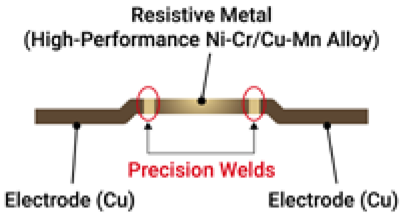


Figure 4: Metal plate resistor structure

In addition to the fundamental structure, sense resistors come in a variety of packages for different applications. As shown in the figure below, traditional top mount packages provide the lowest cost option but also exhibit the lowest power rating. Rear mount packages create a direct thermal contact between the resistive element and the underlying PCB to provide enhanced thermal performance. Finally, wide terminal devices use a reverse aspect ratio for maximizing the surface area of the terminals. Since the terminals provide an excellent path for heat transfer, these devices offer the highest power ratings of any sense resistor.

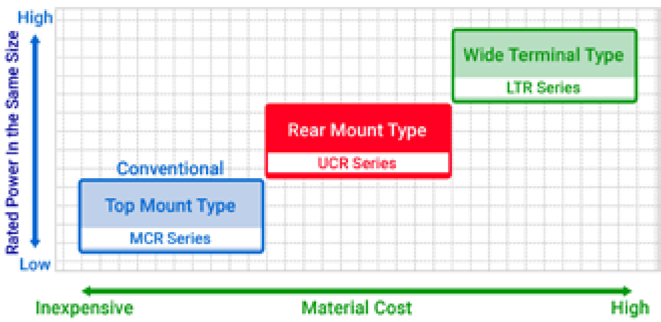


Figure 5: Tradeoff of mounting and terminal styles between cost and power rating

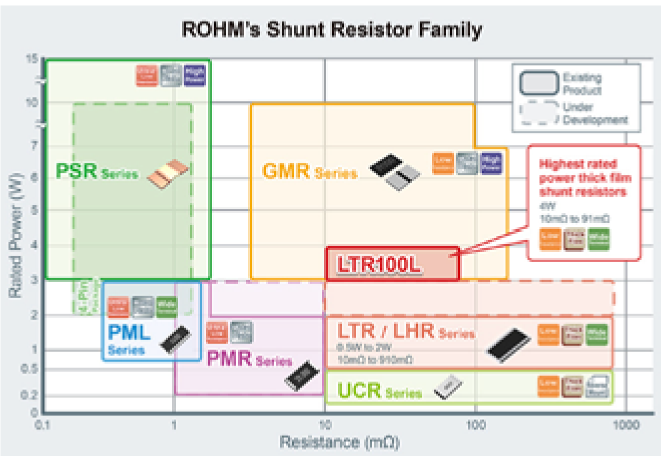


Figure 6: ROHM's shunt resistor product family

ROHM's High-Power Lineup

When considering the performance variables of rated power and resistance, ROHM offers a wide selection of devices to fit virtually any application need. Shown in the figure below are the various families of ROHM shunt resistors along with their performance envelope.

For metal alloy shunt resistors, ROHM's lineup can be segmented into the PS, GM, and PM series. The PS is focused on high-current, ultra-low ohmic resistors in the range of 0.1 to 2 milliohms. The GMR is geared toward a larger range of resistance, from about 3 to 200 milliohms, and offers excellent temperature characteristics. The PM series spans the largest resistance range and is a general purpose design for lower power applications.

For thick film shunt resistors, ROHM offers the LTR100L, LTR/LHR, and the UCR series of devices. LTR resistors are low power devices between 1 and 4 watts featuring excellent temperature characteristics. The LTR/LHR series enhance temperature characteristics even further while still targeting the low power application space. And the UCR devices are general purpose for sub-2W designs.

ROHM has developed and deployed a host of novel structures and design techniques to create devices that vastly outperform their competitors. One example is the thermal performance of the GMR series resistors, which incorporate a proprietary contact structure and a unique alloy for excellent temperature coefficients. When compared to an equivalent competitor, the ROHM device exhibits 57% lower surface temperature at 3W of power dissipation. This directly translates to space savings and cost reduction as a lower temperature derating can be applied at the design phase.

Similarly, ROHM has developed special packaging techniques such as wide-terminal and face-down assembly. Wide terminal devices, as shown in the figure below, create an improved thermal path for contact heat dissipation into the surrounding traces. This allows for higher power ratings and improved derating curves for temperature.

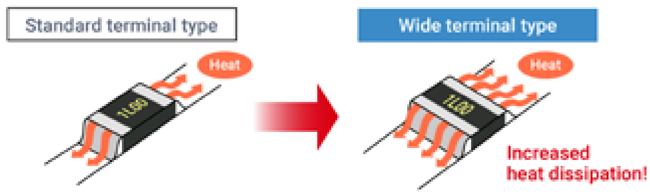


Figure 7: Wide terminal style packages deliver improved thermal performance

Conclusion

Sense resistors are commonplace circuit elements used for monitoring current in numerous electronic devices. ROHM has developed materials, structures, and packaging techniques to create families of sense resistors for any application, from low-power general purpose designs to high-current high-precision configurations. Considering total power, total resistance, and temperature coefficient, one can choose between thick-film and metal topologies. Within each of these families, aspect ratio and package structure can be optimized to minimize total cost and board area while maximizing performance. To learn more, visit: https://www.rohm.com/products/resistors/current-detection-resistors

www.rohm.com

MOSFETs with Top-Cool Packaging

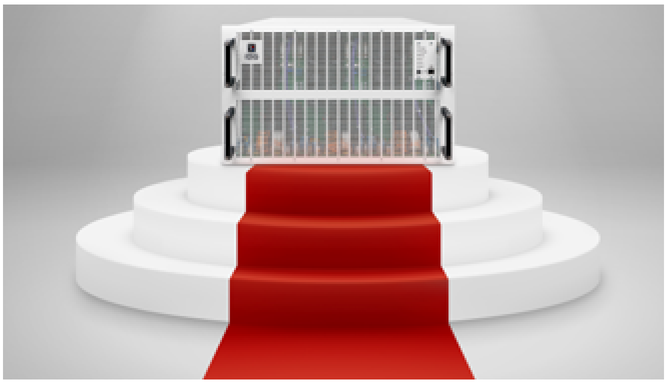
onsemi announced a series of MOSFET devices that feature top-side cooling to assist designers in challenging automotive applications, especially within motor control and DC/DC conversion. Housed in a TCPAK57 package measuring just 5mm x 7mm, the Top Cool devices feature a 16.5mm2 thermal pad on the top side. This allows heat to be dissipated directly into a heatsink rather than via a typical printed circuit board (PCB). By enabling the use of both sides of the PCB and decreasing the amount of heat going into it, the TCPAK57 provides increased power density. Improved reliability of the new design adds to an overall extended system lifetime. "Cooling is one of the greatest challenges in high power design and successfully addressing it is the key enabler to reducing size and weight, which is critical in modern automotive design," said Fabio Necco, vice president and general manager, Automotive Power Solutions at onsemi. "With excellent electrical efficiency and having eliminated the PCB from the thermal path, the design is significantly simplified while reducing size and cost."

The devices deliver the electrical efficiency required in high power applications with RDS(ON) values as low as 1mΩ. Additionally, the gate charge (Qg) is low (65 nC), reducing losses in high-speed switching applications.

www.onsemi.com

Industrial Series 60 KW DC Power Supplies and Loads

EA Elektro-Automatik introduces its 60 kW and 30 kW, EA-PU 10000 Programmable DC Power Supplies, EA-PUB 10000 Programmable Bidirectional DC Power Supplies and EA-PUL DC Programmable



Regenerative Electronic Loads. Typical applications include electric vehicle battery pack testing, powering furnaces in semiconductor wafer fabrication facilities, electrochemical electrolysis processing, and solar inverter testing. The products, without manual front panel displays, are intended for use in production ATE systems and automated process control systems requiring high power.The 60 kW models output maximum voltages of 360 V to 2000 V and maximum currents of 480 A to 80 A; the 30 kW models output maximum voltages of 60 V to 2000 V and maximum currents of 1000 A to 40 A. Overall, the 60 kW series includes 21 models, and the 30 kW series consists of 29 models allowing engineers to select a model that addresses their specific applications. The increased power capability enables engineers to reduce the number of power instruments needed for a high-power system, saving critical rack space and providing more power in a smaller footprint.

www.elektroautomatik.com

Series of Resonant Inductors

ITG Electronics has introduced a series of resonant inductors. Suitable for DC/DC power conversions of up to 3 kilowatts, the company's L101374SP Series of Resonant Inductors comprises 13 distinct high-performance products. They are ideal for power conversion application in data centers, electric vehicles and industrial settings. The L101374SP Series of Resonant Inductors was initially developed for a specific customer application, and is now available to the wider market. ITG Electronics was selected by an industry leader in DC/DC power conversion to design and produce a portfolio of resonant inductors with elevated efficiency and power density. These features – high power and heightened ef-

ficiency – align with those called for in GaN Systems Inc.'s design reference parameters, and is now included in the organization's Technical Manual of P/N GS-EVB-LLC-3KW-GS. The L101374SP Series of Resonant Inductors can accommodate up to 650 volts, and up to 71.0 amperes with approximately 30% roll off.

According to Martin Kuo, Managing Director of ITG Electronics: "The new L101374SP Series of Resonant inductors and LLC transformer P/N T301373SP-04 work well with GAN P/N GS-EVB-LLC-3KW-GS, which are empowering our customers to implement full-bridge LLC resonant converters that exceed the 80+ Titanium standard for power supply units, achieving high-power density (PFC+DC/DC) above 100W/in3 and efficiencies greater than 96%."

www.itg-electronics.com

Zero-Voltage-Switching Power-Supply ICs

Power Integrations announced the InnoSwitch™4-Pro family of digitally controllable, off-line CV/CC Zero Voltage Switching (ZVS) flyback ICs, which substantially reduce the size of power adapters. Incorporating a robust PowiGaN gallium-nitride primary switch and steady-state switching frequency of up to 140 kHz, the highly integrated devices reduce the component count and PCB area required for ultra-compact adapters for cellphone, notebook, tablet and multi-port accessories.

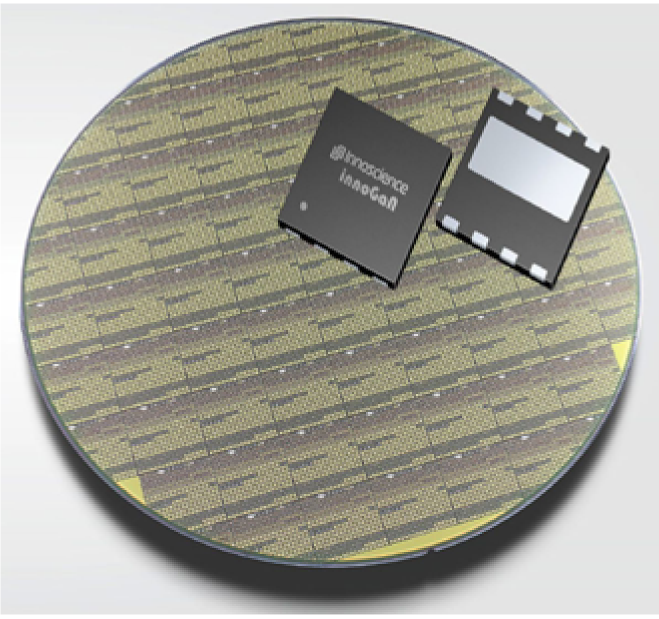
"InnoSwitch4-Pro ICs interface seamlessly with Power Integrations' ClampZero™ family of active clamp ICs to achieve ZVS in both continuous conduction mode (CCM) and discontinuous conduction mode (DCM)," stated Aditya Kulkarni, product marketing manager at Power Integrations. "ZVS, combined with our PowiGaN™ technology, virtually eliminates switching losses. Efficiency exceeds 95 percent, which enables designers to eliminate the heat sinks, spreaders and potting materials typically required for thermal management."

Further size reduction of the adapter can be achieved by the use of a MinE-CAP™ device in combination with InnoSwitch4-Pro and ClampZero ICs. Based also on PowiGaN technology, MinE-CAP ICs enable input capacitance size reduction of approximately 40 percent. Capable of delivering up to 220 W, InnoSwitch4-Pro ICs combine a 750 V PowiGaN primary switch, controller, FluxLink™ reinforced isolation feedback link for secondary-side control, I2C interface, active clamp drive and synchronous rectification in a compact InSOP™-28 package.

www.power.com

650V GaN HEMTs

Innoscience announced a low RDS(on) 650V E-mode GaN HEMT devices. INN650D080BS power transistors have an on-resistance of 80mΩ (60mΩ typical) in a standard 8x8 DFN package, enabling higher power applications, for example in totem pole LLC architectures or fast battery-chargers.



Explains Yi Sun, Sr VP of product development at Innoscience: "We are now able to address high density, high efficiency power conversion applications. Like all our other 650V HEMTs, these new parts are qualified to JEDEC standards for chip and package, and they have also passed DHSOL (Dynamic High Temperature Operating Life) reliability testing according to JEP180 and accelerated life tests up to 1000V give lifetime calculations of 36 years (520V; 150°C; 0.01% failure rate)."

Thanks to Innoscience's innovative strain enhancement layer, InnoGaN devices features low specific RDS(ON) as well as very low dynamic RDS(ON) and excellent reliability. The new 80mΩ RDS(on) parts also feature very good drain source voltage transient (VDS, transient) and pulsed (VDS, pulsed) characteristics – 800V and 750V respectively. Moreover, similarly to the other 650V products, the 80mΩ RDS(on) devices feature a strong ESD protection circuit embedded in the die to ease mass production assembly of these device in package and easy handling. In this case, however, the ESD circuit has been modified to allow a larger negative gate voltage swing down to -6V.

The low RDS(on) INN650D080BS power transistors, which are available in industry-standard 8x8 DFN packages, join previously-announced 140mΩ,190mΩ, 240mΩ, 350 mΩ, 500mΩ and 600 mΩ RDS(on) parts, creating a significant portfolio of available devices, which is continuously expanding towards lower RDS(on) values.

www.innoscience.com

LED Paste for Mini/MicroLED Applications

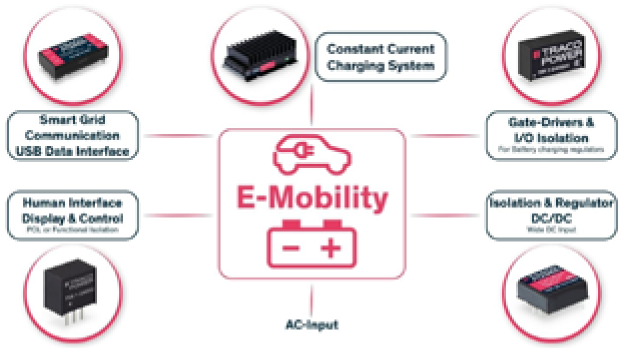
Indium Corporation® has expanded its portfolio of proven pastes with a no-clean, halogen-free solder paste designed for advanced LED applications, including COB, COG, SMT, and other LED varieties.

LEDPaste NC38HF combines wetting performance with stencil print transfer efficiency to satisfy the broadest range of process requirements for miniLED applications. It offers printability down to 60-micron apertures. MiniLEDs typically feature a length of less than 240 microns on the component edge; this material offers excellent compatibility with the current size of miniLEDs and as future die continue to miniaturize.

www.indium.com

DC/DC Converters for E-Mobility

It is safe to say we are all feeling the wave of demand for electric vehicles, charging stations, and the required support infrastructure which are becoming ever more powerful, faster, and more compact. Consequently, more power in a smaller space is required for the operation of the electronics. Compact, highly efficient, reliable and, above all, robust DC/DC converters are required to meet these high demands of e-mobility applications. These converters must be able to withstand extreme and fluctuating temperatures and function reliably in harsh environments for years. With more than two decades of experience in railroad technology, Traco Power has set the goal of bringing robust DC/DC converters with high efficiency and power density to the market, especially suited for applications in electromobility. The range of Traco Power DC/DC converters for e-mobility includes models from 1- 300 Watts. These models are available in various mechanical types such as DIN-Rail, Chassis mount and PCB mountable DIP, SIP and SMD packages and are ideal for e-mobility applications.



Traco Power products are carefully designed and fully compliant with the latest Railway, Industrial and Information Technology standards.

www.tracopower.com

Automotive-Qualified High Frequency Inductors with Tight Tolerances

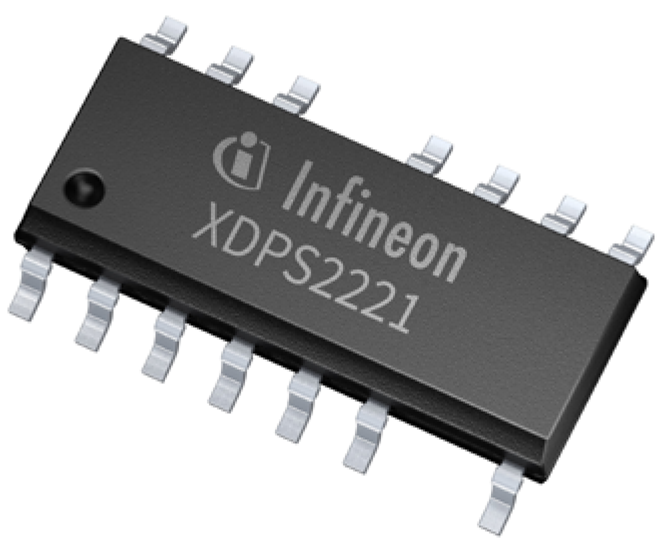
Würth Elektronik now offers WE-MCI—a series of high-frequency inductors boasting a wide range of values: The 0402 package covers inductance values from 1 to 270 nH, while the WE-MCIs in a 0603 package range from 1 to 470 nH. A special feature of these automotive-approved components is their unusually tight tolerances of ±5% or ±0.3 nH for those models below 5.6 nH.

AEC-Q200 qualified, with an operating temperature range -55 to +125°C, the SMT mountable components are suitable for applications in infotainment, keyless access systems, Bluetooth and filter circuits, to name but a few. The WE-MCIs are provided with polarity markings on both sides for improved production control. Design kits are available for both inductor package types, so components with the right values are always at hand. Würth Elektronik will always replenish these design kits free of charge.

www.we-online.com

PFC and Hybrid Flyback Combo IC for GaN-based USB-C Adapters and Chargers

Infineon Technologies introduces the XDP™ digital power XDPS2221, a highly-integrated combo controller IC for USB-PD supports high power designs in wide input and output voltage applications of up to 28 V output voltage.



The device integrates an AC-DC power factor correction (PFC) controller with a DC-DC hybrid flyback controller (HFB), also known as asymmetrical half-bridge (AHB), in one single package. Through the harmonized operation of the two stages, regulatory requirements can easily be met. In addition, the further integration of all gate drivers and a 600 V high voltage start-up cell for the initial IC voltage supply and the certified active X-capacitor discharge enable a low external bill of material (BOM) and component count. Based on a novel zero-voltage switching (ZVS) HFB topology in conjunction with GaN-based devices, it brings class-leading efficiency across various line/load conditions. Thanks to these features and inherent topology advantages, such as zero voltage switching and resonant energy transfer for transformer size reduction, system designs using XDPS2221 can achieve very high power densities.

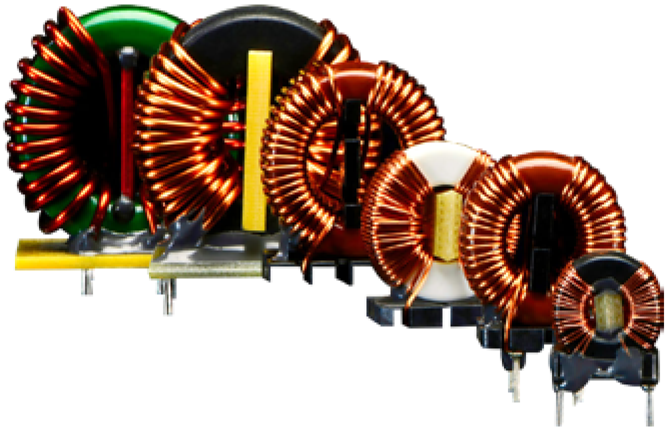
Moreover, the combo IC features a synchronous PFC and HFB burst mode operation for the lowest possible no-load input standby power performance. The quasi-resonant multimode PFC stage is enhanced with automatic PFC enable/disable functionality and adaptive PFC bus voltage control to maximize average and light load efficiency. Optionally, the integrated PFC function can also be disabled, to support the use case with any kind of external PFC Controller.

www.infineon.com

Toroidal Common Mode Chokes Against EMC Interference

Toroidal common mode chokes in THT from knitter-inductive complement the existing product portfolio to meet the requirements of the e-mobility market, among others. The main area of application is the suppression of EMC disturbances in 1- and 3-phase applications at nominal voltages of 230 V and 400 VAC. Because these interferences can occur in different frequency ranges, knitter-inductive offers individualized solutions in addition to the standard versions. Exact selection is crucial for the reliable performance of the components. The latter is also convincing due to its significantly smaller size with the same current rating and its compatibility of very high ambient temperatures. For realizing even more customization, toroidal common-mode chokes allow horizontal as well as vertical mounting plate attachment of the core. Higher dielectric strength is achieved by adding a separator. Another plus is the possible choice of the PCB layout according to customer requirements.

www.rutronik24.com



Programmable DC Power Supply Series Extended

TDK Corporation announces the introduction of six models to the 7.5kW TDK-Lambda GENESYS+™ series of high power density programmable DC power supplies. This expansion now provides incremental and seamless choices in output voltage and current ranging from 0-20V/375A to 0-1500V/5A. Target applications for the 7.5kW power supplies are automotive testing - including electric and hybrid cars, general test or research, measurement, semiconductor fabrication, battery manufacturing, and renewable energy. The six voltage models offer 0-30V/250A, 0-60V/125A, 0-80V/94A, 0-200V/37.5A, 0-300V/25A and 0-1000V/7.5A. The units can operate in constant current, constant voltage, or constant power limit modes and in addition offer internal resistance simulation. The units can be specified to accept three-phase 170 to 265Vac or wide range 342 to 528Vac inputs, with active Power Factor Correction. Operating efficiencies are up to 92%.

The 7.5kW output power enables system configurators to avoid the need to parallel lower wattage power supplies, reducing the rack or cabinet size. The series benefits from DSP (Digital Signal Processing) technology and the latest generation components, including ferrite materials, to obtain efficiencies of 91 to 92%. Less internal waste heat ensures a higher power rating without compromising reliability.

www.emea.lambda.tdk.com

Tactile Switch for Wearable Consumer Electronics

Littelfuse announced the C&K Switches NanoT product line, a series of miniature, surface-mounted, very low profile, waterproof tactile switches.

Smart wearables, health monitoring devices, and other battery-powered IoT devices are driving the need for a higher density of active components integration, seamless rounded screens, and additional functions in increasingly smaller spaces. The result is a demand for the switch interface to be smaller and smaller. The NanoT switch series is the smallest tactile solution on the market. It gives product designers room to build additional functionality into their design or reduce their printed circuit board (PCB) size. The NanoT is ideal for use in a wide range of wearable and portable consumer electronics, including hearing aids, health-monitoring devices, smartwatches, portable IoT devices, and headsets.

“We are excited to release the NanoT switches, the world’s smallest tactile solution currently available for high-end portable, wearable consumer and medical applications,” said Daisy Liu, Global Product Manager at C&K Switches, now part of Littelfuse. “They provide the smallest size, IP67 waterproof tact switch available. They use the surface-mount technology (SMT) reflow process for the top version and Pin-in-Paste (PIP) reflow process for the side version. As a result, this product addresses the market’s demand for smaller components while providing our customers with the ability to deliver high quality and high performance in their latest designs.”

www.littelfuse.com

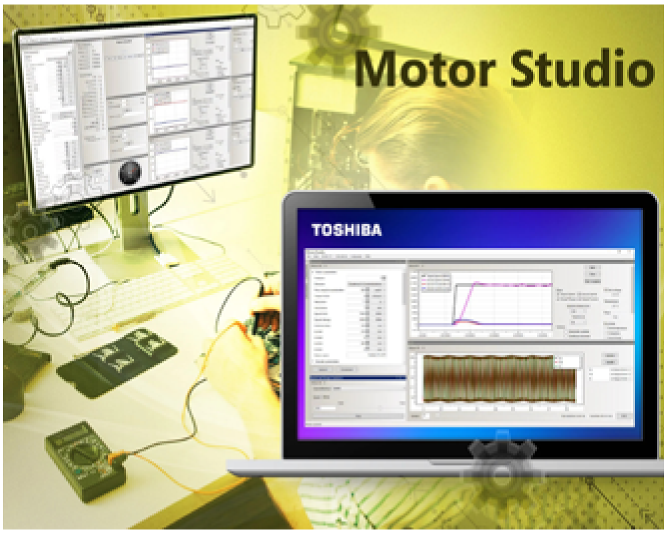
Software and Hardware Ecosystem for Motor Control

Toshiba Electronics Europe has introduced MCU Motor Studio, bringing together PC-based design tools, microcontroller firmware, and low-cost evaluation hardware to accelerate time to market for motor-control applications hosted on Toshiba TXZ+™4A microcontrollers (MCUs).

The MCU Motor Studio firmware suite supports all common energy-efficient motor control strategies including sinewave commutation and field-oriented (vector) control (FOC), sensorless or with precise-position sensing. There is a choice of single-shunt and three-shunt current detection, and support for PWM frequencies up to 156kHz. The firmware caters for all popular motor types, including brushless DC (BLDC) and permanent-magnet synchronous motors (PMSM). Switched reluctance motors (SRM) and asynchronous AC motors are also supported.

Users can control up to three independent motor channels with a single MCU, depending on the variant selected. The TXZ+™4A Series, based on the Arm® Cortex®-M4 core, comprises the M4K and M4M Groups, which enable motor control even with low-cost 64-pin MCUs. Dedicated motor-control features provided on-chip include a hardware vector engine, high-resolution advanced encoder for servo motors, and self-diagnostics that simplify meeting functional-safety standards such as IEC 60730 class B.

The firmware suite provides selectable functionality that lets users quickly configure controls such as zero-current-point detection, initial motor-position detection, and commonly used stop controls including rapid braking. Further functions include magnetic-field stall recovery, load-dependent speed reduction, advanced rotor control with sensorless precise positioning, and linear motion control with sensor-based precise positioning.



https://toshiba.semicon-storage.com

GaN Technology for High Power Density Applications

EPC launches the 80 V, 4 mOhm EPC2619. This is the lead product for a generation of eGaN devices that have double the power density compared to EPC's prior-generation products. The EPC2619 has an RDS(on) of just 4 mOhms in a tiny, 1.5 mm x 2.5 mm, footprint. The maximum RDS(on) x Area of the EPC2619 is 15 mΩ*mm2 – five times smaller than 80 V silicon MOSFETs.

This product is designed for a range of motor drive applications. For example: 28 V – 48 V conversion for eBikes, eScooters and power tools; high density DC-DC converters; solar optimizers; and synchronous rectification converting 12 V – 20 V for chargers, adaptors, and TV power supplies.

The typical RDS(on) x QGD, which is indicative of power losses in hard-switching applications, is 10 times better than 80 V silicon MOSFETs. This enables switching frequencies that are 10 times higher than silicon MOSFETs and without an efficiency penalty, thus producing the highest power density. This makes the EPC2619 ideal for high frequency hard-switching 24 V – 48 V applications, such as used in buck, buck-boost, and boost converters.

The typical RDS(on) x QOSS, which is indicative of power losses in soft-switching applications, is 87 mOhm*nC, two times better than 80 V silicon MOSFETs. This makes the EPC2619 ideal for soft-switching applications, such as the primary rectification full bridge for LLC-based DCX DC-DC converters.

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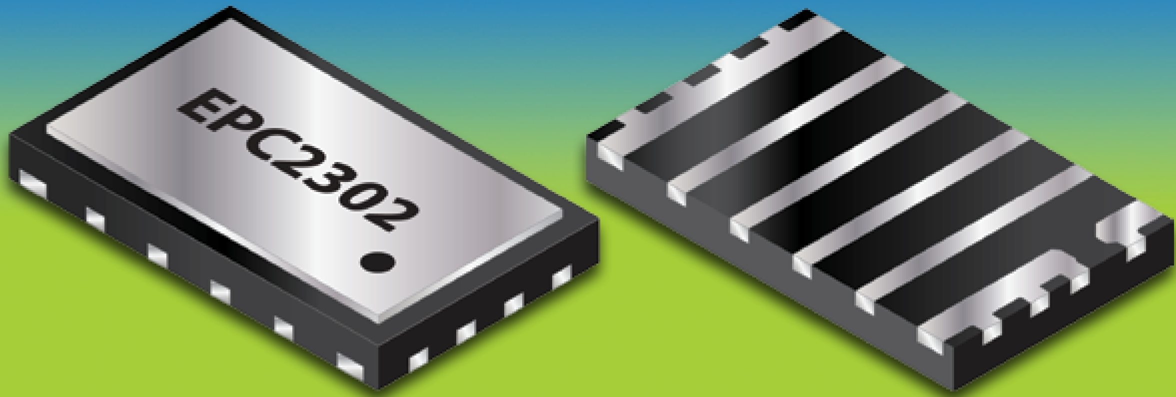
Advertising Index

GaN FETs in PQFN Package

Boost Power Density - Simplify Design



Actual size: 3 x 5 mm

eGaN FETs in 3 x 5 mm QFN

Parameter (5 V_{GS})	EPC2302	EPC2306	EPC2305	EPC2308	EPC2304	EPC2307
V_{DS}	100 V	100 V	150 V	150 V	200 V	200 V
$R_{DS(on)}$ typ	1.4 mΩ	3.2 mΩ	2.2 mΩ	4.9 mΩ	4.1 mΩ	8.2 mΩ
Q_G typ	18 nC	11 nC	21 nC	9.8 nC	21 nC	10.6 nC
Q_{GD} typ	3 nC	1.1 nC	2.6 nC	1.2 nC	2.6 nC	1.3 nC
Q_{OSS} typ	82 nC	41 nC	105 nC	49 nC	115 nC	58 nC
Q_{RR} typ	0 nC	0 nC	0 nC	0 nC	0 nC	0 nC
$I_{D\,(Pulsed)}$	408 A	197 A	329 A	157 A	260 A	130 A

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