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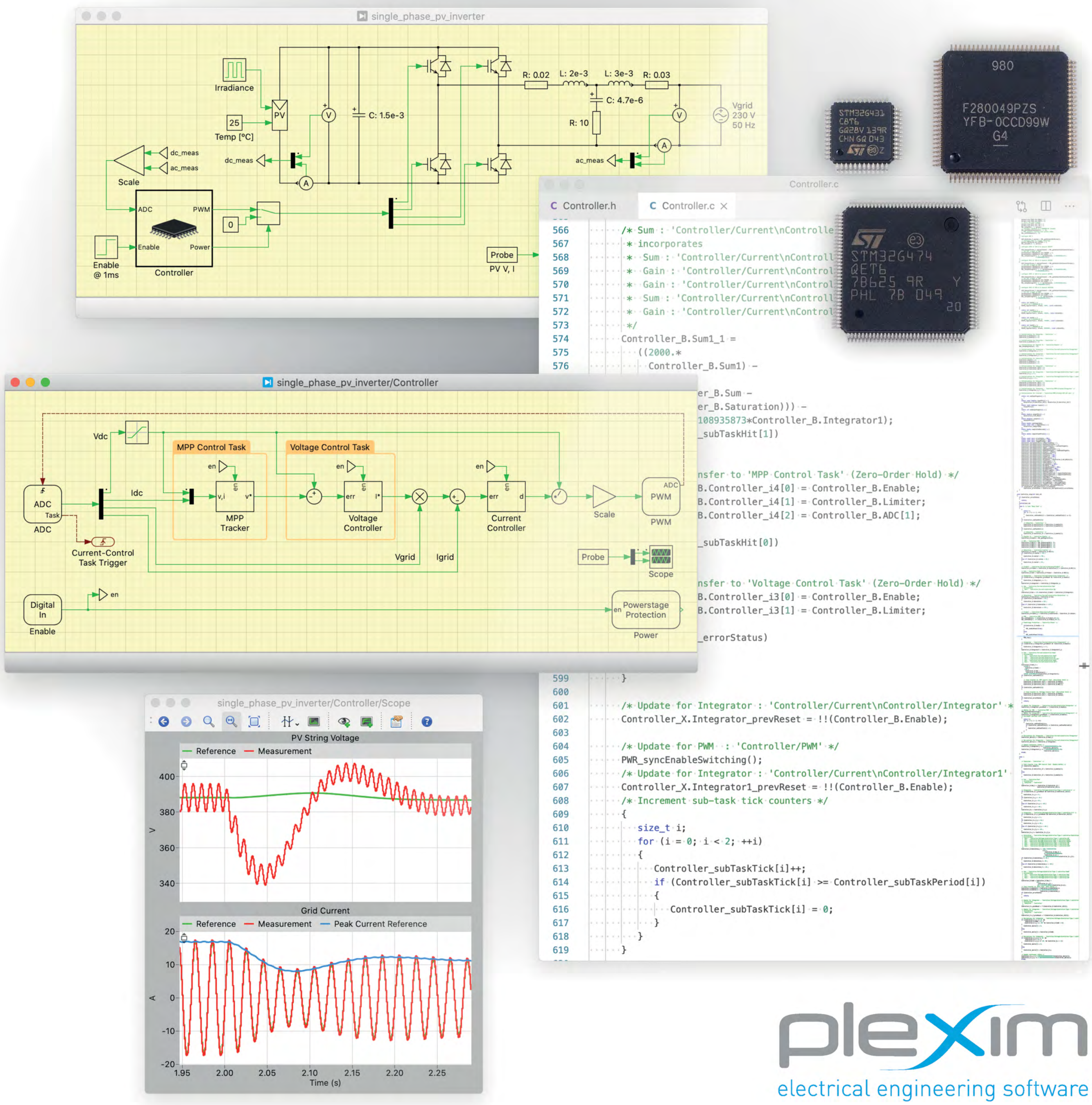
Bodo´s Power Systems®

Electronics in Motion and Conversion

June 2021
15 Years

Automatic Code Generation for Embedded Microcontrollers



plexim
electrical engineering software

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 $L_{inc}(\int Udt)$
- **Secant inductance** $L_{sec}(i)$ and $L_{sec}(\int Udt)$
- **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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What a Journey!

I have a lifetime in power electronics and am now celebrating 15 years publishing my magazine. Prior to this I enjoyed 42 years in electronics and before that I was educated by my electric model trains. I want to thank all of my friends and contributors for making this time a success for both the industry and for myself.

All of my train equipment is still on hand and is often brought back to life, piece by piece. For more than a quarter of a century I served as an advisory board member for PCIM helping to make the conference a success. The new organisers, Mesago, have a rule that states that you are not allowed to continue once you reach 67.

We have enjoyed two successful podium discussions at PCIM this year, with around 100 attendees for each event. Our first discussion was on SiC, followed by a GaN session and by the attendance and questions it is clear that these kinds of discussions are becoming very important to everybody.

Because of the corona pandemic these roundtables had to be virtual again this year and with this in mind we have created a virtual quarterly roundtable which is based on the published wide bandgap articles in my magazine. This is my contribution to help bridge the gap for missing face to face networking and discussion opportunities.

The first expert session was held at the end of March and our next is scheduled for the 30th June.

It is important that design engineers in the field can learn about the new technology of wide bandgap devices so they can create more efficient systems. This is the only way to get our future in line with the growing demand of the power hungry applications.

This is very similar to the mid-80s when I carried out design and application work, for RCA and finally Harris, getting the IGBTs and MOSFETs into European designs, which is about 35 years back in my journey.

We are all looking forward to getting back to normal whatever normal will be in the future.

The pandemic has taught us to use electronic communication more efficiently. Travel will be planned very carefully and knowing the risks will keep a lot of companies preferring to stay virtual to stay save.

It is not only the big events that are changing to virtual formats, so will Bodo's Power Conference. The annual December event will be held virtually for the second time this year. The feedback we have received is that people still do not want to make travel plans at the moment. We too feel that this is not the time travel, and we don't expect to for the rest of the year. So, mark your calendar for "Bodo's Wide Bandgap Event" on December 1-2, 2021. We will once again bring together the experts for SiC, GaN and related topics.

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

My Green Power Tip for the Month:
Explore the areas close to your home. You will be surprised what you have.

Also, you will save fuel if you walk or cycle.

Kind regards

Events

APEC 2021
Online June 14-17
www.apec-conf.org

3D-PEIM 2021
Osaka, Japan & Online June 21-23
www.3d-peim.org

Bodo's WBG Expert Talk
Online June 30
www.bodospower.com/experttalk.aspx

IEEE DMC 2021
Bath, UK & Online July 14-15
https://attend.ieee.org/dmc-2021

IEEE CPE-POWERENG 2021
Florence, Italy & Online July 14-16
https://cpepowereng2021.com

Advancements in Thermal Management 2021 Online August 4-5
www.thermalconference.com

Miniature current sensor

HMSR

Packaged as SO16 surface-mount device with a height of just 6 mm, HMSR current sensor is adapted to the power electronics world for a perfect integration thanks to its SMD automatic assembly and space saving. As a reinforced insulation level, cost effective and miniature solution for current sensing, HMSR provides solutions to photovoltaic, white goods, windows shutters, air-conditioning, high switching frequencies drives applications.

- **6, 8, 10, 15, 20 or 30 A_{RMS} nominal current**
- **0.5% typical accuracy into the operating temperature range**
- **High performance gain and offset thermal drifts**
- **2 µs response time**
- **Operating temperature range: -40°C to +125°C**
- **Unique primary conductor included withstanding overload current bursts up to 20 kA**
- **Double overcurrent detection outputs**

www.lem.com

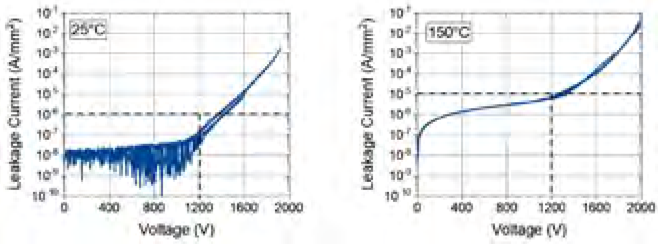
LEM

Life Energy Motion

GaN for 1200V Applications

The manufacturability of 1200V-qualified buffer layers opens doors to highest voltage GaN-based power applications such as electric cars, previously only feasible with silicon-carbide (SiC)-based technology. The result comes after the successful qualification of AIXTRON's G5+ C fully automated metal-organic chemical vapor deposition (MOCVD) reactor at imec, Belgium, for integrating the optimized material epi-stack.

For the first time, imec and AIXTRON have demonstrated epitaxial growth of GaN buffer layers qualified for 1200V applications on



200mm QST® (in SEMI standard thickness) substrates at 25°C and 150°C, with a hard breakdown exceeding 1800V. Denis Marcon, Senior Business Development Manager at imec: "GaN can now become the technology of choice for a whole range of operating voltages from 20V to 1200V. Being processable on larger wafers in high-throughput CMOS fabs, power technology based on GaN offers a significant cost advantage compared to the intrinsically expensive SiC-based technology."

Key to achieving the high breakdown voltage is the careful engineering of the complex epitaxial material stack in combination with the use of 200mm QST® substrates, executed in scope of the IIAP program. The CMOS-fab friendly QST® substrates from Qromis have a thermal expansion that closely matches the thermal expansion of the GaN/AlGaN epitaxial layers, paving the way for thicker buffer layers – and hence higher voltage operation.

www.imec-int.com

Inverter Platform for Battery-Powered Vehicles

SEMIKRON and Silicon Mobility announced the availability of a 24V to 96V inverter platform for automotive battery powered vehicles and industrial off-road vehicles. The Inverter platform delivers from 10KW to 50KW and combines the SEMIKRON SKAI® 3 LV inverter and Silicon Mobility OLEA® inverter and electric motor control solution. SEMIKRON provides SKAI® 3 LV, the power and assembly with an advanced integrated MOSFET module with connected DC-link, gate-driver, protection functions, and sensors. It comes with a complete performance power solution for 3-phase motor-drive and a ready-made power section which reduces time to market. All of this is proposed within a custom-made cover to offer an ultra-compact MOSFET inverter.

The 3rd generation of the SKAI LV industrial MOSFET inverters constitutes the 7th generation of inverter technology manufactured by SEMIKRON, with more than 1.5 Million MOSFET inverters in the field. The 3rd generation is a platform concept that offers standard design versions or can be customized to meet user's needs. The converter connects easily to a custom control board for quick and easy designing, while leaving the control to the customer.

"With Silicon Mobility, a technology leader in ultra-fast control schemes, a perfect match is formed for high quality, high-performance solutions for low-voltage vehicle applications," declared Karl-Heinz Gaubatz, CEO of SEMIKRON. "With this platform, we give low-voltage vehicle manufacturers access to technologies and solutions far above todays state of the art implementations, providing them the extra edge for their designs."

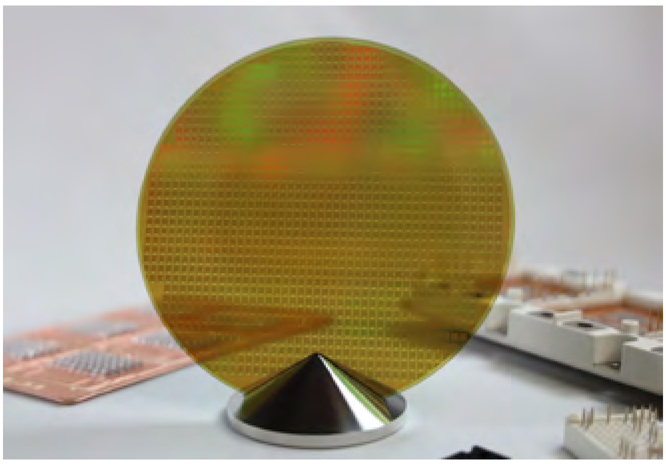
www.semikron.com

Increasing Supply Security for Silicon Carbide

Infineon Technologies has concluded a supply contract with the Japanese wafer manufacturer Showa Denko K.K. for an extensive range of silicon carbide material (SiC) including epitaxy. The German semiconductor manufacturer has thus secured more base material for the growing demand for SiC-based products. SiC enables highly efficient and robust power semiconductors that are used in particular in the fields of photovoltaic, industrial power supply, and charging infrastructure for electric vehicles.

"Our broad and fast growing portfolio demonstrates Infineon's leading role in supporting and shaping the market for SiC-based semiconductors which is expected to grow 30 to 40 percent annually over the next five years", says Peter Wawer, President of the Industrial Power Control Division at Infineon.* "The expansion of our supplier base with Showa Denko for wafers in this growth market marks an important step in our multisourcing strategy. It will support us to reliably meet the growing demand mid to longterm. Furthermore, we plan to collaborate with Showa Denko on the strategic development of the material to improve the quality while cutting costs at the same time."

"We are proud to be able to provide Infineon with Best-in-Class SiC material and our cutting-edge epitaxy technology" says Jiro Ishikawa, Senior Managing Corporate Officer from Showa Denko K.K.. "Our aim is to continuously improve our SiC material and develop



the next technology. We value Infineon as an excellent partner in this regard."

The contract between Infineon and Showa Denko K.K. has a two-year term with an extension option. Infineon has the industry's largest portfolio of SiC semiconductors for industrial applications.

www.infineon.com

Agreement for Software Development Services

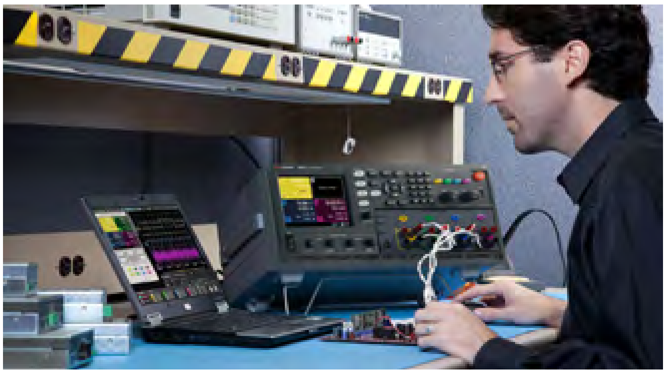
Northforge Innovations announced that it has signed an agreement with Avnet and EBV Elektronik, an Avnet Company, to promote Northforge to Broadcom customers in North America and EMEA.

Both distributors will help Northforge expand its North America and EMEA base of Broadcom customers that may require software development services for Broadcom's StrataDNX™, StrataXGS®, BroadPTP™, BroadSync™, and Broadcom PLP products. Northforge is the only Broadcom Authorized Development Collaborator (ADC) for the StrataDNX line of switch system-on-a-chip (SoC) devices. "Given our close collaboration with Broadcom and direct training from their engineering experts, our expertise and service level commitment are unparalleled. Our rapid response to issues and help with reducing design cycles plays a key role in the software development of our customers' new products," said Brenda Pastorek, President and Chief Operating Officer of Northforge Innovations. "With this agreement, we can reach more Broadcom customers who require our experience and the expertise that we have developed over the years of giving customers the high level of attention that they deserve." "By partnering with Northforge, Avnet expands our service offering to provide top-level software expertise to our Broadcom customers," said Karen Worley, Director of Supplier Business Development at Avnet. "We're proud to partner with Northforge to deliver increased value to our customers' by supporting their Broadcom software development needs."

www.avnet.com

Power Device Testing Solution Selected to Accelerate Development of Semiconductors

Keysight Technologies announced that Semipower Electronic Technology has selected Keysight's power device testing solutions, to accelerate and promote the development of next-generation semiconductors. Semipower's power device testing application center, a comprehensive testing center for power device testing capabilities, has been recognized by the China National Accreditation Service for Conformity Assessment (CNAS) and International Laboratory Accreditation Cooperation (ILAC). Offering third-party testing qualification, the center is critical to promoting the development of the third-generation semiconductor industry. Leveraging Keysight's power device testing solution, the center offers a test platform for third-generation semiconductor devices to ensure performance and reliably speed market introduction. "We are pleased to work with Semipower to accelerate and promote the development of next-generation semiconductors," said Thomas Goetzl, vice president and general manager of Keysight's Automotive and Energy solutions. "Keysight is committed to innovation in the field of power semiconductor test and for we work closely with key partners to provide powerful test tools in conjunction with advances of industry critical technology waves."



Semipower chose Keysight's PD1500A dynamic power device analyzer / double pulse tester to deliver repeatable, reliable measurements of wide bandgap semiconductors. The off-the-shelf measurement solution enables faster time-to-market by providing quick and reliable results, while ensuring a safe test environment.

www.keysight.com

Developing a 300 MWp Solar Project in Spain

Spanish project developer Tartessos concludes a service agreement with RP Global as the two renewable energy companies set out to develop a 300 MWp PV project together in the Castilla-León region in Spain. "RP Global is a recognised international player with over 35 years of experience in the market and a well-established team of development experts. This makes RP Global a great fit for us", says Dr. Rainer Kistner, Managing Partner of Tartessos Power Development. The land for the 300 MWp project has already been secured and rigorous environmental impact assessments have raised no red flags. "Tartessos's experience and strong track record of project delivery convinced us that they are an ideal company for us to partner with to develop this significant project.", explains Jorge Rodriguez, RP Global's CFO and Country Manager for Spain, adding: "Identifying the right long-term local partner to develop our projects is becoming more and more important for us, as we aim to develop a 2GW pipeline of wind and solar PV in Spain by 2024." The development of further joint projects in the region are being discussed. The companies are also exploring the possibility of converting the planned 300 MWp solar park into a wind-solar hybrid project.

www.tartessospower.com

HITACHI
Inspire the Next

HPMSIM Hitachi

HPMSIM, Hitachi's new online power simulation tool is designed to help assist you in choosing the right Hitachi IGBT, Hybrid SiC and SiC MOSFET, suited to your needs.

Our new platform allows you to analyse the performance of our products to fit your specific application.

How to get started:
https://pdd.hitachi.eu/simulations

Why us?

- Convenience of selecting the right power module based on your application requirements
- Provides in depth information on switching and conduction losses along with junction temperatures
- Both 2 level and 3 level inverter topology available
- EV power modules simulation option available

Contact us:

For further information on our products or services, please get in touch with one of our experts on:

pdd@hitachi-eu.com

Joining for Electronics Market Growth

Indium Corporation announced today that Solder Chemistry is now part of the Indium Corporation family. The joining of these two companies further expands Indium Corporation's reach in the European electronics market and creates an extended platform for Solder Chemistry's distinctive product offerings and technology. Each company will continue to offer products and solutions via its established sales and service networks. "Solder Chemistry and Indium Corporation operate with the same customer goals and benefits in mind," said Brian Craig, Managing Director of Indium Corporation's European Operations. "Both companies share a commitment to keeping our factories running efficiently through the supply of advanced materials, superior technical support, and excellent customer service." "Solder Chemistry and Indium Corporation are both committed to working side-by-side to secure our future success," said Robert Sudnik, Managing Director, Solder Chemistry. "I am eager to work directly alongside Indium Corporation in bringing this new relationship to life and taking advantage of the resources this brings to our customers and the broader electronics industry." Indium Corporation has been active in the European market for over 30 years, including facilities in Milton Keynes, UK. Indium Corporation was among one of the first soldering materials suppliers to earn the IATF-16949:2016 management system certificates at five of its manufacturing facilities that produce products for automotive applications.

www.indium.com

Collaboration to Further Promote Energy Harvesting Innovation

Specialist in advanced power management ICs (PMICs) for energy harvesting e-peas is further strengthening its commercial presence. The company has entered into a distribution partnership with Steliau Technology. This will cover the French and Italian regions. Drawing on almost twenty years of industry experience, Steliau supplies end-to-end connectivity solutions to its expansive customer base. The company's multidisciplinary team is highly adept at supporting a wide variety of different types of IoT-related deployment. These go from smart homes and electronic shelf labels through metering, industrial automation, environment monitoring, asset tracking and lighting management systems, all the way up to large-scale smart city implementations. e-peas' AEM Series PMICs supervise the extraction, storage and delivery of harvested energy. Covering photovoltaic, vibration, thermal and RF based harvesting methods, they will complement Steliau's established ecosystem. Working in conjunction with the wide range of wireless modules (WAN, LPWAN and cellular IoT) that the company offers, these devices will enable the power derived from the surrounding environment to be maximized. "We see a great deal of potential for inclusion of the PMICs from e-peas in our customers' products and installations. The low thresholds at which these devices can start operating is a clear differentiator, bringing major operational advantages to any system which is reliant on energy harvesting," states Pascal Reynoud, Steliau France's General Manager. "In addition to being specified into new hardware designs, there are also opportunities for the e-peas PMICs to be retrofitted into existing deployments.

www.e-peas.com

Uniting Activities at Düsseldorf Harbour

On 16th November 2020 Asahi Kasei Europe started office operation at its new location at Düsseldorf Harbour, Germany. In March 2021, the Asahi Kasei Europe R&D Center relocated from Dormagen to the new location. By uniting European sales, marketing and R&D activities, the Japanese technology company further enhances its business approach towards the European automotive industry.

Asahi Kasei is starting a new chapter of its business expansion on the European market: On 16th November 2020, Asahi Kasei Europe GmbH and its sister company Asahi Kasei Microdevices Europe GmbH started office operation at the new "C-View Offices" at Düsseldorf Harbour, Germany. After the cornerstone laying on 7th October 2019, the construction work went smoothly and was finished on schedule. The Asahi Kasei Europe R&D Center – originally located at CHEMPARK Dormagen near Düsseldorf – relocated to the new location in March 2021.

Hideki Tsutsumi, Managing Director at Asahi Kasei Europe: "This relocation marks the next important milestone of Asahi Kasei's expansion on the European market. Europe is at the forefront of an evolution in the automotive industry that is said to happen once in a century. In addition, it is the forerunner in environmental topics. Uniting sales, marketing, R&D and technical service activities at one single location will enable us to quickly address the changing demands by customers and to enhance joint projects with local partners.

https://asahi-kasei.eu

VISIT OUR VIRTUAL BOOTH

virtualbooth.fujielectric-europe.com

TRAIN

High Power next Core (HPnC)

with Fuji Electric's X series - 7G IGBT

X series 7G

MAIN FEATURES

- **Latest chip technology**
  - Fuji Electric's X series IGBT and FWD with low losses
- **High reliability**
  - CTI>600 for higher anti-tracking
  - High thermal cycling capability with ultra sonic welded terminals and MgSiC base plate
  - Improvement of delta T_j power cycle capability by using 7G Package Technology
- **RoHS compliance**
  - Ultrasonic welded terminals
  - RoHs compliant solder material
- **Over temperature protection**
  - Thermal sensor installed
- **Easy paralleling**
  - HPnC module has a minimized current imbalance
  - Easy scalability

Leader in GaN Power ICs to Go Public at an Enterprise Value of $1.04 Billion

Navitas Semiconductor announced that it has entered into a definitive agreement to combine with Live Oak Acquisition Corp. II ("Live Oak II"), a publicly-traded special-purpose acquisition company. The transaction, which values the combined entity at a pro forma equity value of $1.4 billion, will result in Navitas becoming a publicly-traded company on a national exchange under a new ticker symbol.

Gallium nitride (GaN) is a next-generation semiconductor technology that runs up to 20x faster than legacy silicon, and enables up to 3x more power and 3x faster charging in half the size and weight. Navitas GaNFast™ power ICs integrate GaN power and drive plus protection and control to deliver simple, small, fast and efficient performance.

Driven by increasing demand for connectivity, electrification away from fossil fuels, and efficient sustainable energy sources, Navitas predicts GaN ICs can address markets estimated to grow to over $13 billion in 2026. Markets include mobile, consumer, enterprise (data center, 5G), renewables (solar, energy storage) and EV / eMobility.

Gene Sheridan, co-founder and CEO of Navitas commented: "Navitas was formed with the vision to revolutionize the world of power electronics while addressing significant sustainability challenges for our planet. Not only has Navitas' world-class team invented and patented revolutionary new technology, but we have also overcome all the key hurdles associated with successfully bringing it to market. We are proud to enter the public capital markets with strong operating momentum and investor partners who share our enthusiasm for our long-term mission."

www.navitassemi.com

The 2021 VLSI Symposia

The 2021 Symposia on VLSI Technology & Circuits have announced their technical program, which highlights the theme "VLSI Systems for Lifestyle Transformation." Due to continuing concerns over the global COVID-19 pandemic, the Symposia will be held on a worldwide accessible schedule from June 13th – 19th with a fully virtual format. Despite the difficulties of COVID-19, VLSI development continues to advance at a fast rate. The latest in innovative and life-enhancing circuits and technologies will be presented at VLSI Symposia 2021. The Symposia program provides a unique perspective on the microelectronics industry by integrating the technology ecosystem of converging industry trends – machine learning, IoT, artificial intelligence, wearable/implantable biomedical applications, big data, cloud / edge computing, virtual reality (VR) / augmented reality (AR), robotics, and autonomous vehicles – with the advanced circuit design and application platforms that will realize the future promise of "ubiquitous intelligence."

www.vlsisymposium.org

Measurement System for DC Meters Used in EV Charging Stations

Danisense has announced a partnership with ZES ZIMMER to deliver highly accurate, stable DC meter test systems. Comprising the Danisense DS600 current sense transducer paired with the LMG600 power analyser from ZES ZIMMER, the system is already being used by renowned German standards organization, VDE, to calibrate and certify DC meters used in EV charging stations which are proliferating as consumers switch to electric cars. Loic Moreau, VP marketing at Danisense: "We are very pleased to partner with ZES ZIMMER to deliver this easy-to-use DC measurement package. ZES ZIMMER is recognized as a technical leader in the field of power analysis, and the fact that VDE is using the solution should give consumers massive confidence that they are being correctly billed."

www.danisense.com

UK Facility Achieves AS9100D Certification

TT Electronics announced that its Eastleigh UK facility has achieved AS9100D certification for the manufacture of systems for the aerospace industry. This certification marks TT's ongoing commitment to provide innovative, safety-critical solutions to the global aerospace supply chain.

AS9100, standardised by the globally recognised International Aerospace Quality Group (IAQG), is considered the highest international standard for quality assurance across the aviation, space, and defence industries, and has been widely adopted to promote quality, safety, and continuous product and process improvement. Upgrading the Eastleigh facility to meet AS9100D, the most current version of the standard, was the result of a lengthy audit process in which TT demonstrated a high level of excellence in all areas of the company's quality management system. The Eastleigh location is the twelfth TT location worldwide to meet the rigorous requirements of AS9100 certification, strengthening the company's position as a leading aerospace manufacturing partner – dedicated to providing custom technology solutions. "This certification is an important step in our aerospace growth strategy. Our facility in Eastleigh, which is also SC21 accredited, specialises in the design and manufacture of aircraft interior solutions for commercial aircraft," said TT Electronics EVP, Charlie Peppiatt. "TT has supported tech-

nology innovations in this sector for decades, including lightweight, space-saving, and power-efficient cabin signage and mood lighting. While we have always been focused on providing our customers with quality products and services, achieving the AS9100D certification is a well-earned achievement that confirms our steadfast emphasis on quality management."

www.ttelectronics.com

APEC Industry Session Explores Rapid Growth Markets

The Power Sources Manufacturers Association (PSMA) Marketing Committee is sponsoring an Industry Session at APEC 2021 ad-

dressing the trends within fast growing market sectors. The presentations and audio recordings will be available to APEC registrants ON DEMAND beginning on Wednesday, June 9, 2021. There will also be a live Q&A session during the week of June 14 where you will have the opportunity to interact with live speakers and follow up on any questions you have from the on-demand sessions.

The Market Trends Industry Session (IS02) will feature eight presentations by industry leaders focusing on important aspects of a number of dynamic and rapidly growing market sectors.

Ada Cheng and Marijana Vukicevic, Co-Chairs of the Market Trends Industry Session, commented "We are excited that the PSMA Marketing Committee is organizing this year's Market Trends Industry Session. This cohesive session features knowledgeable and respected representatives from industry who will focus on issues that impact the future growth of key industry market segments." Ada and Marijana encourage everyone to register for APEC and attend this valuable industry session and to consider participating in the other PSMA-sponsored Industry Sessions during the week.

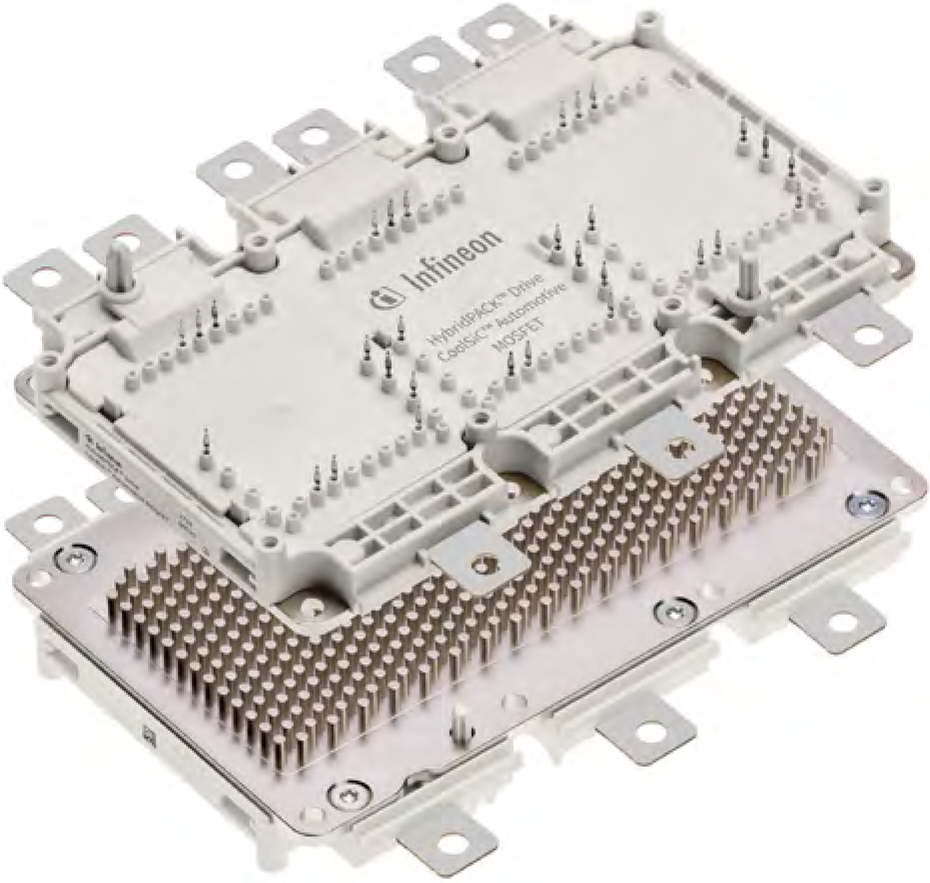
www.apec-conf.org

Partner of European Hyperloop Week

Würth Elektronik will support the first European Hyperloop Week as an exclusive partner. From July 19 to 25, 2021, a conference filled with round table discussions, keynotes, and the presentation of vehicles called "pods" will take place in Valencia. The highlight of the event will be the pod competition. Representatives from the manufacturer of electronic and electromechanical components will also present. Leading up to the main event, a major contribution is already occurring Würth Elektronik is sponsoring three Hyperloop teams, supplying components and carrying out the thermal and EMC testing in joint laboratories, which are available at the University of Valencia as part of the long-standing research cooperation with Fundación Catédra.

www.we-online.com

Automotive Qualified SiC Six-Pack Power Module for EV Traction Inverters



Infineon Technologies introduced an automotive power module with CoolSiC™ MOSFET technology, the HybridPACK™ Drive CoolSiC™, a full-bridge module with 1200 V blocking voltage optimized for traction inverters in electric vehicles (EV). The power module is based on the automotive CoolSiC trench MOSFET technology for high-power density and high-performance applications. This offers higher efficiency in inverters with longer ranges and lower battery costs, particularly for vehicles with 800 V battery systems and larger battery capacity.

"The 800 V system of the Electric Global Modular Platform (E-GMP) represents the technological basis for the next generation of electric vehicles with reduced charging time", said Dr. Jin-Hwan Jung, Head of the Electrification Development Team at Hyundai Motor Group. "By using traction inverters based on Infineon's CoolSiC power module, we were able to increase the range of the vehicle by more than five percent because of efficiency gains resulting from the lower losses of this SiC solution compared to Si based solution."

"The automotive e-mobility market has become highly dynamic, paving the ground for ideas and innovation", said Mark Münzer, Head of Innovation and Emerging Technology at Infineon. "As the price of SiC devices significantly decreases, the commercialization of SiC solutions will accelerate, resulting in more cost-efficient platforms adopting SiC technology to improve the range of electric vehicles."

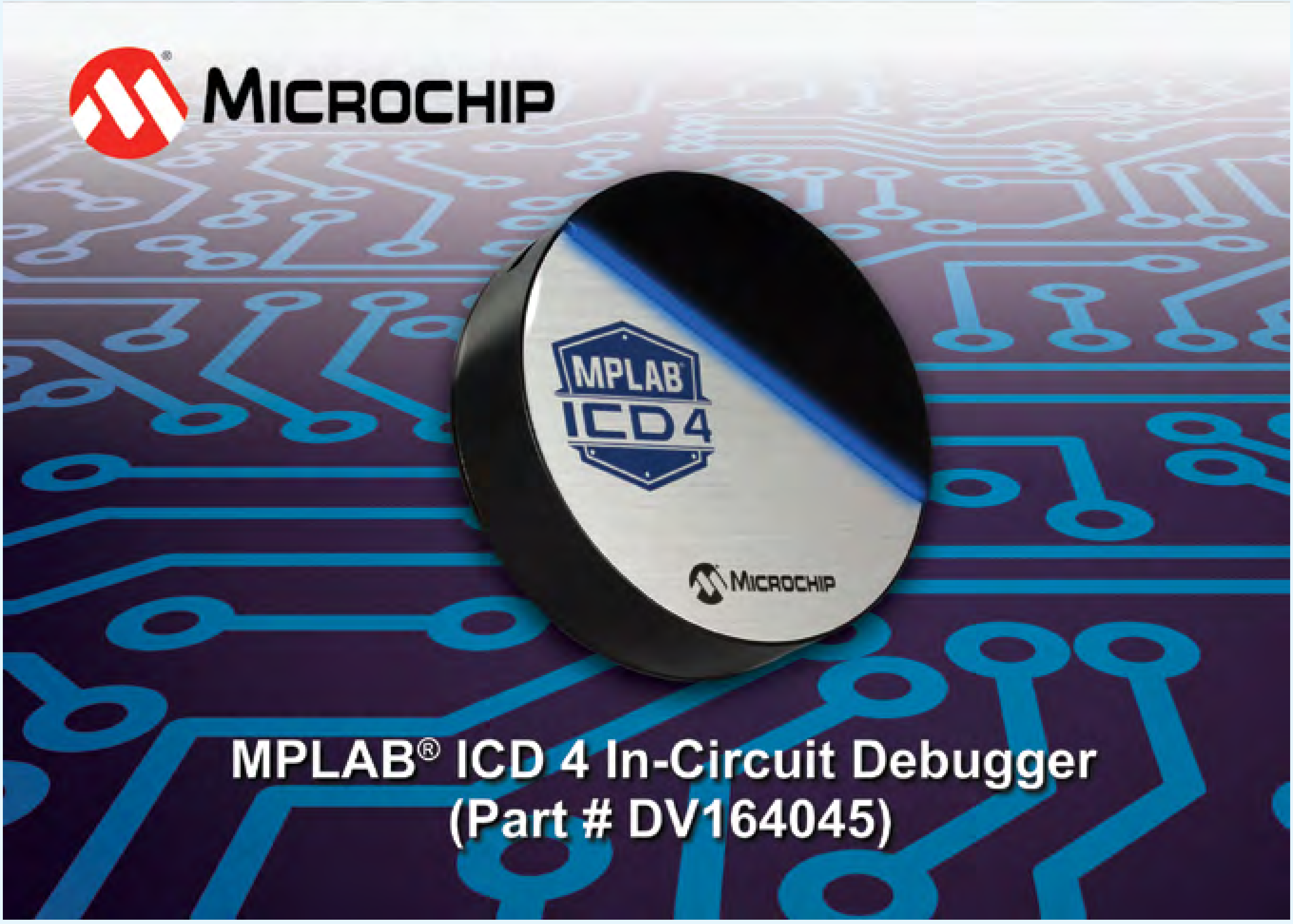
The HybridPACK Drive was first introduced in 2017, using Infineon's silicon EDT2 technology, specifically optimized to deliver the best efficiency on a real-world driving cycle. It offers a scalable power range of 100 kW to 180 kW within the 750 V and 1200 V class. This product is Infineon's market-leading power module with a track record of more than one million pieces shipped for more than 20 electric vehicle platforms. The new CoolSiC version is based on Infineon's silicon carbide trench MOSFET structure. Compared to planar structures, the trench structure enables a higher cell density, resulting in the best-in-class figure of merit. Therefore, trench MOSFETs can be operated at lower gate-oxide field strengths, resulting in increased reliability.

The power module offers an easy upscale path from silicon to silicon carbide with the same footprint. This allows the inverter design to achieve higher power of up to 250 kW in the 1200 V class, greater driving range, smaller battery size and optimized system size and cost. In order to offer an optimal cost-performance ratio for different power levels, this product is available in two versions with different chip counts, resulting in either a 400 A or 200 A DC rating version in the 1200 V class.

www.infineon.com/sicatv

Win a Microchip MPLAB® ICD 4 In-Circuit Debugger

Win a Microchip MPLAB ICD 4 In-Circuit Debugger (DV164045) from Bodo's Power and if you don't win, receive a 20% off voucher, plus free shipping for one of these products.



The new MPLAB ICD 4 introduces a faster processor and increased RAM to deliver up to twice the speed of ICD 3 for the in-circuit debugging of PIC® microcontrollers and dsPIC® digital signal controllers. The MPLAB ICD 4 also introduces a wider target voltage range and an optional 1 A of power via an external power supply.

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Time-to-Market - The Key to Success

The power semiconductor market is seeing a strong move by a large number of Si users to SiC. We asked Josef Lechner, VP Sales & Marketing EMEA at United SiC, and Harald Thomas, Business Segment Manager Power at Angst+Pfister Sensors and Power, about strategies and challenges.

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

Bodo: United SiC is a global player. How has the company developed and how are you positioned globally?

Josef: The company was founded in Princeton in 1999 by a small team of researchers. At that time, SiC technology was still in its infancy. Today, the company has nine corporate locations worldwide in the U.S., Asia and Europe. Early on, UnitedSiC opted for the concept of the "fabless company". In other words, the company deliberately decided not to manufacture its own semiconductors and instead concentrated on R&D, product design, and customer support.

Bodo: Which role do regional distributors play in your sales structure?

Josef: Apart from a few key accounts, e.g. Tier 1 customers and OEMs, sales are mainly handled by our distributors. When selecting regional distributors, in addition to the local presence, their technical competence in design-in is crucial for us.

Bodo: Harald, your company has long been known as a distributor under the name Pewatron. Recently, you have now been operating as Angst+Pfister Sensors and Power (APSP). What is your main focus?

Harald: The new company name also defines the focus of our work. These are the areas of sensors and power. We have been active in both areas for more than 30 years and have had great success. With the existing setup, it was clear that we were moving in the direction of e-mobility, autonomous driving, and charging stations. In 2016, we were then able to gain a very strong partner for our ideas in United SiC, who is tremendously supporting us in achieving our goals.

Bodo: How would you describe APSP's role in this? What added value can you offer your customers?

Harald: APSP acts as a link between customers and manufacturers. You could also call it an extended workbench. We have been developing and supplying integrated solutions for many years and thus bring the decisive advantage for the customer. We relieve him of the design-in and give him the freedom to concentrate on his core competencies again. For the power sector we support many projects that also involve customer-specific solutions.

Josef Lechner, Vice President Sales & Marketing EMEA, United Silicon Carbide

Harald Thomas, Business Segment Manager Power, Angst+Pfister Sensors and Power

Bodo: United SiC recently introduced the first SiC FETs of the new Generation 4. What are the main advantages and developments compared to the previous series?

Josef: We have introduced just now four new 18mΩ and 60mΩ SiC FETs of the new 750V Generation 4 series. The new 750V parts – first in the market – allow for example additional design margin for 400V/500V battery and bus voltage applications. Gen 4 will enable next-generation, high-performance power designs providing lowest RDS(ON) per unit area, superior high frequency soft-switching and excellent hard-switching efficiency as well. All this while retaining drop-in compatibility with all typical SiC MOSFET, Si IGBT, and Si MOSFET drives.

We will introduce in the Gen 4 family concept more 750V devices and also expand this "platform concept" into 1200V and 1700V before the end of this year. We will also offer a much tighter gradation for RDS (ON), starting with 4.8mΩ and up. This will enable an even more precise replacement in existing architectures. We will also have D2PAK-7L packages for SMD assembly in our portfolio in addition to the usual TO247.

Bodo: For which applications was this new generation designed?

Josef: With our SiC FETs, we are primarily addressing applications in the Automotive sector (e.g. on-board chargers, EV infrastructure), battery charging, IT infrastructure, renewable energy and circuit protection.

Figure 1: New Gen 4 D2PAK-7L package by United SiC

Harald: This development not only supports on-board chargers or charging stations for e-mobility, but also many other applications in which efficiency in power conversion is the issue. Examples are bi-directional charging (DAB inverters) or well-known LLC topologies.

Bodo: APSP has developed the BeFast evaluation kit for these SiC FETs. What is the motivation behind this? What benefits can developers derive from it?

Harald: Our original motivation was the tiny 9mΩ of United SiC's 3rd generation 1200V cascodes. We wanted to demonstrate that in a very simple way. However, initial research showed that there was no uniform characterization or standardization of wide-bandgap switches. Thus, it was clear that we need a simple tool that allows an uncomplicated and fast characterization. The BeFast kit helps to save a considerable amount of time at the beginning of a new development and to avoid going through several development cycles because of some stray inductances and capacitances. 30% of the development time is typically spent on component selection and characterization. We also had to do a few rounds until it fit. Why should you do all this voluntarily when you can buy something like this ready-made?

The adaptation to the new generation with 750V was only a small step then - and not a complicated one. We offer customers a small upgrade kit for this, which is available either individually or together with the 3rd generation board.

data sheets have actually been rewritten. As an example, NVE adapted the new IEC60747-17 standard for its isolators in a very short time.

Bodo: What is planned next?

Harald: We are already working on the update for the 4th-generation 1200V series. There, we will also use the SMD packages from United SiC for the first time. Increasingly powerful SiC semiconductors in SMD version, like the D2PAK-7L package, simply offer more pins and reduce pin resistance compared to the TO-247-4L. This will soon be seen in many developments, too.

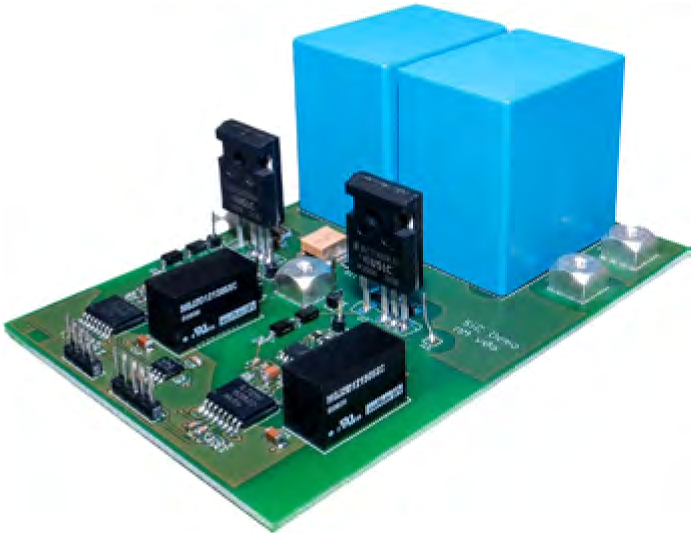

Figure 2: BeFast Evaluation Board by Angst+Pfister Sensors and Power

Josef: Currently, the development in the field of power is rapidly accelerating. The trend is clearly moving away from Si to SiC. Time-to-market is becoming the decisive factor. That is where tools like BeFast are very valuable for our customers. We will therefore also promote the board via our own website.

Bodo: When you look at the board, you immediately notice that there are many other components on it. Why is that important?

Harald: Yes, BeFast does also include the required DC-DC converters which we took from Murata´s MGJ2D series and digital wide-body isolators from NVE´s IL7xxVE series. Optionally, fast Murata NXFT thermistors can be integrated and used for battery temperature monitoring. For extremely fast wide-bandgap devices like the SiC FETs, the basics simply have to be met. These are isolation, lifetime, very high CMTI values (V/ns), delay, skew, or even new test standards. But what do you do if you can't find this information in the data sheet? We have invested a lot of time to save customers this effort. Together with the partners involved,

Bodo: What can we expect in the field of power electronics in the future?

Josef: The SiC market is poised to explode. Electric vehicles will become one of the largest markets for SiC applications. The need for smart grids and grid resiliency will further drive SiC adoption, for example in the fields of energy storage, wind and solar energy, vehicle-to-grid adoption (V2G), or dynamic power routing.

Bodo: What do you see as the biggest challenges at the moment, also due to the worldwide pandemic?

Josef: The supply for raw material is very tight. But we have serious suppliers and major raw material inventory, so that we still can provide 20 weeks lead time. However, we expect increasing lead times in the very near future - also for our final products. The supply situation is very tough in active and passive components as well which is and will continue to be limiting our customers´ ability to finalize their designs and products. And, of course, this also delays time-to-market.

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https://sensorsandpower.angst-pfister.com/befast

Automatic Code Generation for Embedded Microcontrollers

Block diagrams are a natural way to model and simulate closed-loop controls. Before digital controls can be used in a power electronics application, a block diagram design must be translated into C code and deployed on an embedded microcontroller. Compared to hand coding, automatic code generation significantly speeds up the implementation, reduces programming errors and leads to better maintainability.

By Jost Allmeling, Plexim

Electrical engineers may not be good software developers
The development of a power electronic system is a multidisciplinary endeavor. It includes not only the design of the power stage, but also the development of the controls, which are often implemented on a microcontroller. Few developers are equally skilled in all disciplines to design every part of the system with the same high level of quality. Electrical engineers, like myself, are usually not professional software developers by education. During their studies, most of them have developed small programs in C or in scripting languages, but only few were involved in large software projects and have learned to follow the principles of structured programming.

In their jobs, however, electrical engineers are often assigned the task of programming embedded microcontrollers, and for good reasons: They have experience in how to control a power electronic circuit and they know the requirements of the entire system. Moreover, they have a good understanding of the microcontroller's on-chip peripherals such as PWM generators and analog-to-digital converters (ADCs). On the downside, for a typical electrical engineer a product development is completed when the code compiles without errors, when the system behaves as expected, and when all tests are passed. Especially with today's short time-to-market pressures, there is little intrinsic motivation to write code that can be reused and maintained over the entire lifetime of the product.

As a result, the handwritten codebase often lacks modularity, clear structure and proper documentation. For outsiders, it can therefore become difficult to figure out from the code what function it performs. Even the authors of the control code themselves may scratch their heads when revisiting their own code a few years later, wondering what they had in mind when writing it. That is why we should support electrical engineers in what they are good at, namely electronics and control design, and leave the software architecture and the implementation either to experienced software developers or to a computer program that generates the code automatically.

Modeling controls as block diagrams
The most natural way to sketch control systems are block diagrams representing signal flows. They visualize the underlying control concept in a clear and understandable manner. Functional units that belong together can be encapsulated in subsystems in order to hide complexity and create a hierarchical structure. It is not surprising that most simulation software for control systems is based on block diagrams.

While the simulation software PLECS was primarily developed to accelerate the simulation of power electronic circuits, it also provides an extensive collection of signal processing blocks for the design of control systems. The PLECS library includes continuous and discrete transfer functions, discontinuous and non-linear blocks as well as elements frequently required for power electronics applications such as coordinate transformations, phase-locked loops (PLLs) and PID controllers. As an example, Figure 1 shows the block diagram of a current controller used in a solar inverter.

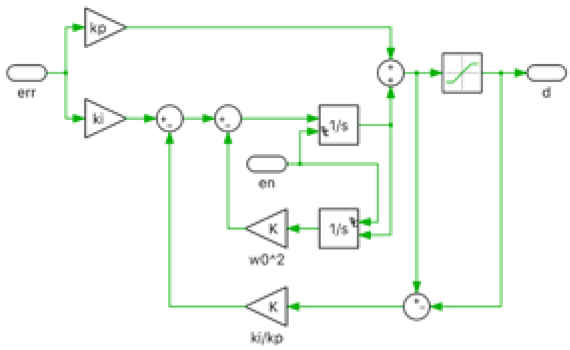

Figure 1: Current controller with resonant integrator and anti-reset windup

Like with similar tools, block diagrams designed in PLECS can be translated into equivalent C code. Figure 2 shows an excerpt from the code generated by PLECS for the controller in Figure 1. The generated code can be compiled and executed on different target systems, such as microcontrollers. Automatically generating control code from a block diagram model, rather than using the model merely for offline simulation and implementing the code by hand, has some significant advantages:

- The control engineer can focus on functionality rather than its implementation.
- An experienced embedded software developer is not needed.
- Changes to the model are possible even late in the development process.
- The model inherently provides clear and up-to-date documentation.
- The model and its implementation are always in sync.

I do not want to hide the fact that using the model as the sole basis for defining the control code also has some disadvantages:

- The model must contain extra information about data types, sample rates and execution tasks.
- Diff tools for tracking changes are still in their infancy when dealing with block diagrams.
- The user gives up precise control over implementation details and low-level optimizations.
- Not all of the advanced low-level functionality may be available through model components.

Despite its many benefits, automatic code generation will only be accepted if it accelerates and simplifies the development process right from the start. The time savings, however, depend very much on the toolchain that is being used. At Plexim, we have taken great efforts to make embedded code generation with PLECS and the PLECS Coder an easy and intuitive experience.

Accessing I/O peripherals

When starting with a microcontroller project, it is usually not the implementation of the control algorithm itself that causes the biggest headache, but configuring and accessing the microcontroller's I/O peripherals. Before you can begin to generate a PWM and acquire ADC readings inside an interrupt-driven control loop, you need to study technical manuals of more than 1000 pages. Not only newcomers struggle with such a steep learning curve. Even if you already know the ins and outs of one microcontroller family, you may need to start almost from scratch when dealing with microcontrollers from another manufacturer. Although microcontrollers from competing manufacturers may offer similar peripherals, the naming conventions and implementation details can be quite different. This presents a major obstacle when you want to port your project to a new target microcontroller, especially if the development was made with a vendor-specific toolchain.

```c

/* Integrator : 'Current\nController/Integrator' */
if ((Current_Controller_X.Integrator_prevReset &&
    !Current_Controller_U.en))
{
   Current_Controller_X.Integrator_x = 0.;
}
Current_Controller_B.Integrator = Current_Controller_X.Integrator_x;

/* Sum : 'Current\nController/Sum'
 * incorporates
 *  Gain : 'Current\nController/Kp'
 *  Signal Inport : 'Current\nController/err'
 */
Current_Controller_B.Sum =
   (20.*Current_Controller_U.err) + Current_Controller_B.Integrator;

/* Saturation : 'Current\nController/Saturation' */
Current_Controller_B.Saturation = Current_Controller_B.Sum;
if (Current_Controller_B.Saturation > 325.)
{
   Current_Controller_B.Saturation = 325.;
}
else if (Current_Controller_B.Saturation < -325.)
{
   Current_Controller_B.Saturation = -325.;
}

```

Figure 2: Snippet of controller C code generated by PLECS

For an efficient workflow involving automated code generation, it is not sufficient to translate only the target-independent part of the control algorithm from a block diagram to C code and import the generated code into a target-specific software project. This approach would still require the user to write and maintain glue code for addressing the target-specific peripherals, which is a manual and error-prone task. If a fully automated workflow with one-step code generation is desired, all information about the target peripherals must be included in the model. Peripherals can be represented in the model by individual blocks that behave as signal sources or sinks during a simulation. During code generation, these blocks can inject target-specific code into the project to configure the corresponding peripherals and provide data access.

Target blocks in PLECS

For selected microcontroller families commonly found in power electronic applications, Plexim offers dedicated Target Support Packages (TSPs) to be used in conjunction with PLECS and the PLECS Coder. These TSPs contain a library of target blocks that represent the various on-chip peripherals of the respective microcontroller. Target blocks can be distinguished from other control blocks by their rounded corners.

Each target block has a dialog that allows the user to configure the corresponding hardware peripheral. In case of an analog input, the user can choose the ADC unit, the input channel(s), scale, offset and acquisition time window. As each data acquisition is initiated by an event, such as a timer, the user can also specify a trigger source. Instead of setting individual bits in configuration registers, the user configures the peripherals at a more abstract level using natural-language options. Although the options may vary slightly between different microcontroller families and not all hardware resources are available on every chip, the hardware abstraction provided by the target blocks makes it quite easy to port a model to another microcontroller.

Target blocks in PLECS not only provide intuitive access to digital and analog inputs or outputs. They can also combine multiple peripherals to offer more complex functionality, such as peak current control with ramp compensation and leading-edge blanking. Figure 3 shows the complete controller model for a solar inverter, including the target-specific peripheral blocks. The current controller subsystem contains the model of Figure 1.

When looking under the hood of a target block, you will notice two different implementations, as in a configurable subsystem. One implementation is text-based and contains meta code in the Lua scripting language. It is used to generate code for the on-chip peripherals according to the dialog box entries. The other implementation is a PLECS model that emulates the behavior of the hardware peripheral during an offline simulation. In case of an ADC, the offline model consists of a triggered sample-and-hold element and a quantizer.

Code-generation subsystem

To make use of the offline models for the I/O peripherals, the controls must be wrapped in a subsystem along with the target blocks. When a target block representing a data source, such as an ADC, is placed in a subsystem, an input terminal will be added to the subsystem block. This input can be connected to a signal source outside the control subsystem, for example to a measurement in the electrical circuit model. Likewise, a target block representing a data endpoint, such as a PWM generator, will create an output terminal at the subsystem. This output can be used as gate signals for semiconductor switches in the power circuit. Grouping the controls

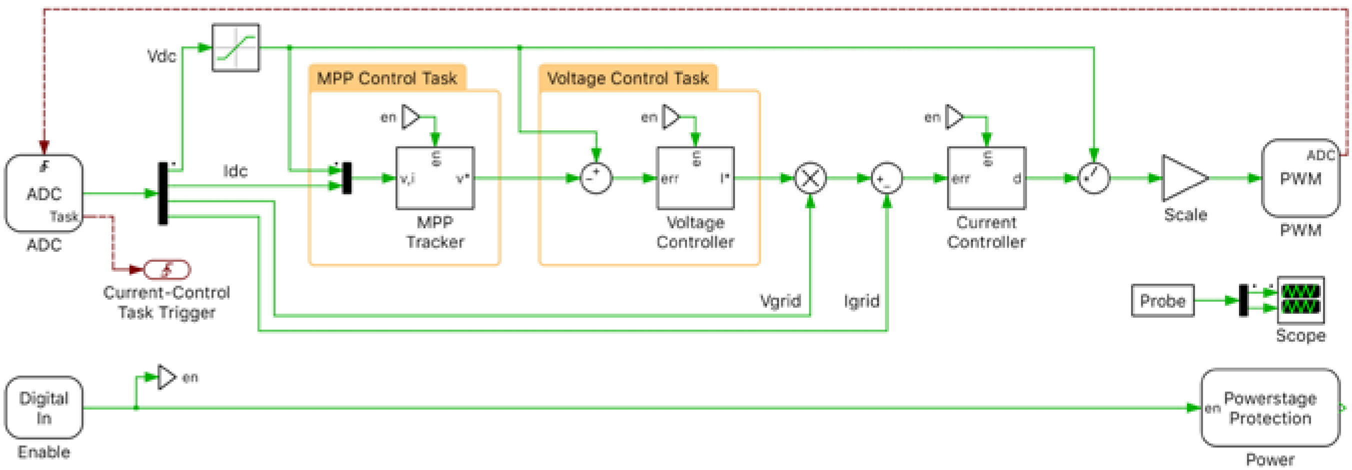

Figure 3: Complete controller model for a solar inverter including trigger and task management

in a subsystem does not adversely affect the control code generation, as the PLECS Coder can be told to generate code for a single subsystem only. On the contrary, when following this approach, the control system can be developed and verified against a plant model using offline simulation before the code is deployed to a microcontroller. The fact that the exact same model can be used without modification for both offline simulation and code generation ensures that model and code are always in sync. Figure 4 shows the overall circuit model of the solar inverter, with the controller model from Figure 3 wrapped in a subsystem.

Event-based execution of control tasks

When employing microcontrollers for closed-loop control of power electronic systems, the acquisition of current and voltage measurements is typically synchronized with the PWM generation. Synchronous sampling ensures the acquisition of currents and voltages with the lowest possible switching harmonics. In most digital current control loops, a PWM generator periodically triggers an ADC for sampling the analog measurements. As soon as the ADC has finished converting the sampled quantities, it signals the presence of new digital values by triggering an interrupt. Within the interrupt service routine, the control algorithm is computed using the newly acquired values and an updated duty cycle is passed to the PWM generator. In other configurations, it may be more appropriate to let the PWM generator or an independent timer trigger the interrupt and initiate the computation of the control task.

In PLECS we have introduced a special signal type (depicted as a dashed brown line in Figure 3) to define and visualize the propagation of trigger events. To model the control loop described above, the user first needs to select under which condition the PWM generator should emit a trigger event, for example at counter underflow or overflow. The trigger output of the PWM generator is then connected to the trigger input of the ADC block to control the timing of the acquisition. To indicate that the control task computation is invoked each time after a conversion is finished, the trigger output of the ADC must finally be connected to a special "Control Task Trigger" block.

Multi-tasking environments

A single control loop is normally not sufficient for the control of inverters and drive systems. Most often you will find a cascaded structure with a fast inner current control loop and a slower outer loop for voltage or speed regulation. While the calculation of the outer loop can take some time, the calculation of the simple current control task is typically fast. However, since the current control is highly dynamic, it must be performed with a higher execution rate. In order to optimally utilize the computing power of the microcontroller, such cascaded control schemes can be implemented with preemptive rate-monotonic multitasking, where the fast current control task interrupts the computation of the slower outer control loop. The control model must be split into multiple tasks with different sample rates and interrupt priorities. In PLECS, this partitioning is performed graphically using frames that each comprise a group of blocks. Each frame references a specific task defined in the Coder settings. If your target is a multi-core processor, you can distribute individual tasks to different cores. In Figure 3, the yellow frames assign separate tasks to the maximum power point tracker (MPP) and the voltage regulator, which operate at lower sampling rates than the rest of the control system.

Blocks that are to be computed in the same task do not necessarily have to be placed together in the same frame. As multiples frames can reference the same task, the assignment of blocks to different tasks does not interfere with the logical structure of the control system. Other embedded code generation tools employ subsystems or special blocks to separate the individual tasks from each other. However, reusing such existing structures for a different purpose might be confusing. On the contrary, the task frames in PLECS let a user immediately recognize a group of blocks sharing an implementation-specific attribute.

State charts for supervisory control

Procedural functionality traditionally performed by Programmable Logic Controllers (PLCs) is not easily represented with block diagrams. To model startup, dc-link pre-charge and error modes, state machines are more appropriate. State machines describe event-driven systems that move from one discrete state to another in response to discrete events. Included in the PLECS library is a state machine block providing a chart editor that lets you graphically create state machines using common concepts such as boxes for states and curved arrows for transitions, and simulate them together with the surrounding block diagram. You can feed continuous or discrete signals into a state machine block to react to external events and output discrete signals from a state machine. Actions are specified in the C programming language and can be associated with states and transitions. Thanks to built-in timer events, state machines are useful for implementing supervisory controls. The PLECS Coder will automatically insert the equivalent C code for a state machine block into the embedded project when generating code for the model.

External Mode

Once the embedded code is generated and uploaded to the target microcontroller, the so-called External Mode can be activated in PLECS to connect the program on the microcontroller with the original PLECS model.

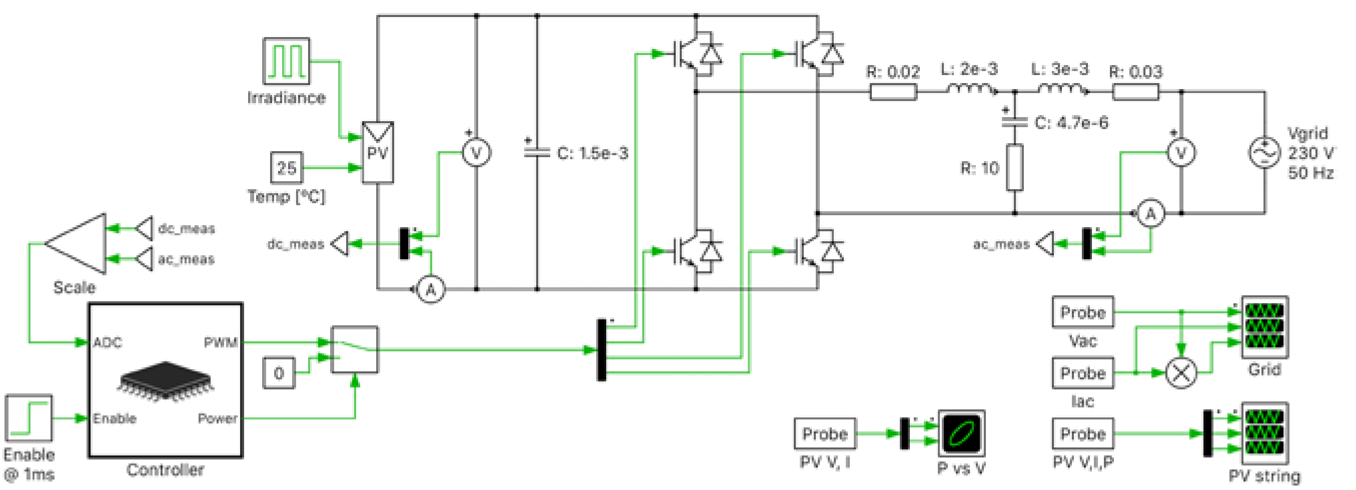

Figure 4: Power circuit of the solar inverter with controls wrapped in a code-generation subsystem

This allows the user to observe real-time data in PLECS and tune parameters such as setpoints. When operating in External Mode, the scopes in the PLECS model are populated with live data from the microcontroller, such as depicted in Figure 5. The user determines interactively how the scope data is updated: continuously or depending on a trigger condition. Real-time data obtained from the microcontroller can be compared with stored results from offline simulations by superimposing the

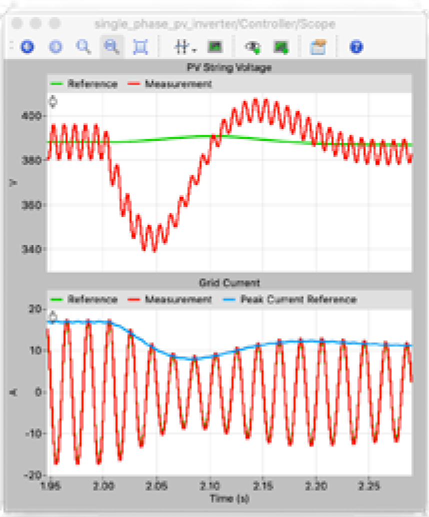

Figure 5: PLECS Scope for observing real-time data from the microcontroller

waveforms in a PLECS scope. Thus, the External Mode provides an intuitive way to interact with the microcontroller and to test and debug the control code. Instrumentation in External Mode of course consumes some processing power of the microcontroller and may be limited by the bandwidth of the communication interface.

Software-in-the-loop testing

Another powerful way to verify the control code is software-in-the-loop (SIL) testing. Instead of generating code for a specific microcontroller, the PLECS Coder can be instructed to produce independent C code for a generic target. In this case, the target blocks such as PWM and ADC will not insert code for the peripherals. In an offline simulation, the user can now choose to simulate the generated code in lieu of the original control model. In this “Codegen” simulation mode, the generated code is linked to the offline implementation of the peripherals. If the control subsystem is connected to a plant model as in Figure 4, the complete power electronic system can be simulated. Toggling between the “Normal” and “Codegen” simulation modes allows the user to identify any discrepancies between the original control model and its implementation in C code, such as the discretization of time-continuous control blocks. Further validation and verification may include a hardware-in-the-loop (HIL) simulation of the real microcontroller together with the plant model simulated on a real-time platform such as the RT Box.

Conclusion

PLECS in conjunction with the PLECS Coder lets control engineers not only model and simulate controls for power electronics, but also easily implement those controls on selected microcontrollers. This automatic code generation workflow neither requires special software development skills nor in-depth knowledge about the microcontroller peripherals. The iterative development approach using a PLECS model allows a design to evolve from an initial concept to a robust implementation. The PLECS model serves both as the definition and the documentation of the control algorithm. SIL and HIL simulation can be applied to test the generated control code.

Extended trial license

Plexim is offering extended trial licenses for PLECS and the PLECS Coder to readers of Bodo’s Power Systems. If you enter the keyword “Coder-21” in the remarks field of your trial request, you will receive a free license valid until the end of 2021.

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Swept Transient Loops Improve Accuracy and Design Information

In our last article, we showed how LTspice® could be used to simulate clean and dependable Bode plots for switching power supply designs. The technique of combining knowledge of the operation of real-world analyzers with the built-in features of LTspice® allowed us to do this faster and more reliably than ever before. In this article, we show how swept loops surpass the performance of small-signal analysis. For the first time, we can answer important design questions for high-performance power supplies.

By Dr. Ray Ridley, Art Nace and John Beecroft
Ridley Engineering, Inc. Camarillo, California USA

Buck Converter Test Circuit
The buck converter is the most prolific topology in power these days since they are being used in huge quantities for point-of-load applications. The test circuit we will consider is a buck converter operating at 100 kHz. The load is 12 V, 20 A, and the input voltage is a nominal 48 V. Figure 1 shows the complete circuit, including feedback components for a loop crossover of 9 kHz. It is the industry norm to put the crossover frequency at 1/10 of the switching frequency but there is a great deal of interest these days in raising it higher. A higher cross-over results in smaller output capacitance for a transient load. In this article, we will try to answer an important question: How high the crossover frequency can be raised before encountering instability?

Figure 1 shows the transient simulation circuit for the buck converter, with the model of the RidleyBox®/AP 310 configured to measure the loop gain. This process was explained in reference [2].

Small-Signal Circuit with Vorpérian Switch Model
The conventional approach to analyzing the control loops of converters was put in place by Vorpérian in 1986 with his seminal work on the PWM switch model [3]. After the addition of a current-mode extension in 1989, almost nothing has changed since then. We now have many years of multiple dissertations and books covering the same ground, applying the model to different situations.

While the small-signal models are enormously useful, they do suffer from fundamental limitations that are rarely talked about or explored. The mathematics required to fill the gaps are complex, and too particular to any given converter situation. We will explore those limitations here.

Figure 2 shows the Vorpérian switch model with the parameters of the converter in Figure 1. LTspice® rapidly solves the ac analysis of this circuit, producing the needed plots from the analyzer subcircuit shown.

The internal circuit parameter values are shown under the circuit settings heading on the schematic. These define the small-signal operating point of the circuit for the given load and input line. This entire model schematic is generated automatically by the software program RidleyWorks® [4].

The result of the small-signal model sweep is shown in figure 3. The crossover frequency was 9 kHz with a phase margin of 65.3 degrees, indicating a rugged loop design. (The simulation time was less than one second, demonstrating one of the powerful benefits of using small-signal models.)

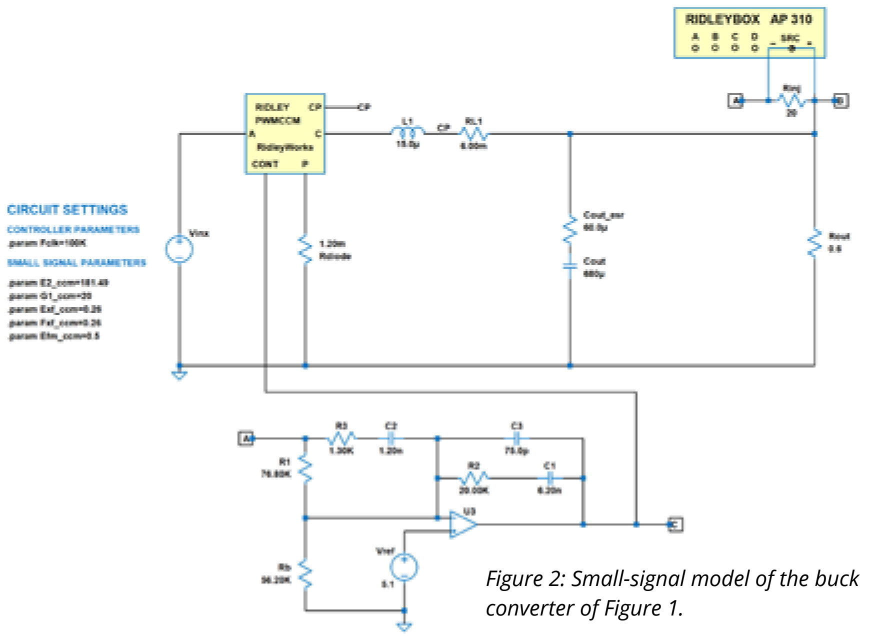

Figure 2: Small-signal model of the buck converter of Figure 1.

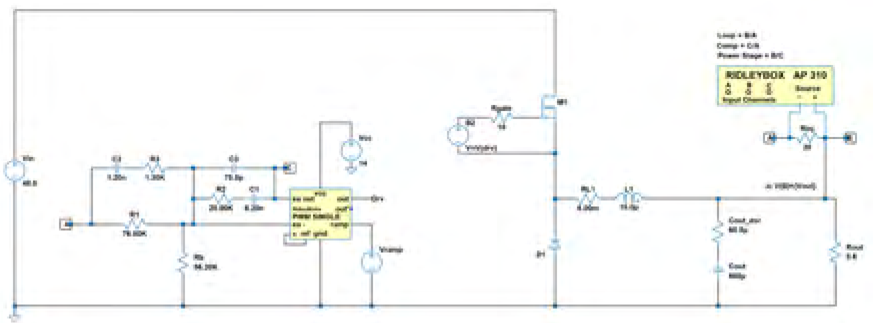

Figure 1: Buck converter test circuit with Frequency Response Analyzer subcircuit in LTspice®.

The red curve in Figure 3 is the result of sweeping the circuit of figure 1 without generating small-signal models. You can see that there is almost perfect agreement between the two curves, with only a 0.5-degree discrepancy at the crossover frequency. When approaching 50 kHz (half the switching frequency) there is a somewhat larger discrepancy in the phase response.

The simulation and processing time for the swept transient circuit was 5 minutes

20 seconds. Analyzer settings were used to obtain the smoothest curves possible rather than the shortest simulation time.

At this crossover frequency design point, either the fast small-signal circuit, or the swept transient circuit provide proper results for assessing the design.

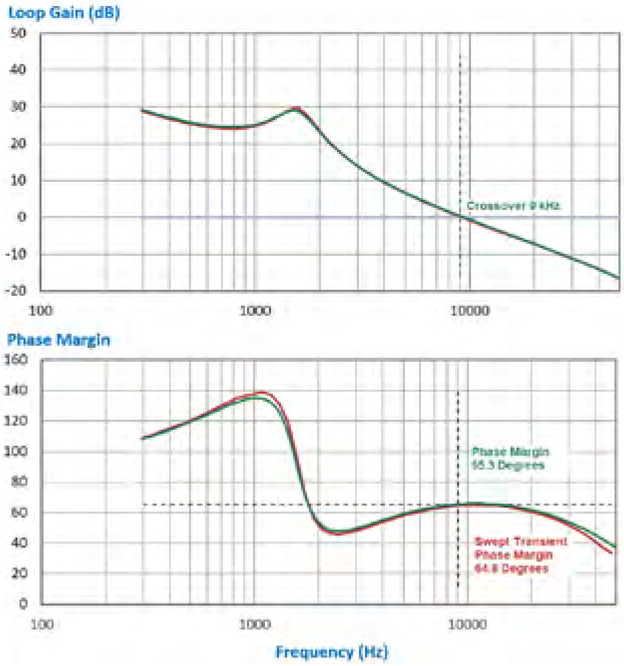

Figure 3: Loop plots from the small-signal model and the swept transient circuit.

Increasing the Loop Gain of the Small-Signal Circuit

The gain of the feedback compensator can be changed to push the crossover frequency to 43 kHz. As you can see from figure 4, the phase curve remains invariant. This indicates that there will be a 43-degree phase margin at this crossover frequency. Most small-signal modeling papers for power converters will state that the models are only good for low frequencies, but they are not specific about exactly what that implies. Errors are expected at higher frequencies.

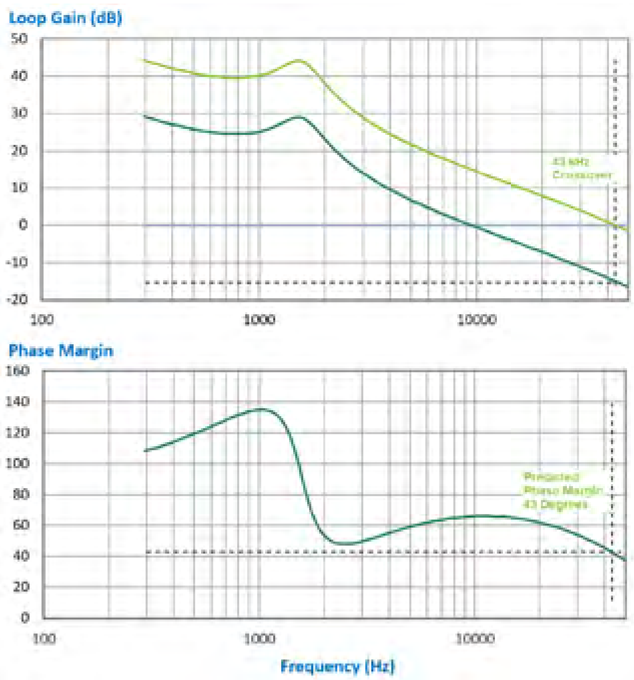

Figure 4: Small-signal model prediction for 43 kHz loop crossover.

The small-signal loop gain would also indicate that there would be substantial phase margin at 50 kHz. We know from Nyquist that this cannot be true – the phase margin will always be zero at half the switching frequency.

Increasing the Loop Gain of the Swept Transient Circuit

For the swept transient circuit, we obtain much better phase information. There are three swept transient curves shown in figure 5: the red curve crosses over 0 dB at 10 kHz, the blue curve at 25 kHz, and the gold curve at 43 kHz. The green curve shows the data from the small-signal model. Each of these curves has a different prediction of what the phase margin of the system would be at 43 kHz.

As the crossover frequency of the swept transient curves increases, the phase of the loop deteriorates substantially at higher frequencies. At the 43 kHz crossover frequency (gold curve), the phase margin of the loop is only 19.5 degrees - an unacceptably low value.

Note that great care must be taken when sweeping systems that are close to instability. In this case, the signal injection size was started at 600 mV, and reduced to just 3 mV at higher frequencies. More details of the variable source are given in [2].

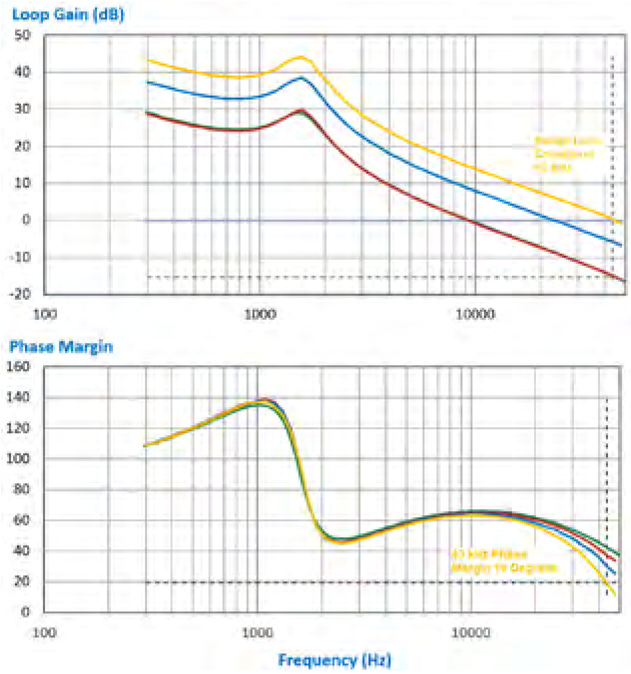

Figure 5: Swept loop gain and phase with increasing crossover frequencies.

Figure 6 shows clearly shows the error in loop prediction for the small-signal model. There is more than 25 degrees of error versus the actual 43 kHz transient loop sweep.

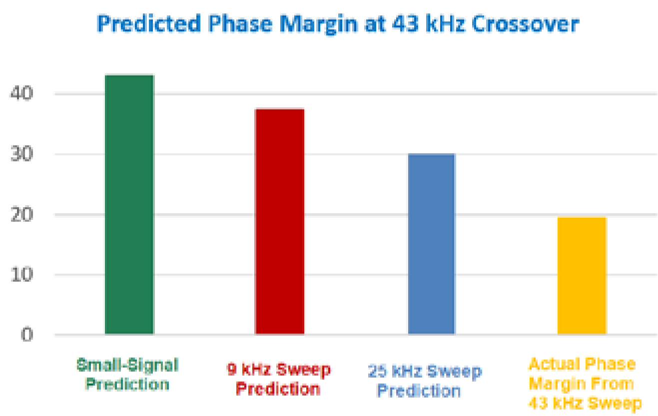

Figure 6: Phase margin predictions at 43 kHz crossover. The small-signal model gives 25 degrees of error.

Now we have the interesting situation that the original transient circuit is giving much better results than the small-signal model. This is even more intriguing when you realize that it requires no analytical effort to generate the circuit to be swept. What is typically regarded as a “brute-force” approach to design curves is fundamentally superior to the much-researched analytical solutions. Good news for working engineers!

You can also estimate from the curves of Figure 5 that it would be possible to increase the crossover frequency to just above 30 kHz while maintaining a 45-degree phase margin. This is useful design information that is not available from the analytical methods of small-signal modeling.

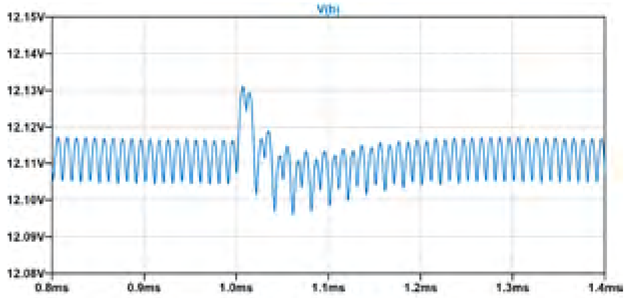

Figure 7: Step-load response clearly showing oscillatory behavior.

Figure 7 shows a step load response on the output of the converter with a 43 kHz loop. You can clearly see the oscillatory behavior corresponding to the 19-degree phase margin. It would be recommended to reduce the loop to around 30 kHz to eliminate this behavior. There are, of course, more factors to be considered in the design. The loop will move according to the input line to the converter, and it must be designed for the worst case. Variations in clock switching frequency are also very important.

Summary

The method of sweeping transient simulation circuits to obtain loop gains is a rugged way to look at the stability of your power converter without having to generate sophisticated small-signal models. It is also more accurate than the small-signal modeling approach, especially as the performance of a loop is pushed to its limits.

The swept transient loop gains clearly show the phase deterioration of the loop as the gain of the circuit is increased. This is a powerful feature, allowing you to accurately predict the stability of your system at higher performance levels.

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[5] Learn power supply design in our Hands-on Workshops for power supply design
[6] Join over 5,000 engineers on our Facebook Power Supply Design Center group. Advanced in-depth discussion group for all topics related to power supply design.
[7] Frequency Response Measurement Two-Hour Masterclass. An extended training session with live measurement examples on switching power supplies.

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Bulk Capacitor Optimization for Offline Power Supplies Using Galium Nitride-IC

The adoption of USBPD 3.0 and Type-C connectors is expected to standardize power adaptors across previously segmented electronic markets. Gone are the days when travelers needed to carry separate adaptors for their laptops and cell phones. Aftermarket adaptor manufacturers are focusing their efforts on servicing this new market opportunity. The need for high efficiency, cost-effective solutions for higher power density has never been greater.

By Chris Lee, Product Manager, Power Integrations

Adaptors rated at under 75W can be broken down into: input filter, diode rectifier, input and output capacitors, IC controller, auxiliary power supply, magnetics, power devices and heatsinks. Integrated solutions have come a long way in shrinking and simplifying converters to the point where the largest remaining components are the magnetics, the input 'bulk' capacitors, output capacitors, and the EMI input stage. Significant research and engineering effort has been focused on high frequency AC/DC converter design to reduce the size of the magnetics. However, the input bulk capacitor occupies the same or greater volume as the magnetics within an adaptor.

A new IC from Power Integrations, MinE-CAP, has been designed to address input bulk cap optimization for universal input designs. Using Power Integrations' PowiGaN gallium nitride technology, MinE-CAP safely enables the use of 160 V rated capacitors for universal input designs, reducing bulk capacitor volume by up to 50%.

MinE-CAP is a low impedance switching circuit positioned in series with the low-voltage capacitor (CLV in Figure 1). It monitors the voltage across CLV and connects and disconnects the capacitor as the input line voltage increases/decreases around a threshold. The MinE-CAP circuitry can be paired with a high frequency power conversion stage to maximize space savings.

System Considerations

The rule of thumb for universal power adaptors is that the value of the DC bus capacitance, in µF, is chosen to be 1.5 to 2 times the output power requirement, in watts, when the design considerations is as low as 90 VAC. For high-line-only applications, the total capacitance can be reduced significantly. With this key concept in mind, MinE-CAP enables designers to significantly reduce the input bulk capacitor size. The figure below shows a schematic layout for a typical MinE-CAP application.

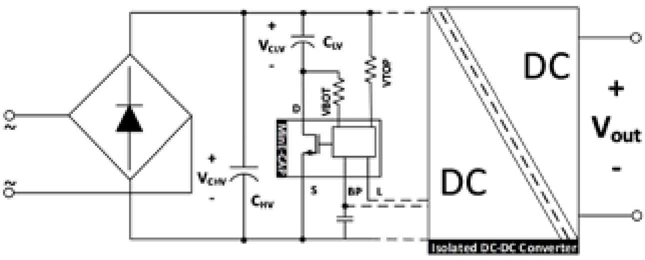

Figure 1: Typical MinE-CAP application

CHV is a high voltage capacitor (rated at 400 V) that typically accounts for around 20% of the total capacitance. CLV is a low voltage capacitor (160 V) that accounts for about 80% of the total capacitance. This split in capacitance enables the capacitor volume to be reduced by up to 50%, leading to an overall reduction in adaptor size of up to 40%.

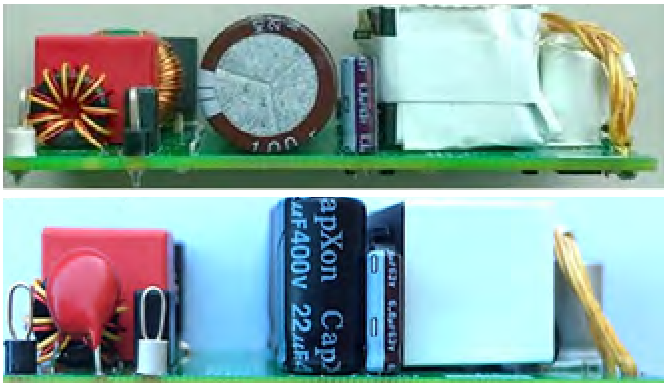

Figure 2: First level optimization of 65 W adaptor

In Figure 2, the top image is a typical 65 W adaptor that requires a single 400 V, 100 µF capacitor. The bottom image shows the space savings achieved by using MinE-CAP in the exact same 65 W adaptor design. The total input capacitance is split into two 160 V, 47 µF capacitors and one 400 V, 22 µF capacitor. The total capacitance is therefore actually increased by 16% while, at the same time, the bulk capacitor volume is reduced by 40%.

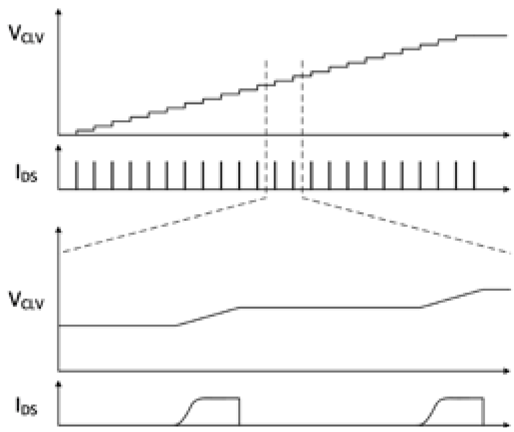

Figure 3: Charging algorithm used for low-Line start-up

Typical Applications

Designers can take existing designs and modify the input bulk capacitor stage to decrease the space occupied by the input stage. This allows them to shrink the enclosure or, conversely, they can add more capacitance in the same enclosure and increase the power.

Another design usage for MinE-CAP is in applications that require peak power delivery. Increasingly, on-board protocol chips are in bidirectional communication with the device being charged. These chips typically monitor and report adaptor temperature, faults and power delivery capabilities. Designers are taking advantage of this bidirectional communication to provide 1.5 to 2 times the nameplate power. These peak power algorithms significantly reduce charging times. However, input bulk capacitance limits the peak power delivery capabilities. With MinE-CAP, the input bulk capacitance can be increased significantly using the same space. This enables prolonged peak power delivery even at low line.

MinE-CAP Basics

MinE-CAP operates by precisely charging and monitoring the voltage across CLV, only introducing this capacitor into the circuit at low AC line when maximum input capacitance is required. MinE-CAP is designed to engage and disengage CLV dynamically during every line AC cycle, as required. The power supply therefore operates smoothly across the entire specified input voltage range. For the design referenced in Figure 2, effective low-line total bulk capacitance is 116 µF while the effective high-line bulk capacitance is 22 µF.

When the system is in high-line, the MinE-CAP measures the differential voltage across CLV via VTOP and VBOT. It regulates the voltage on CLV to support power delivery in the event of a line or load step.

MinE-CAP Start-up

Traditionally, at start-up the inrush current into the bulk capacitors can affect the reliability of the fuse, bridge rectifier and capacitor, as this current is only limited by the line impedance and input filters. As the adaptor power rating increases, the inrush current increases, often requiring the use of an NTC thermistor to protect the fuse and diode bridge. However, the NTC thermistor reduces the overall efficiency of the system and adds a hotspot to the input stage. Therefore, the fuse and diode bridges are often oversized and the thermistor is undersized to limit its impact on system efficiency.

In a MinE-CAP design, 80% of the bulk capacitance is disengaged from the application at start-up. In low-line start-up conditions (V_{IN} < 150 VAC), MinE-CAP performs precisely controlled active charging of C_{LV}. At the low-line start-up condition, it is important to pre-charge C_{LV} to support full power capability prior to enabling the DC/DC converter. The MinE-CAP IC configures the internal high-voltage switch as a current source, to provide precise, constant current, pulse-charging of C_{LV}, see Figure 3. This approach allows fast charging of C_{LV} and ensures the power supply is ready to deliver full power in less than 250 milliseconds from the initial AC line connection. This controlled charging of the C_{LV} allows MinE-CAP designs to eliminate the inrush NTC thermistor, improving the overall system design by removing a thermal hotspot and increasing conversion efficiency.

For high-line applications (V_{IN} > 150 VAC), C_{HV} alone supports the full power delivery. MinE-CAP performs a slow charge-up of C_{LV} and regulates the voltage below the capacitor rated voltage. This improves hold-up time of the power supply due to line drop-out.

Protection Features

In addition to the precision start-up algorithm, MinE-CAP integrates a suite of protection features including over-temperature, pin open/short fault detection, and surge protection. In the event of a fault, MinE-CAP disengages C_{LV} from the system. To prevent further system damage, MinE-CAP communicates the fault information to the power conversion stage via the L-pin. This multipurpose pin is also used to communicate the DC bus voltage information to the power supply controller IC during normal operating conditions.

Summary

The GaN-powered MinE-CAP enables the use of 160 V rated capacitors in universal input designs that are normally restricted to only 400V rated capacitors, resulting in space savings equivalent to those achieved by adopting higher switching frequencies. The precision start-up algorithm eliminates the need for an NTC thermistor without impacting the end user experience. The DC bus voltage and fault information is communicated to the DC/DC converter via the L-pin. Pairing MinE-CAP with the InnoSwitch IC family maximizes integration, minimizes component count, simplifies layout and optimizes power supply size.

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Integrated Power Module Now Delivers 25% More Power

SEMIKRON's SKiiP 4 now features a new, high-performance pin fin cooler optimised for baseplate-less designs alongside variable diode/IGBT chip area distribution for different asymmetric distributions between diode and IGBT chips that offer huge benefits on the generator and grid-side of compact wind power converters, for example.

By Marco Honsberg, Anastasia Schiller, and Hendrik Flohrer, SEMIKRON Elektronik GmbH & Co KG, Nuremberg

For over 20 years, SEMIKRON intelligent integrated power modules – also known as SKiiP modules – have proven to be a reliable solution for electric energy conversion, offering a high level of integration in compact dimensions. In addition to the actual power electronic components – the IGBTs and SEMIKRON CAL4F diodes in half bridge configuration – SKiiP modules also include a gate driver unit for safe signal insulation including comprehensive protection functions, ultra-precise current and voltage sensors, and an efficient heatsink.

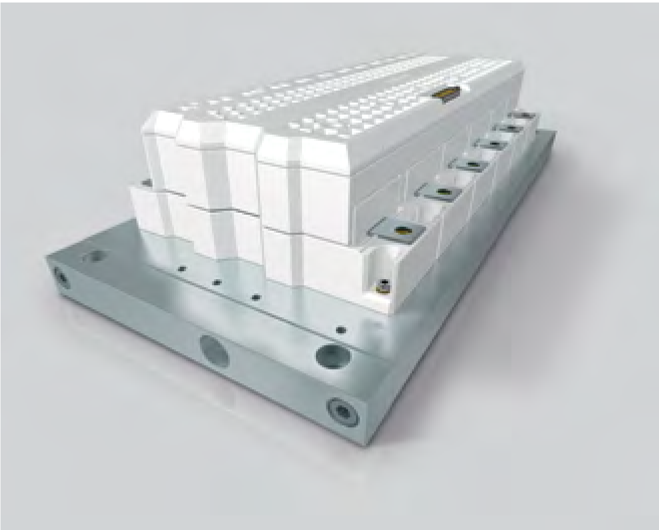

Figure 1: SKIIP 4 module with six paralllel half-bridges o a water cooler

The roots of these intelligent power modules can be traced back to the wind power converter market with its ever changing, ever increasing requirements, which have forever fuelled the development and improvement of SKiiP technology. Power electronics have to be reliable and robust to be able to operate in the ambient conditions that prevail in the applications they are used in. Thanks to innovative packaging technologies such as sintering and solder-free contacts, the new SKiiP 4 meets these demands.

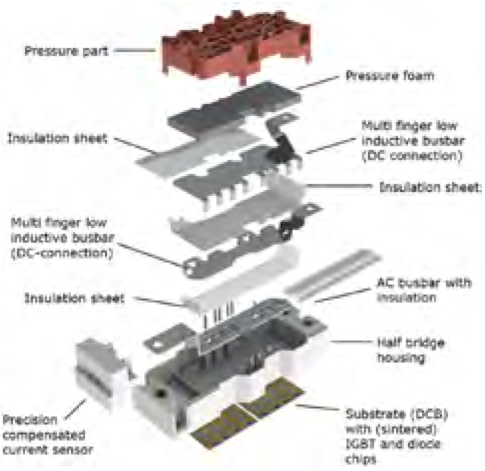

Figure 2: Exploded view of a SKiiP 4 half-bridge

Structure of a SKiiP 4 module

The SKiiP 4 module is based on a baseplate-less design and is pressed directly onto the top of the cooler. Between them is a predefined thin layer of highly effective thermally conductive material. Figure 2 shows the key components in the SKiiP 4 half-bridge configuration.

The SKiiP 4 DCB shown in Figure 2 is a two-part substrate which the IGBTs and diodes are sintered to and which is pressed onto the heatsink by the overlying structures. The entire half-bridge design ensures that the forces from the pressure part are distributed evenly to the busbar sandwich construction from the top down. This is facilitated by a layer of pressure foam. The busbar sandwich construction comprises laminar busbars stacked one above the other with insulation sheets in between. This pressure is then transferred to the underlying DCB substrate, which in turn is evenly pressed onto the surface of the cooler.

Conventional module designes, where using the copper layer on the substrate and a bond connection to unbundle the signals, will involve a number of compromises. The SKiiP 4, in contrast, has three additional levels that ensure that signals such as the (+) and (-) DC link voltage as well as the (AC) output are transferred to the DCB substrate homogenously. The laminar design achieves ultra-low stray inductance in the power module, while the multi-finger contacts ensure that the signals are transferred "downwards" to defined points on the DCB substrate. Besides the desired ultra-low stray inductance from the power connections right down to the chips, another important benefit of the laminar multi-finger design is the very homogenous distribution of these signals across the DCB substrate. This results in a very even distribution of static and, more importantly, dynamic stresses on the individual chips.

Thanks to these design details, the SKiiP 4 half-bridge offers various advantages over conventional module designs in high-current applications, one being its superior robustness, a key parameter that is even is further improved thanks to the purpose-developed fully digital SKiiP 4 driver. The entire logic circuit of the gate driver is integrated into SEMIKRON-developed ASICs that work with no more than a few external components and are controlled by a high-speed processor. To detect dangerous situations, the driver uses DCB substrate temperature, driver temperature, information from the integrated fast and precise closed-loop current sensors as well as desaturation detection. Where necessary, the driver can then initiate soft IGBT turn-off in response and send fault condition feedback to the master control unit via the digital interface.

A host of parameters, protective functions and safety limits can be set via the CAN bus interface, ensuring a high level of flexibility and configurability. SKiiP 4 also has a Fault Ride Through (FRT) mode that can be activated if needed, as would often be the case in double fed induction generator (DFIG) applications. The programmable digital driver offers the customers a host of configuration options


A better way to deliver power
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for heavier payloads
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via the CAN interface and comes ex works with a wide variety of adjustable, flexible options, meaning that even the most unusual of customer-specific functions and interface design variations are possible.

Reliability and robustness

Besides the robustness of the SKiiP 4 half-bridge and the many different driver protection functions, other factors also hugely affect its reliability in the field – ambient conditions or how the power modules are operated in the field including the stresses acting on the components. In the wind converter market, humidity and temperature as well as load cycling capability play an important role. SKiiP 4, developed essentially on the basis of class 3K3 climate conditions, has been hugely expanded at key points as seen in the temperature/humidity graph (Figure 3).

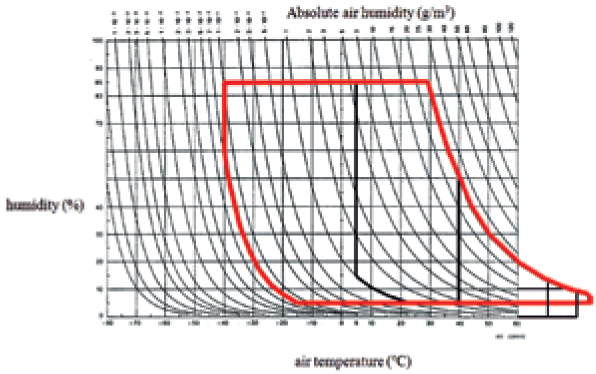

Figure 3: Class 3K3 climate conditions (black) and the extended region achieved by the SKiiP 4 (red)

As seen from the higher and lower temperature regions, SKiiP 4 (red) is rated for environmental conditions that go far beyond the limits of the class 3K3 conditions (black), underlining the robustness of this complex component with its integrated power stage, driver and integrated current sensors, including in off-shore wind power applications. In fact, the conditions that wind power units operate in are not fully covered by the 3K3 operation class. The actual climate conditions that occur are one of the known cause of some of the premature breakdowns in the field after years of problem-free operation. The development and suitable choice of packaging can help reduce the failure rate significantly, as verified by statistics on SKiiP 4 failure rates in comparison to failure rates for power modules with fewer protective functions. This applies not only to thermal cycling capability or humidity sensitivity, but also to the load cycling capability, a key parameter in power module design, especially for generator-side power electronics.

With a few exceptions, the majority of modern wind turbines use back-to-back converters (Figure 3a): a grid-side converter that operates at 50/60 Hz output frequency and a generator-side converter which usually works at an output frequency of not more than a few hertz (DFIG and Direct Drive) up to more than 100 Hz (permant magnet and induction generators).

Here, operation at low frequencies can cause clear temperature swing in the power electronic components, because at this generator frequency the load current is controlled alternately by the diodes and the IGBTs. Owing to the limited thermal capacity that can be allocated to the diodes and IGBTs, the temperature increases are higher, the smaller the output frequency is. For the generator-side power module, this leads to a particularly high load cycling that impacts the mechanical connection between the chip itself and the connection to the DBC substrate as well the bond wire, resulting in ageing. What is more, the large-area DCB-to-chip connection is particularly sensitive to stresses caused by load cycling.

Sintering

As early as in 2007, SEMIKRON developed a sintering process that would be used to connect chips, introducing it for the first time in a series produced power module in the SKiiP 4. Here, instead of a conventional solder connection between chip and DCB, silver sintering powder that has roughly four times the melting temperature of conventional solder is processed under pressure at clean room conditions, resulting in an extremely strong and durable connection between the metalised chip undersides and the metal surface of the DCB substrates.

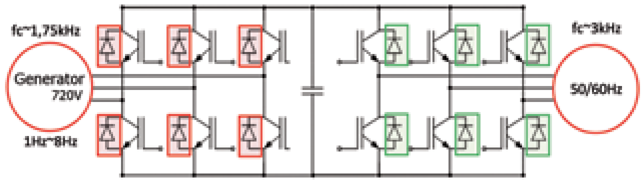

Figure 3a: Full scale back-to-back converter (Direct Drive)

Sintering is not without its challenges, however. This is owing to the fine structures in the silicon chips and the enormous pressure acting on the components. An examination of the number of load cycles the sintered connections can withstand shows that the load cycling capability of sintered chip connections is six to eight times higher than conventional soldered connections. Sintering is therefore crucial when it comes to achieving a high degree of reliability, an absolute must in wind converters, especially on the generator side. The sintering process used by SEMIKRON is continually being improved on with a view to further improving reliability.

In addition to high load cycling capability, the maximum junction temperature also plays an important role in ensuring that a converter works safely and reliably and calls for the effective dissipation of the thermal losses in the chips.

Cooling

In today's market for industrial converters and solar inverters for PV systems, air-based cooling systems are the most widespread solution. When it comes to wind energy applications, water-based coolers have proved to be most effective owing to the high power density and performance requirements that wind converters have to fulfil. SKiiP modules come with water or air-based coolers.

High-performance cooler (HPC)

Since early 2021 SKiiP 4 has been available with a purpose developed high-performance pin fin water cooler as an alternative to the existing water-based cooler. The two different SKiiP 4 water coolers, which have been optimised for baseplate-less SKiiP 4, are shown below (conventional water cooler in Figure 4a and the new HPC in Figure 4b).

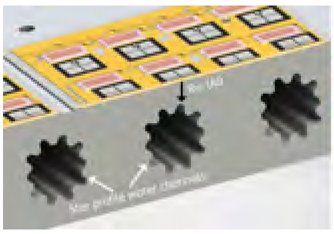

Figure 4a: Conventional star shaped cooler

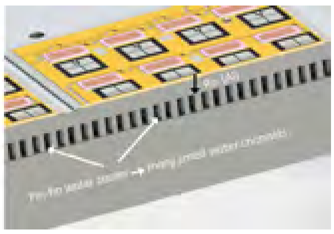

Figure 4b: New high-performance cooler (HPC)

The thermal resistance in the chips on the conventional shaped cooler (Figure 4a) depends to a relatively high degree on the position of the chips. This is owing to the different distance between each chips and the concentrated water channels in this cooler. Related to manufacturing constraints, the path that the power losses produced in the IGBTs and diodes take through the aluminium to the water channel is relatively long.

The new pin fin high-performance cooler design offers far more favourable conditions. The cross-section of the cooler shows that the distance that the heat travels from the chips to the water is far shorter and distributed far more homogenously across the entire DCB substrate for all the chips. The geometry of the resulting pin fin design was optimised for the respective chip sizes and chip positions on the baseplate-less SKiiP 4 half-bridge. As a result, the thermal resistance of the chips mounted on the DCB on the high-performance cooler is roughly half that of the predecessor water cooler for a similar amount of coolant flow rate. The permissible loss in pressure, however, is only ever so slightly higher.

For the new SKiiP 4 mounted on the high-performance cooler, this means an increase in output current by some 25 %, i.e. a 25% increase in power for the same junction-to-water temperature increase, i.e. DT(j-w). Figure 5 shows the maximum junction temperature as a function of the output current for the conventional cooler (the NHC300) and the new HPC.

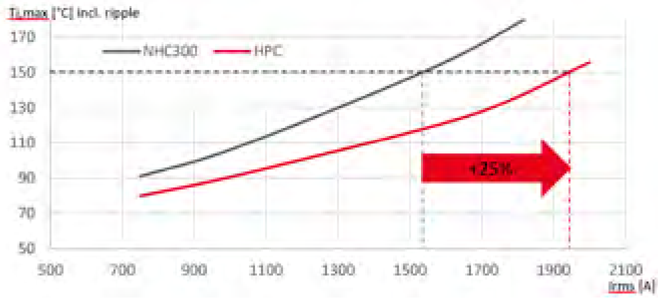

Figure 5: Higher output current with SKiiP 4: Possible currents with conventional NHC300 cooler and new high-performance cooler (HPC)

This data was generated using the new web-based simulation tool SEMIKRON SEMISEL V (https://semisel.semikron.com/) and refers to the new SKiiP2414GB17E4-4DUHP on HPC based on the parameters V_{DC} = 1150 V, m = 0.85, cos(ρ) = 0.85, f_c = 2.5 kHz, T_w = 55 °C (16 l/min 50 % ethylene glycol).

One of the main reasons why this huge increase in power was possible was the short paths from the point where the power losses occur in the chip to the water, i.e. because the use of an additional base plate in the design was avoided. This means that more compact converters with far greater power density can be built at far more favourable prices per unit of power.

For SKiiP modules, which are already in widespread use in wind converters built by leading manufacturers worldwide, this basically opens up the possibility of them being retrofitted as part of an upgrade. This means it is possible to replace a standard SKiiP in an existing wind converter by a new SKiiP variant that is compatible from the point of view of the mechanical design but that delivers 25 % more power. The result is a considerable increase in output power with a minimum of time and effort.

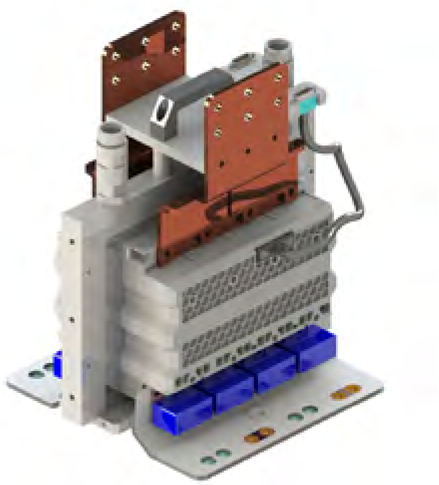

Figure 6: Double SKiiP on HPC

A double-sided cooler design with a SKiiP 4 module on each side (Figure 6) brings about further improvements in power density. In the right arrangement, this can also make it easier to render the DC link.

To have a better picture of how a double-sided SKiiP 4 can fit on a DC link design (not shown here) – as an assembly for example – Fig. 6 shows some of the optional add-on parts, such as the laminated busbar construction for DC(+) and DC(-) connecting the double-sided SKiiP to the DC link, the two water supply lines, and the mounting bracket. The double-sided high-performance cooler (DHPC) has two separate internal pin fin fields connected in parallel, meaning it works the same way as two independent HPCs and can be easily simulated using the new SEMISEL V tool.

This special design can make it easier to render the DC link, provided the SKiiP is positioned on one side of the DHPC, e.g. to one generator phase, and the SKiiP on the other side of the DHPC is assigned to a grid phase. This would ensure that part of the current takes the shortest path from the generator side through the DC link to the grid side. At the same time, this would result in lower losses and ripple currents in the DC link capacitor than in separate dedicated generator and grid-side converters located at some distance to one another.

Asymmetric chip distribution

Owing to the comparatively low frequencies on the generator side and the high frequencies on the grid side as well as the direction of the flow of current, the requirements that the power stages have to meet can vary substantially. Depending on the type of generator used, it may well be that far more powerful and thus bigger diodes are needed for the generator than standard modules can provide. The most obvious option would be to add more standard half-bridges and create the diode space required for the application. This, however, would increase the overall volume and would mean the purchased IGBT chip area was not being used, which is why this approach is not the ideal way to go.

Owing to the unique multi-finger busbar design and the resultant, extremely homogenous signal distribution across the DCB substrate, the SKiiP 4 half-bridge has one very crucial advantage over conventional module designs. The proportion of the total chip area allocated to the diodes can be increased on the DCB substrate without causing severe undesirable current distribution effects on the DCB substrate. In practice this means that for the very first time in a power electronic module customer or application-specific variations of the SKiiP 4 standard half-bridge are possible and, thanks to the possibility of asymmetric chip distribution, IGBT performance can be successively replaced by diode performance with decent granularity. If needed, the designated diode space can even be increased to as much as 50% without an additional half-bridge being required.

Such adjustments make particular sense in generators that produce high output voltages at low rated frequency already. Applications have shown that even a 13 to roughly 20% increase in diode space in the SKiiP 4 half-bridge can easily achieve the necessary longevity thanks to the high load cycling capability resulting from the sintered connections.

The double-sided high-performance cooler combined with asymmetric chip layout are the key to making power modules more compact and more adaptive, cutting down on raw materials use and achieving huge cost savings.

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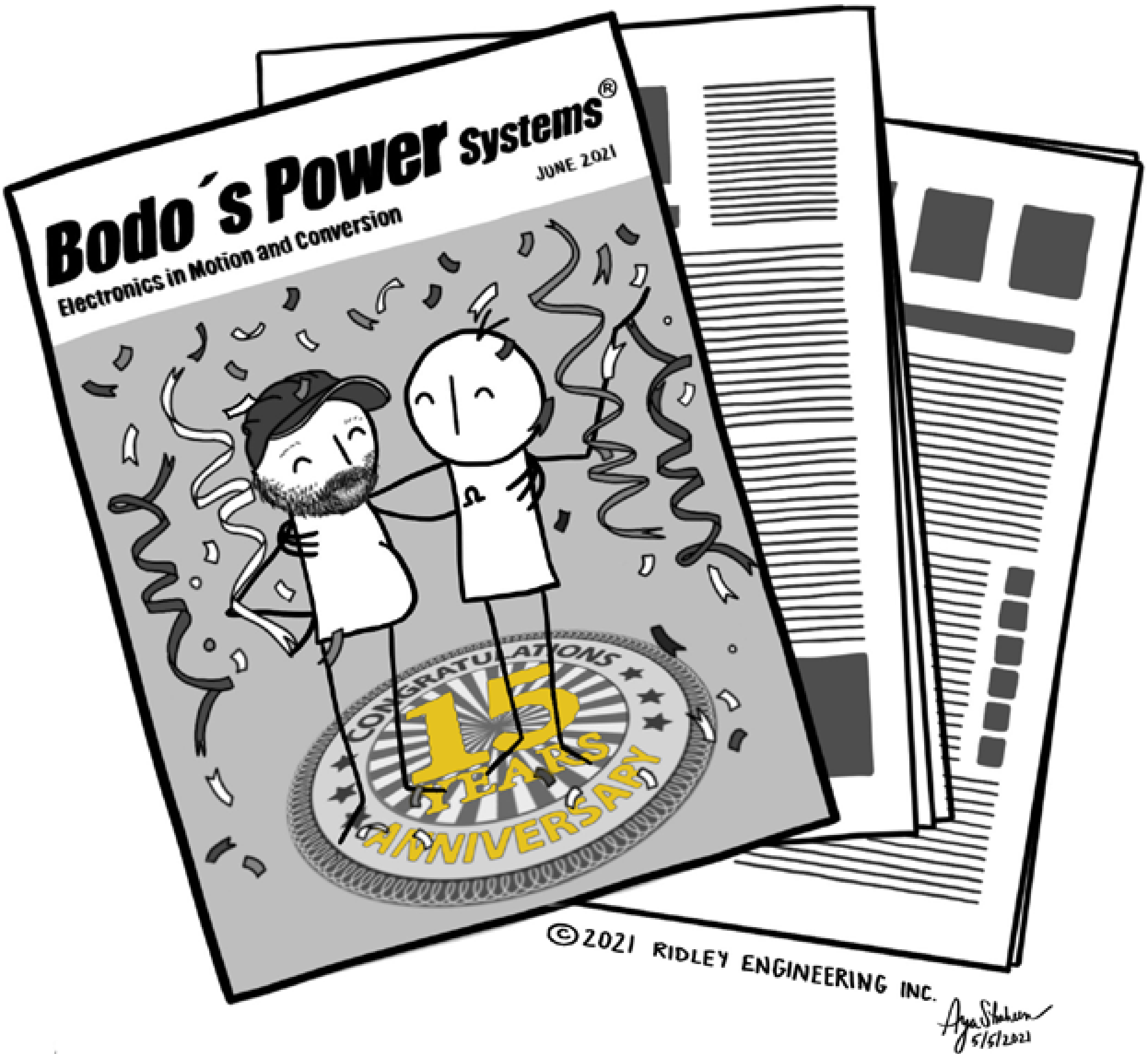
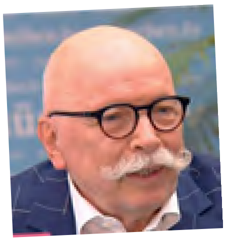


"Bodo has my utmost respect. He entered the magazine market just after we decided to exit due to the difficult conditions for publications. Now, the magazine is doing great, and is almost the only print version still available. Great work! He had a vision, and stuck to it. You are continuing the good work for him now."
Dr. Ray Ridley, President,
Ridley Engineering Inc.

"Over the past 15 years the power industry has gone from MOSFETs and IGBTs to GaN and SiC. No other journal has kept up with this transition as effectively as Bodo's Power Systems, making it the best place to go to understand the state-of-the-art in power systems."
Alex Lidow, CEO and Co-founder,
Efficient Power Conversion

"Dear Bodo, Congratulations on your magazine's 15th anniversary! Bodo's Power Systems has become a fixed instance for the electronics industry. It provides a unique platform for the power community to share deep technical knowledge. Your articles stand out by high quality journalism and expertise – motivating our team to regularly provide insights for your magazine. Competence makes the difference! We are looking forward to our joint projects in the future."
Wolfram Harnack, President,
ROHM Semiconductor Europe

"I still remember well when Bodo announced his own industry magazine about 15 years ago. There were quite a few doubters as to whether he would be successful. However, with his conviction, authentic approach and excellent industry networking, he quickly succeeded in generating circulation momentum and a compelling brand. Today, Bodo's Power Systems magazine contributes greatly to our strong industry community with its unique blend of people and technology articles as well as aspirational advertising. Congratulations on 15 years!"
Eckart Seitter, CEO, Vincotech GmbH

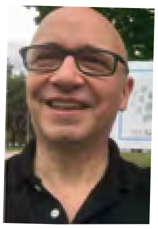


„To enter the oversaturated market of electronics trade magazines and, against all odds, to survive with flying colours, requires the courage, persuasiveness and competent tenacity of Bodo, whom I hold in high esteem as a colleague with outstanding reliability. I congratulate him on this 15th anniversary and wish him continued success on the international power electronics stage for many more years to come!"
Roland R. Ackermann, Presse-Service Ackermann

"15 years has come so fast! Congratulations to Bodo and the team for their wonderful industry platform "Bodo's Power Systems". During the past decade, media formats have evolved dramatically, but delivering the technology to the industry on a timely base has always been the core of Bodo's Power Systems. As the person in charge for Bodo's Power Systems China, I am honored to be part of the team. Last but not least, looking forward to our next decade of success with you."
Min XU, Senior Planning Editor, Bodo's Power Systems China

"Happy Birthday, Bodo's Power Systems! I am convinced Bodo's Power Systems is the global number one magazine in power electronics. Its feature articles and news give a perfect overview of what is happening on the market, a must-read every month! For me personally, it has been a pleasure to work with Bodo and Holger in the past years and I hope to continue that for the next 15 years."
Stefan Häuser, Director Market and Application Strategy, SEMIKRON INTERNATIONAL GmbH

"Dear team of Bodo's Power Systems, many congratulations on your 15th anniversary! You are publishing thematically and professionally interesting topics for the power community. The international orientation of the magazine reflects the line-up of the electronics and supply industry. You stand for quality and have your ear to the pulse of the readers with a lot of commitment and passion. All the best and here's to the next 15 years!"
Alexander Gerfer, CTO, Würth Elektronik eiSos Group



"When I think of the power electronics industry. I think of Bodo's first as the first resource for what is going on in development and the community. Thank you and Congratulations of 15 Years of service and commitment!"
Mark A. Occhionero, Ph.D., Senior Scientist, Chief Technical Officer VP, CPS Technologies

"Plexim and I have been working with you Bodo since 2007. It has always been a pleasure and it should be that way in the future as well. Business partners come and go, friends stay. All the best for the future and we at Plexim look forward to the next 15 years of working with Bodo's power."
Orhan Toker, Vice President Sales & Marketing, Plexim GmbH

"Congratulations to Bodo and the entire team on celebrating this well-earned anniversary! For 15 years Bodo's Power Systems is serving the global industry with outstanding quality content focusing purely on power electronics. I am pleased to be your long-term partner and friend, even before 2016. I wish you a continued successful development and all good in your future endeavors."
Claus A. Petersen, Senior Vice President, Danfoss Silicon Power

"Congrats to a long-term companion! Vivid communication amongst the players is vital for an industry. It accelerates progress and leads to new directions. Bodo's Power Systems – like the PCIM Europe – has supported the power electronics community in that way for many years.
Let's keep rolling together."
Lisette Hausser, Vice President, Mesago Messe Frankfurt

"There are few stable things in the modern world. And Bodo's Power Systems magazine is one of them. Through times Bodo proved to be the voice of power electronics world sharing it with all of us. Looking forward to another 15 years of development, success, and friendship. It is going to be a very exciting journey!"
Alexey Cherkasov, MBA, Head of Marketing Department, Proton-Electrotex

"Happy 15th anniversary to Bodo and the team at Bodo's Power Systems magazine! Our shared passion for power semiconductors has been the basis of our long-term partnership for many years. I am looking forward to reading and learning from your interesting stories about power semiconductors in the years to come."
Dr. Peter Wawer, Division President Industrial Power Control, Infineon Technologies AG

"Dear Bodo, it was a great idea when you established this monthly journal on power electronics engineering. Electrical energy conversion by power electronics became one of the key innovation drivers in our society. "Bodo's Power Systems" is connecting the power electronics people: From the semiconductor device engineer to the designer of power electronics systems. Thank you for this!"
Eckhard Thal, Chief Engineer Power Semiconductors, Mitsubishi Electric Europe

„Congratulations to the 15th year anniversary of the publication and specially to Bodo with his contribution to our industry !! Demetrios (Jim) Marinos, executive VP Marketing and Engineering for Payton America Inc, has been involved in the design and development of switch mode power systems for military applications and magnetic designs since 1982."

Jim Marinos, Executive VP Engineering, Payton America Inc.

"From the day we started AgileSwitch, we felt that Bodos Power was the most influential publication in the industry. And, after articles, news releases and ads over the past 10 years, that has proven to be true. Of course, your visit to Philadelphia was also a special treat for us. Congratulations on your anniversary!"

Rob Weber, Product Line Director (DGD), AgileSwitch

"Globally respected, always informative and inspirational in his vision, Bodo is an institution who has been the voice of power electronics for the last 15 years. His authority and perception of future trends makes him a trusted advocate of wide-bandgap semiconductors. Cheers to 15 years and best wishes on many more."

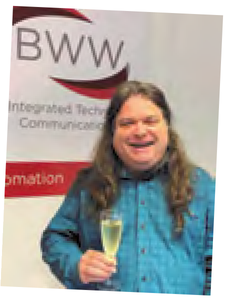
John Palmour, CTO, Wolfspeed

"Bodo Congratulation to the outstanding sucess in initiating, developing and establishing „Bodo´s Power Magazine" on a worldwide scale. I remenber back on a discussion in the beginning of the last Decade when Bodo asked me to join the company I was working for or to start his own company with the idea of developing a Power Electronic Magazin. As we can see now you have taken the rigth decision. From nothing to a worldwide recognized Magazin in this technical disciplin. As a result: this is Unique!"

Leo Lorenz, ECPE

"Bodo Arlt is a name synonymous with Power Electronics and the magazine that bears his name, Bodo's Power Systems, has become the go-to publication for our industry. Bodo's Power is highly respected by my clients and I always enjoy working with its editors, Bodo and Holger, who bring expert analysis and comment to this complex subject."

Nick Foot, CEO BWW Communications



"Not only those of us who are privileged to call Bodo Arlt "friend," but virtually anyone involved in the advancement of power electronics technologies has much to be thankful for his vision, energy and support. Congratulations and best wishes on this special anniversary of Bodo's Power Systems Magazine. Well done! Thank you!"

Greg Evans, P.E., CEO, WelComm, Inc., B2B Marcom Experts

"Power Electronic Measurements (PEM) Ltd have enjoyed our long association with Bodo's power. The magazine promotes interesting power electronics technologies not just from the major corporations but also from smaller niche companies, such as ours, enabling PEM to reach a global audience, from new product promotion to comprehensive technical articles. Thank you Bodo and team."

Dr Chris Hewson, Managing Director, Power Electronic Measurement (PEM) Ltd

"Time flies. Looking back at the vast online library of past publications, I am reminded of the sheer pace and commitment of the semiconductor industry to contribute to society. On this 15th anniversary of Bodo Power's first publication, it was a joy to reflect upon the contributions over time and the publication's proficiency to bring the community together. Congratulations to our partner and friends at Bodo's Power in reaching this milestone."

Neil Markham, Head of Power Device Division, Hitachi Europe Ltd.

"Congratulations to the entire team from Bodo's Power Systems on this milestone anniversary! Our industry needs strong, independent press. Bodo and team have met that challenge, delivering in-depth coverage of innovations in power including GaN, adapters and chargers, LED drivers, motor drives, traction, and the newest developments for electric vehicles. The Power Integrations' team wishes you continued success."

Balu Balakrishnan, President and CEO, Power Integrations

"Congratulations on the 15th birthday to Bodo Arlt and his entire team. As a partner from the very beginning, we have accompanied the magazine intensively over all these years - whether as an interested reader or as an author of technical articles. For us, it is impossible to imagine our core market of power electronics without Bodo's Power Systems."

Thomas Schneider, Managing Director GVA Leistungselektronik GmbH

Looking forward to the next Years

1.5kW GaN Inverter for Battery-Powered Motor Drive Applications

GaN transistors and ICs increase power density in motor drive applications. An optimal lay-out approach allows obtaining ring-free output switching waveforms and clean current reconstruction signals either from leg shunts or from in-phase shunts.

By Marco Palma, Director of Motor Drive Systems and Applications at Efficient Power Conversion

Introduction

Many applications such as warehouse autonomous robots and lean production lines collaborative robots require that inverters for each motor have high power capability while being compact and light. This poses a challenge to designers because power, size and weight have always been opposing attributes. In battery powered applications, every cubic inch of occupied space and every gram of weight saved allow longer operation time between two battery charges. GaN FETs from Efficient Power Conversion help designers in increasing the power density to win the challenge.

EPC9145 Motor drive power evaluation board

EPC2206 80 V 2.2 mΩ eGaN® FET (Figure 1) is an optimum candidate for applications where the Bus voltage is below 70 V_{DC}. In motor drives, PWM frequency is usually kept below 50 kHz and dead times are above 500 nanoseconds. In these cases, the switch R_{DSON} is the primary parameter that designers look at. The thermal capability, in particular, the device junction to case thermal resistance, $R_{\theta jc}$, is the second parameter to be considered. Conventional MOS based solutions have one, or many devices in parallel per each switch and are based either on 5 x 6 mm or 10 x 10 mm packages, as shown to scale in Figure 1.

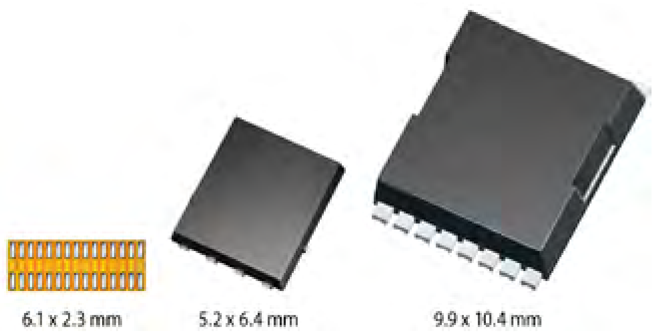


Figure 1: EPC2206 80V 2.2mohm GaNFET (on the left) compared to similar RDSON MOSFETs. Picture in scale.

Figure 2: EPC9145 - 3 phase inverter power board based on EPC2206 – 10 x 12 cm

EPC9145 is a motor drive evaluation board that features the EPC2206 and has everything needed except the microcontroller to drive a motor on the board. It can be operated with a maximum bus voltage of 70 V_{DC}, and a maximum phase current of 25 A_{RMS}. The motor controller can be chosen from those available on the market and can be connected using the proper EPC mate board. In Figure 2, from the left to the right there are the control connector, the signal conditioning circuit for voltages and currents feedback to the external microcontroller, the ceramic capacitor bank, three phase inverter with leg shunts and phase shunts and, finally, the motor connector.

dv/dt Switching waveforms

The EPC9145 PCB has been laid out following the EPC optimal layout rules (Figure 4), that guarantee the lowest inductance in the power loop. The main criterion is to observe symmetry in the component placement, and to constrain the entire high frequency path in the top and first inner layer. In EPC9145 case, layout is slightly more complex because there are leg shunts in the high frequency power loop as shown in Figure 3.

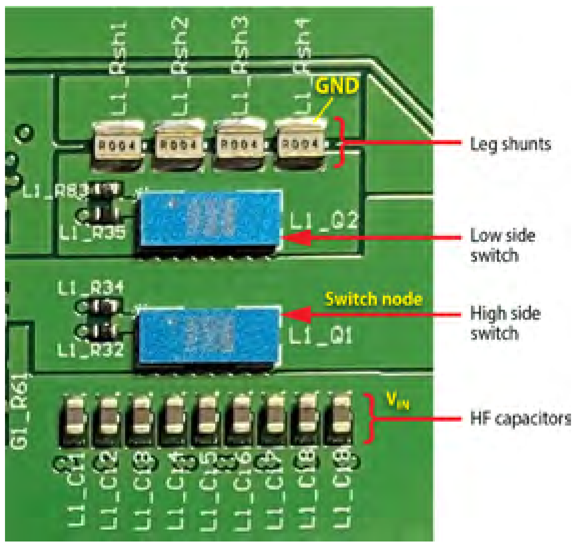


Figure 3: Detailed view of the switching cell

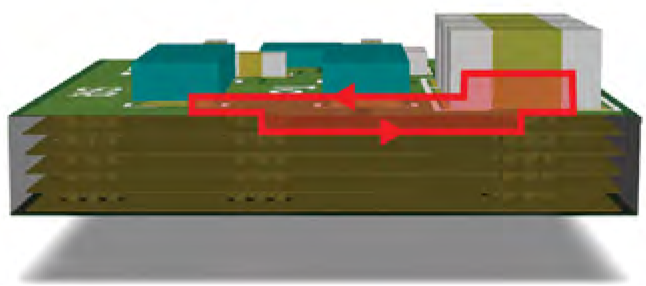


Figure 4: EPC optimal layout recommendation

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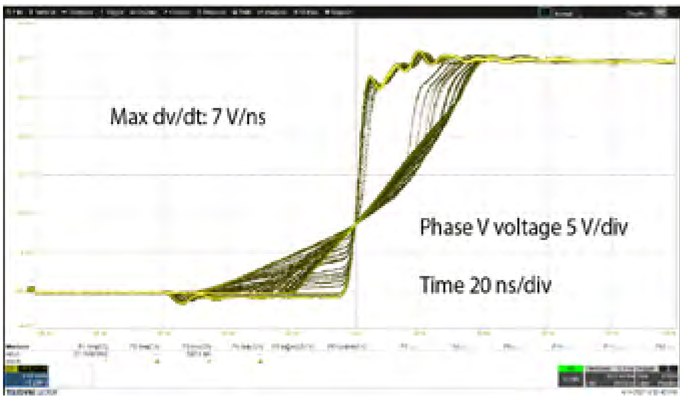

Figure 5a: Phase V rising edges at 30V bus

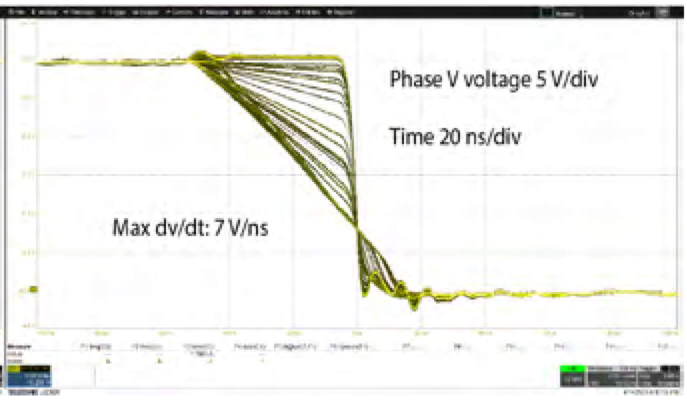

Figure 5b: Phase V falling edges at 30V bus

The HF capacitors are nine 220 nF size 0603, all in parallel, to reduce the overall inductance at high frequency. The same principle applies for the 1mΩ leg shunt sensor, which is made with four SMD resistors 4 mΩ 0805 wide body. The result is visible in Figure 5 where the switching node of phase V swings over time in both rising and falling edges as shown.

The pictures in Figure 5 have been obtained with infinite persistence to capture all waveforms, so that the maximum dv/dt is clearly visible. No voltage overshoot has been observed and the dv/dt is clearly in range used in typical motor drive applications. The careful reader can observe that the dead time was set to 50 ns (2.5 divisions).

Current sensing in-phase vs. leg shunts

When using discrete eGaN FETs or a GaN ePower^{TM} stage IC in an inverter for motor drive, it is common to use an in-phase current shunt together with an isolated (functionally or galvanically) IC that extracts the low voltage differential signal across the shunt resistor from the common mode of the switching phase. This approach has the advantage of giving the user continuous access to the phase current signal across the entire PWM period, except during switching events, where the signal may be influenced by the phases dv/dt. However, when compared to leg shunt sensing, the higher cost and lower bandwidth of the in-phase shunt solution may be detrimental for GaN inverter adoption in motor drives.

EPC9145 offers the user the chance to test both solutions and decide which fits best in his application. In fact, there are in-phase 1 mΩ shunts as well as 1 mΩ leg shunts per each switching cell. The 20x amplification gain, the offset and polarity are the same for both circuits so that the user can connect either the one or the other sensing scheme to the external microcontroller without making any firmware change. As shown in Figure 5, the insertion of the shunt in the low side leg does not have detrimental effect on the switching behaviour.

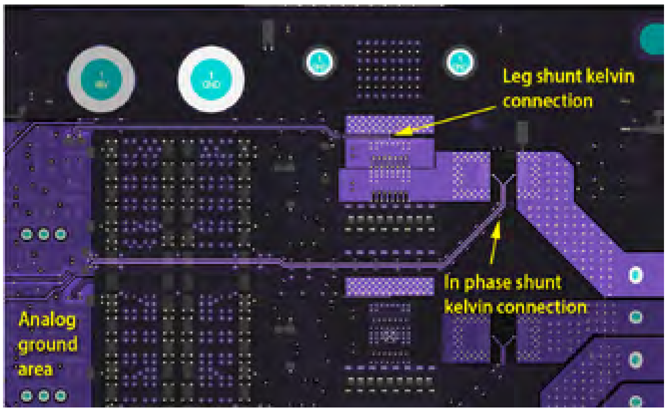

Figure 7a: Inner layer with shunt signal kelvin connections

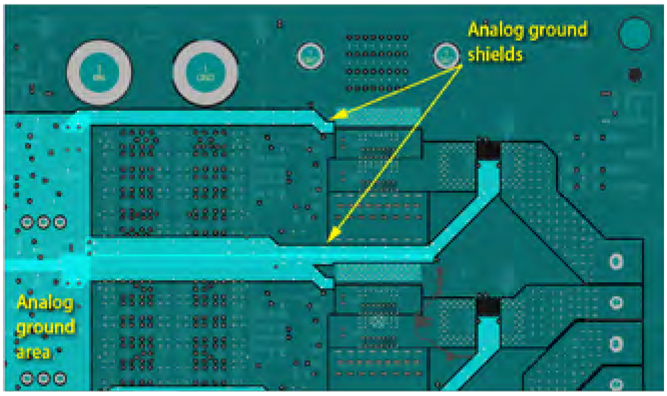

Figure 7b: Layers above and below with analog ground shielding of shunt kelvin traces

A comparison of the two current measuring methods, as well as the signal obtained from a current probe connected at the output of the inverter, is shown in Figure 6. When phase voltage is high, the signal across the leg shunt is null and the output of the amplifier is centered at 1.65 V; when phase voltage is low, the current which is flowing in the in-phase shunt is also flowing in the leg shunt so the two amplified signals overlap. Conventional field-oriented control algorithms measure the current in the middle of the phase low voltage pulse (indicated by two stars in Figure 6), so, by simply changing the position of three jumpers on the EPC9145 board, it is possible to use any of the two signals.

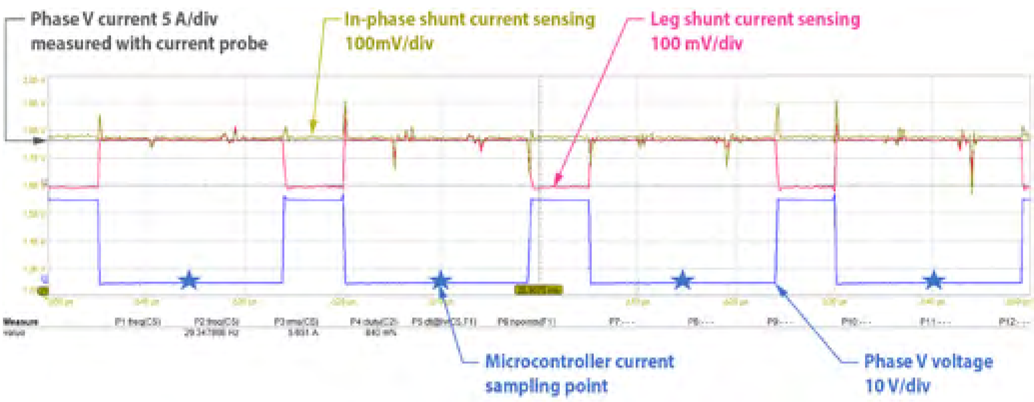

Figure 6: In-phase and leg shunt current sensing comparison – NOTE: noise in the picture is picked up by non-optimal measuring setup. Real signals are cleaner as it can be shown by controller current reconstruction.

Layout rules for accurate current sensing

The EPC9145 demonstrates the good practice in routing low voltage signals from the shunt resistors across the power board to the point where they are amplified and brought to the microcontroller connector. The main criterion is to perform kelvin measurement across the shunt and bring the traces as close as possible and shielded by analog ground cages on layers above and below the routing layer as shown in Figure 7. Another good practice is to divide digital and power ground from analog ground and connect them together in one single point far from the power loop paths.

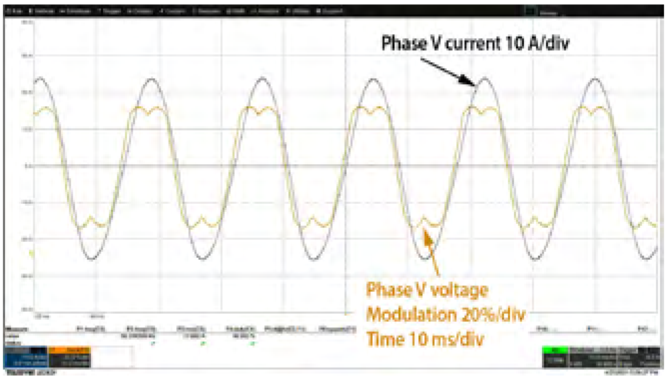

Figure 8: 40 kHz 50 ns DT operation, 60 VDC 17.5 A_{RMS} phase current – leg shunt measure

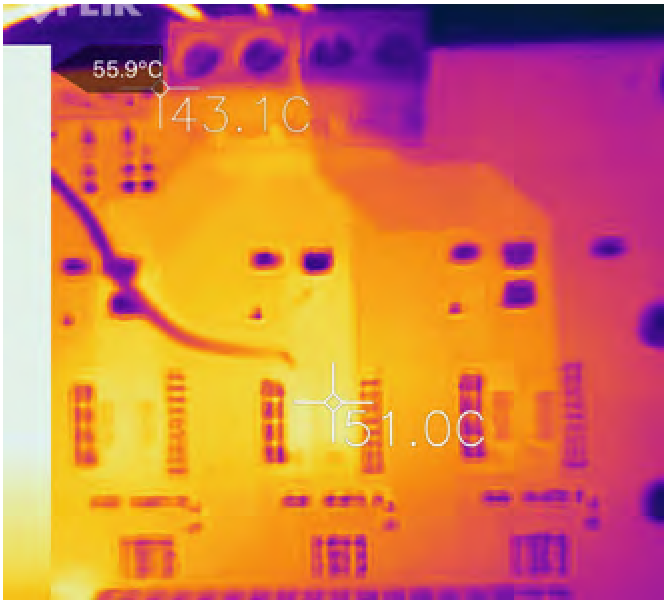

Figure 9: Infrared picture (confirmed by thermocouple) at 60 VDC 10 A_{RMS} phase current 40 kHz 50 ns DT

Operation without heatsink

Both in phase and leg sensing were used when testing the EPC9145 in a motor bench setup with a hysteresis brake. Current and voltage waveforms at 17.5 A_{RMS} 60 V_{DC} are shown in Figure 8.

Figure 9 shows the temperature across the EPC2206 without heatsink and no air convection. In this case the current is 10 A_{RMS} at 60 V_{DC} and the difference vs. ambient temperature is 30°C. Tests with heatsink with and without air convection are on-going and results will be reported soon in the board quick start guide.

Benefit of 100 kHz operation

An eGaN-based inverter can be easily operated at 100 kHz. The advantage is that the input voltage and current ripple decrease when the PWM frequency is increased, allowing the user to remove the

electrolytic capacitors and use only ceramic that are smaller, lighter, and more reliable. The EPC9145 is populated on the top surface with ceramic capacitors and on bottom with electrolytic capacitors. There are placeholders on both top and bottom layers so the user can mount, or un-mount the capacitors and make their own trials and judgements to find the right operating point that optimizes weight, size, and thermal operation.

Conclusions

Many battery powered motor applications are moving from conventional Si MOSFET, low PWM frequency to GaN inverters that can run at higher PWM frequency and bring the advantage of reducing the size and the weight without sacrificing the overall system efficiency. With proper gate driving and optimal layout, the switching waveforms are clean and dv/dt is easily managed.

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Motion Control Technology in the Industrial Sector

Vincotech offers a wide range of power modules featuring high level of integration and innovation aimed to fully support the Motion Control strategies for industrial applications, including general purpose VFDs as well as application-specific designs.

By Michele Portico, Sr. Product Marketing Manager, Vincotech GmbH, Germany

Motion Control Technology

Electric motors are all around us in appliances such as washing machines and refrigerators, and in transportation modes such as cars and in planes. We would not have many of the common modern conveniences we enjoy every day without electric motors. The first motors were invented in the early 19th century by historical figures and company founders such as Werner von Siemens, Thomas Alva Edison, Nikola Tesla and George Westinghouse. Without electric motors everyday life would be very difficult to imagine.

Motion control is an automation technology that has become a major part of the modern industrial machine design. It is about making a mechanism move under control. Therefore, it requires careful mechanical designing and incorporation of several motor control elements. In particular, motion control technology is advancing to ensure improved performance, ease of use and enable wider application of servo and motion controls.

Vincotech is the market leader in the design and manufacturing of energy conversion power electronics solutions which support motion control strategies for industrial applications, including industrial motor drives, embedded drives, heat pumps, HVAC systems, elevator and servo drives.

Industrial motor drives

In many industrial applications, motors need to be operated at different speeds and torques. These applications require a power conversion unit to be placed between the grid and the motor (Figure 1) that is usually known as a Variable Frequency Drive (VFD).

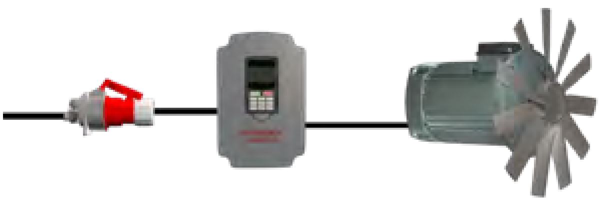

Figure 1: VDF

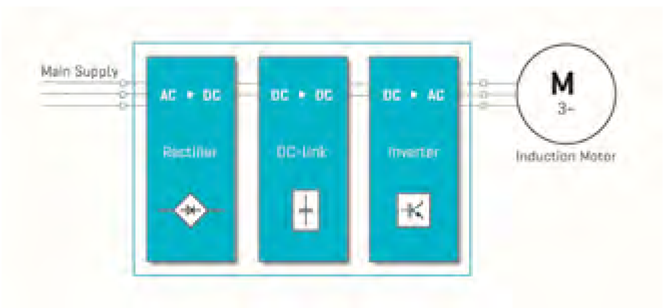

Figure 2: Energy conversion process

The most important advantage of a VFD is its ability to adjust the motor speed to the needs of the entire application. The second most important advantage is its ability to adjust the motor's torque. This feature protects the motor and the system driven by the motor from damage as the torque can be limited or precisely adjusted. Also, power savings can be considerable with being able to control the motor's torque. For example, a VFD driven motor connected to a fan will only consume 1/8th of its rated power when operating at half speed, due to the cube root speed-to-power relationship of this system.

The controlled stopping or braking of a motor can be as important as its controlled acceleration. The greatest advantages of VFDs are realized in the braking of elevators and conveyors. This braking or reverse operation of motors is of great interest in many other applications, too. Reverse operation is possible by changing the rotary field in the motor by the VFD without having to change the order of the phase cables to the motor. VFDs also eliminate the need for valves, dampers and gear boxes. This leads to more compact systems, lower maintenance and lower operating costs.

The important components inside a VFD are the power rectifier diodes, the brake chopper, and the power semiconductor switches. Power rectifier diodes are used to rectify the AC input voltage. The brake chopper is used to dissipate the regenerated energy from the motor during braking and it protects the DC link capacitor from damage. The power semiconductor switches are used to convert the rectified input voltage back to a controlled variable voltage and variable frequency output.

The Vincotech offer for industrial applications comprises power integrated modules (PIM/CIB – converter, inverter and brake), six-packs (three-phase modules), half-bridges and rectifier modules engineered to support standard drive applications for industrial use and motor power ranges from 1 kW to 200 kW.

Embedded drives

Discrete drives are standard solutions designed to control a wide range of motion applications. Nevertheless, higher integration and more complex subsystems are some of the current trends in the industrial market, and more and more companies provide embedded drive systems with different level of customization.

Embedded drive systems integrate drives and electric motors to reduce the space occupancy thanks to their compact and hermetical design. Since they are dedicated to specific applications, design

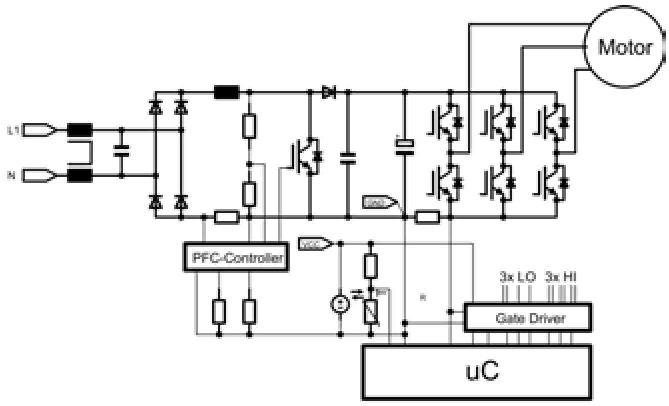

Figure 3: Power Integrated Module (PIM) with PFC

engineers can optimize them in order to reduce the size and cost of the final product and to increase the reliability and performance.

An embedded drive circuit consists of an input rectifier, PFC boost stage and a three-phase output inverter. Depending on the application, the best choice of a module for this circuit is a highly integrated IPM (Intelligent Power Module) or a very flexible PIM (Power Integrated Module). The IPM also has the logic components and gate drives required for power switches. The PIM provides just the power components, so the gate drive has to be mounted on the system's PCB (Figure 3).

Two key requirements for electronically controlled motors embedded in pumps, compressors, fans and other such applications are:

- Power Factor Correction (PFC): PFC is mandatory for drives connected to the public power grid.
- Hermetic motor integration: A hermetically sealed, integrated motor requires a compact design and thermal management. Interior space is limited and a hermetic seal prevents any airflow from reaching components on the system's PCB board. The heat generated by gate drives, shunt resistors and the like has to be dissipated by a connected heat sink.

Vincotech's power module portfolio for embedded drives features 600V and 1200V IPMs as well as power integrated modules with PFC circuits (PIM+PFC) that achieve the highest level of integration of any power module available on the market today. That makes these modules the best solution for space-constrained mechanical environments. The overall system's size, cost, and time-to-market can be reduced by integrating all of a motor drive's functional blocks, apart from the input filter, DC capacitor and microcontroller.

IPMs are needed to achieve the functional integration and power density necessary for this type of design. The extent to which IPMs are integrated, varies. At minimum, a standard IPM features a simple three-phase inverter bridge with a compatible gate driver. With more extensive integrated modules, engineers can create more compact designs and take advantage of a proven combination of power components and gate driver circuit - the most critical elements in the inverter's design. This mitigates the risk associated with circuit design, speeds up development and slashes time to market.

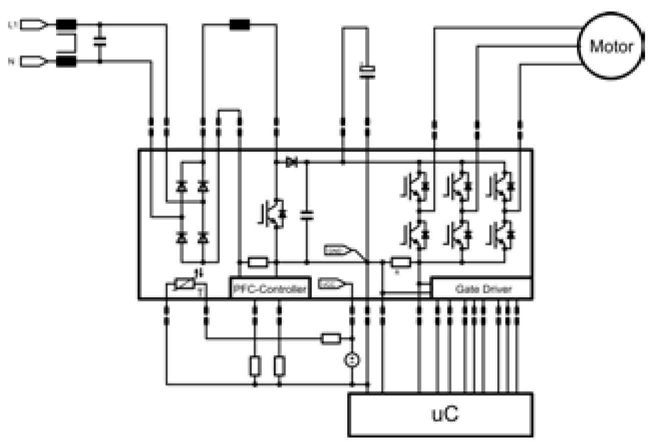

Figure 4: Intelligent Power Module

Power semiconductors, integrated circuits, SMDs and resistors integrated into the substrate can all be combined with the benefit of thick-film technology, thereby maximizing functional integration of the *flow* IPM 1B power modules (Figure 4). This design incorporates all active power components for a three-phase inverter with Active Power Factor Correction (APFC), including capacitors to compensate for inductive loops, shunts for sensing current, a PFC controller with its surrounding circuit to serve as a voltage divider, and DC capacitors.

Only the power components – the input rectifier, PFC boost stage and three-phase output inverter – are integrated in PIMs. The gate drive circuit and other logic circuits have to be mounted on the external PCB. An integrated DC capacitor is provided to reduce inductance and enable ultra-fast turn-off for the PFC switch.

Some versions of these modules provide a shunt resistor to sense current for PFC or inverter control. The emitter structure in the low-side switches is open, so three external shunt resistors may be connected for vector control-based inverter designs. A temperature sensor provides the heat sink temperature at the module's position.

Heat Pumps and HVAC

Increasing the power density is one of the main goals in the design of heat pump and HVAC systems. This goal can be achieved by:

- moving towards more compact designs
- increasing the efficiency of the energy conversion
- integrating more cost-effective solutions

Vincotech's PIM with interleaved Power Factor Correction (PFC) circuit is a unique and innovative topology for power modules featuring a high level of integration as well as improved energy conversion efficiency.

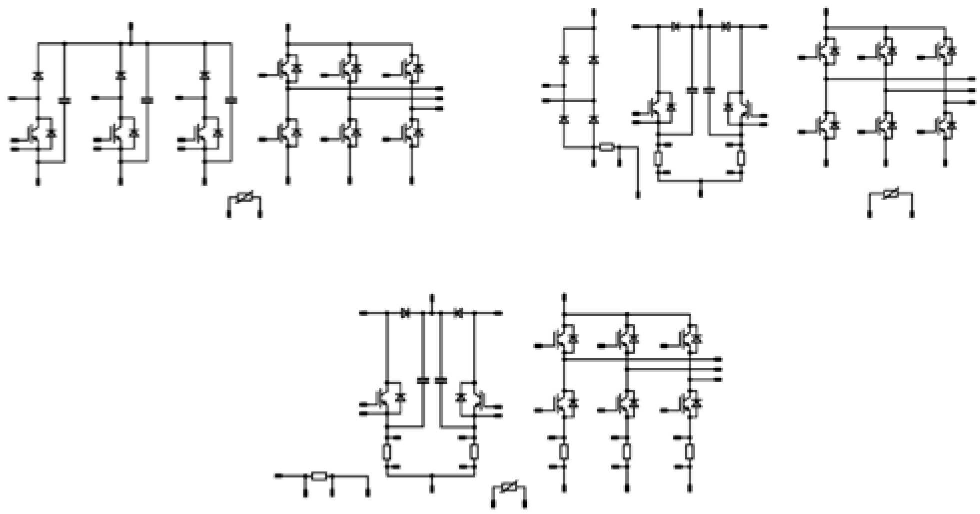

Figure 5: PIM with interleaved PFC

Interleaved configuration offers several benefits, including:

- ease of PCB design
- higher efficiency of the energy conversion
- better heating distribution
- smaller components on the PCB
- easier design of EMI filtering
- reduced output RMS current

Vincotech's new 600V *flow*PIM+PFC family is composed of three different sub-families featuring two-leg interleaved PFC circuit with and without an integrated input rectifier, and three-leg interleaved PFC without an input rectifier, respectively (Figure 5). All of them are equipped with both a three-phase motor inverter and a temperature sensor.

Products with two-leg interleaved PFC feature also shunt resistors in the motor inverter as well as in the PFC circuit. The common and leg shunts in the PFC allow a perfect balancing of the current in the PFC circuit that leads to an increased lifetime of the chipset. The integrated shunt resistors in each leg of the inverter result in vastly improved motor control.

Furthermore, the DC-link voltage overshoot is dramatically reduced thanks to the on-board capacitors.

Special care is paid to the layout of the products in order to offer the best compromise between cost and performance. The power pins on the edge of the power modules result in a simplified and more cost-effective PCB design. The thermal design is also optimized thanks to the separation of inverter and PFC parts.

modules as well as sixpack power modules for the motor stage. Sixpacks are equipped with high speed components in order to mitigate the overall power losses while operating at high switching frequencies. A tandem diode solution is also offered in order to reduce power losses even further and assure a long life cycle of the products (Figure 7).

Conclusion

Modern life is unthinkable without the benefits provided by electric motors in the industrial sector. Power conversion devices are a pivotal part of the motion control in industrial applications. With these devices, the speed and the torque of the electric motors can be adjusted within a wide range to meet the needs of different applications.

Vincotech's product portfolio provides the functional integration and power density

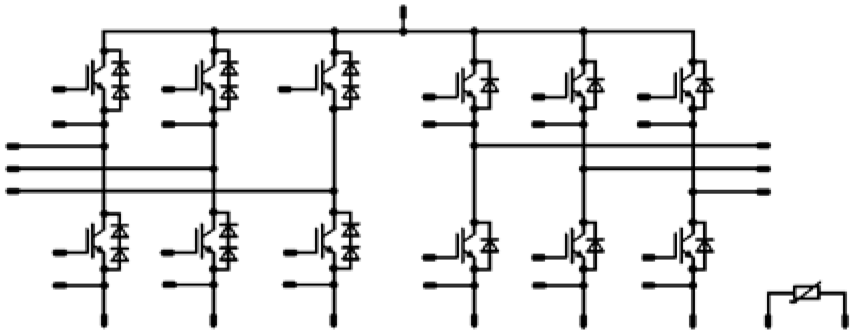

Figure 6: Twin-pack with tandem diode

Elevator drives

A long life cycle and high switching frequency in the converter stage are the main requirements for power modules used in drives for elevator and escalator systems. Vincotech's offer comprises standard sixpack as well as sixpack equipped with high speed components.

Special topologies, integrating two sixpacks for both the converter stage and the motor stage, are also available in order to provide a more compact solution and meet the aforementioned specifications.

Twin-packs are typically equipped with standard as well as high speed components. A tandem diode solution is also used to reduce power losses and then enhance the life cycle of the module even further (Figure 6).

Servo drives

Servo drive systems typically require switching frequencies in the range 10 kHz ÷ 16 kHz and output current overload up to 130% of the nominal current value.

Vincotech offers a full comprehensive product portfolio comprising input rectifier

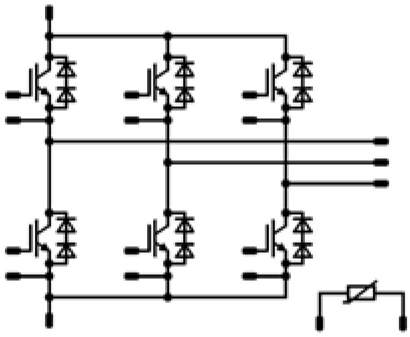

Figure 7: Sixpack with tandem diode

that engineers need to support the motion control strategies for industrial applications. The outstanding level of integration and innovation of Vincotech's products help system engineers to come up with more compact designs and to take advantage of a proven combination of power components and gate drive circuits. This mitigates the risk associated with circuit design, speeds up development, and dramatically reduces time to market.

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Permeability (Apparent; Sheared) – Advanced Validation of Magnetic for High Power and Energy Application

The analytical models regarding magnetic components` performance, cored with discretely distributed multi gapped design, are far away from satisfied, which significantly limits the high power & energy applications.

By JC Sun, Bs&T Frankfurt am Main and
Yi Dou, Researcher of DTU Kopenhagen

Introduction
Even the efforts undertaken where the modelling for the air-gapped core was built can be found in [1] and [2], the discussion only cover the length of air-gaps is relative small (the ratio between the air-gap and the entire effective magnetic flux length is approximately in the order of 10-4 for grinding and for 10-5 lapping & polishing, mainly for signal processing application. Thus the measurement validation for the components, such as by following standard IEEE 393, takes the role to provide credible design and application reference. In this article, we propose utilizing the novel damp-oscillation method by Bs&T pulse to measure and analyze the next-generation power and energizing magnetic components in range of kW & MW for traction & MV dc grid. The discussion based on case-study covers more based on the large air-gap length (the ratio increases to order of 10-2 e.g. the calculated effective permeability in range of 2 digital. Two key parameters, the sheared permeability, and the apparent permeability, to qualify the component performance, shift from the material & core, are discussed. Precise, robust and easy measurement under defined large energizing condition shows much better treatment of the difference between cores and the components, and enables specification measurement with limit value.

Uncertainty from the known modelling
The concept of distributed air-gaps in magnetic core has been proposed for decades while the understanding is reduced with key word flux fringing. However, the cost countering the benefit from the concept is controversial, mainly for the complexity of hardware implementation and difficulty of design and performance estimation.

In any case, the reluctance model is the most popular and simplest modelling for the component designers, where the material is regarded as structural homogeneous and magnetic isotropic, whereas the saturation behavior is simplified as a saturation magnetic flux density, rather than an incremental process, where the density is manipulative because the effective cross section is unknown. However, the magnetization process from the materials science, or the magnetism in condensed matter`s view, is way more complicated, by giving the demagnetization factor, either in internal demagnetization factor and external demagnetization factor of great relevance[5].

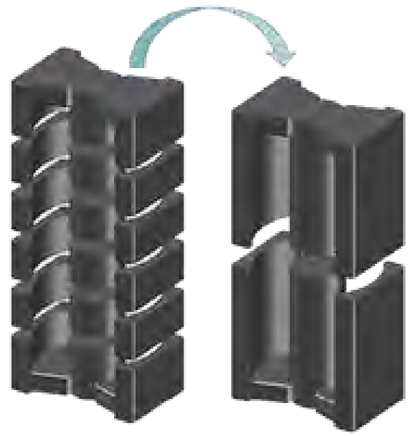

Figure 1: A demonstration for distributed and single air-gap core from Shandong Dongtai Electronics Co.

It is well known that the materials in the magnetic cores are impossible to model for the magnetic features and the loss estimation, even the model for the homogeneous magnetic material has been discussed for tens of years. Within different types of cores (such as ferrite cores, metal alloyed powdered cores), the submicron crystalline structure of the magnetic materials and the filling material makes it difficult to apply only one theoretical models and also the manufacture process and induced uncertainty even discourage any attempt to model the commercially available magnetic cores. In general, the impact to shape the cores` performance can be only validated by external demagnetization factor, as well as percolative behavior for powdered composite due to internal demagnetization factor only by measurement [5].

Particularly for the gapped magnetic cores, priority-arts can be found, including the McLyman`s method, where the gap-length was corrected based on simplified wire configuration and the core shapes but the results only valid when the gap-length is relative low (the lg/le is within the order of 10-4 ), and the Alex van Bossche`s method, taking consideration of bobbin and wire configuration for selected cases, where the effective area for the magnetic loop was corrected empirically. For the other applications, core shapes and emerging materials, people still know little and has no modelling for the estimation and rely on personal experience and know-how with singular project and temporal mood. Besides, few works mentioned that the position of the winding even shape the magnetic flux in the component, rather than only by the core shapes.

The finite-element-analysis (FEA) simulation is a powerful tool to estimate performance for gapped cores for designers. As shown in Figure 2, which is an illustration for the discrete gapped core, the performance of the winding and the core can be precisely reflected by numerical solution but only after the core performance has been known well. Obviously, the FEA cannot distinguish the macroscopic structure for different material (such as between powder element and ceramic grain in a core). Thus the measurement is the only way to provide design and manufacture reference as well as for the component validation, under the circumstance where no analytical model for both materials and general magnetic cores.

Bs&T Damp-Oscillation Solution

The basic concept for damped oscillation method in Bs&T pulse micro can be found in [3][4]. In the first place, the energy (in range of 1~200 Joule) for damped oscillation will be charged in the capacitor where the voltage can be controlled from 100 V to as high as 1000V to provide precisely energy for the oscillation. Once the capacitor being charged, a damped oscillation will be conducted on the D.U.T., during which the voltage and the current of the D.U.T. will be sampled and processed to achieve the performance evaluation, and will complete inductance analysis for magnetization and demagnetization path. In this demonstration, the distributed gapped toroidal cores were tested and evaluated by the set-up to reveal their performance and the results will mainly provide the sheared permeability (reset gain) and the apparent permeability as evidence for the gapped toroidal cores, especially to adapt the modern applications with different configuration, where lg/le is mechanically fixed in the order of 10-2. The toroidal shape is chosen for its asymmetry, even in practices, only the middle part is locally multi gapped, refer Figure 1.

The parameters of the magnetic core in the case study is shown in the table and the photo of the core with 8 air-gaps is also shown.

Item	Parameter
Outer diameter	92.5 mm
Inner diameter	52 mm
Height	40 mm
Number of turns	10

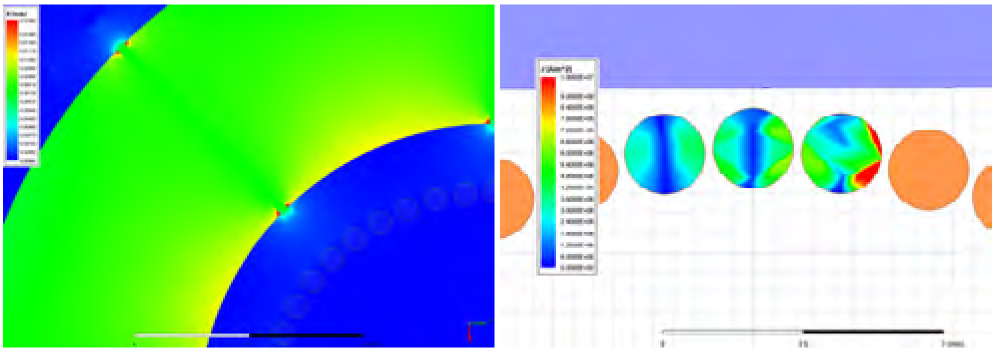

Figure 2: A demonstration of flux density and current distribution for gapped core by FEA simulation

During the test we kept the exactly same winding configuration and measurement condition, e.g. impulse energy, but the air-gap are distributed in one, two, four and eight pieces to distinguish the performance. Obviously with the conventional reluctance model,

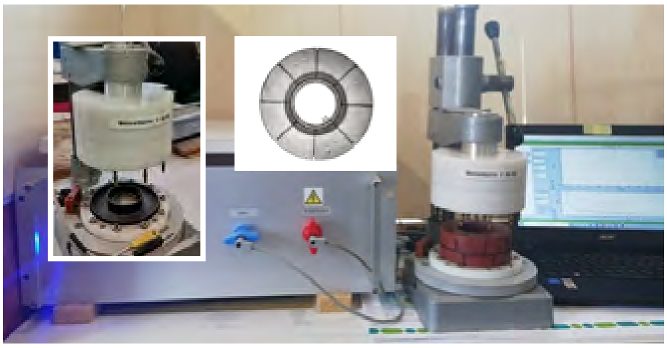

Figure 3: Device Under Test cored with discretely distributed multi gapped (8 gaps/ 0.7 mm for each) toroidal shape, adaptor with defined wire & number, number of turns(10) and its terminals in experimental set up with BsT-pulse micro (with friendly support by Tridelta Weichferrite GmbH)

the performance is expected same, while the difference can be observed by our damp-oscillation solution.

Apparent permeability

In the first place, we measured the differential inductance for the different configuration of ferrite element as gapped core for the same total air gap length, as in the Figure 4. In Figure 4 (a), the excitation current varies up to approximately 1300 A, where as the saturation process can be fully mapped. It is obviously found that the nonlinear saturation branch at the lower current area while merge as one inductance curve at higher excitation area. In the Figure 4 (b), a zoom-in figure highlights the differential inductance difference, which can come up to one sixth of the initial inductance,

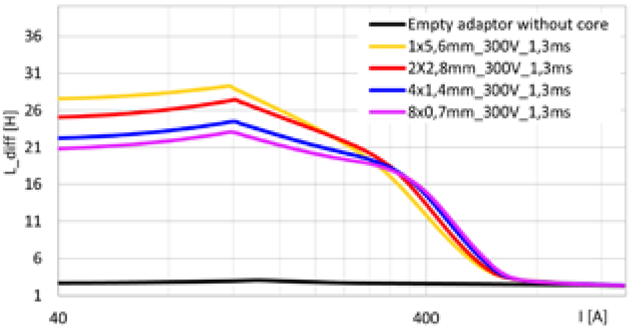

Figure 4: Measured inductance for the distributed gapped toroidal core

which is hardly modeled by analytical models. In Figure 4, the measured differential inductance is also plotted to indicate the shifting from the air-gap distribution.

Then a key definition, the apparent permeability should be introduced here, to normalize the shifting of the core. The concept of the apparent permeability is to separate the impact of the magnetic element, regardless which element how configured within the defined winding topology, thus the apparent permeability is normalized by the measurement of the device without the magnetic element core, but only of the windings. In Figure 5, the measured pulsed amplitude permeability [IEEE 389] of the devices are plotted as the function of the magnetic flux density. Interestingly, the pulse amplitude permeability for the devices reduce with the increasing

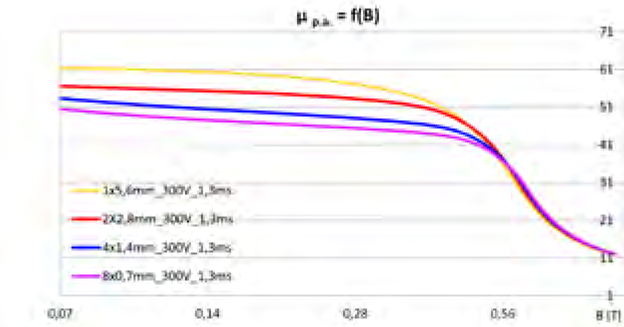

Figure 5: Measured pulsed amplitude permeability as a function of the magnetic flux density

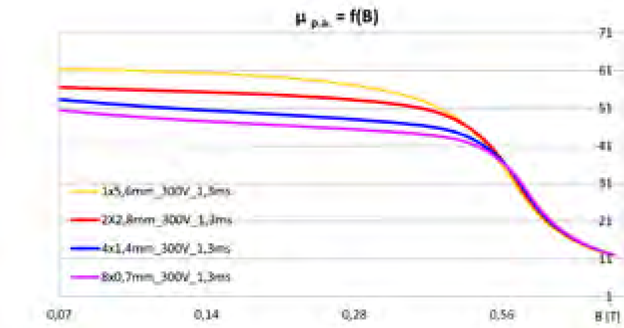

Figure 6: Apparent permeability during magnetization and demagnetization process

of the number of gaps, though the total length of the air-gaps are all the same as 5.6 mm. However, when the saturation dominate the operation, the permeability merge as one curve and the impact of the air-gaps fade along the higher magnetic flux density. Correspondingly, the apparent permeability can be get as shown in Figure 6 (a) and (b) for both the magnetization and de-magnetization process. It is found that not only the number of the air-gaps would influence the apparent permeability, but also the mag- and de-mag process will also shift the permeability thus the true operation is much more complex to be modelled by simplified equation.

Sheared permeability (Reset Gain)

Another valuable term called reset gain can be initially found from IEEE standard 393-1991 as

$$G = \frac{\Delta B_2 - \Delta B_1}{\Delta H},$$

where two points can be selected on the B-H curve measurement by the measurement with pulsed excitation. This reset gain can be normalized to sheared permeability with absolute permeability value in vacuum, which has very similar definition by using magnetic flux density divided by the magnetic field strength. Hereby in our post-processing given by fact that demagnetization and magnetization are parallel at origin starting point of hysteresis by large gap, we selected using sheared residual induction Br at current zero crossing point and coercive force Hc by definition also delta B =0, to evaluate the reset gain, which indicated in Figure 7. During the

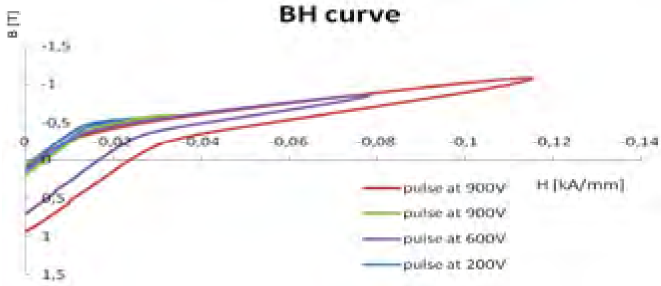

Figure 7: Demagnetization curve around the first current peak comparison with different initial energy

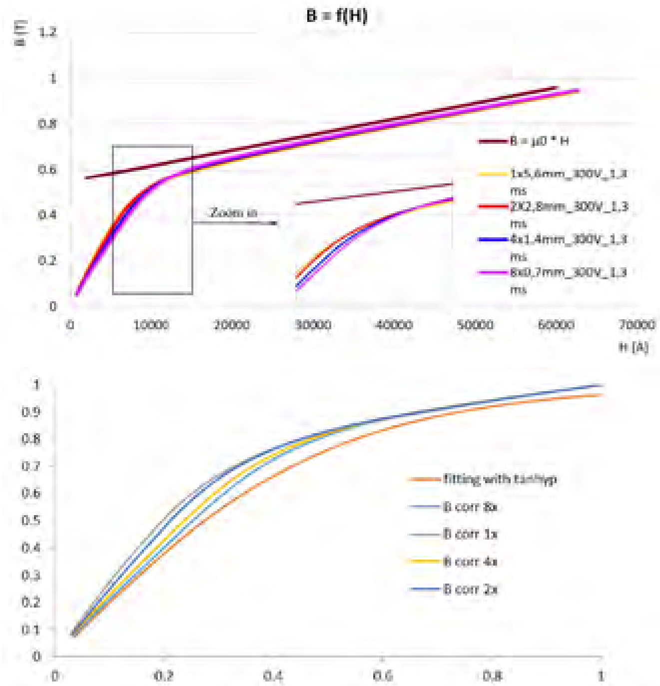

Figure 8: Demagnetization curve comparison among different air-gap configurations 8(a) overviewed (b) normalized with fitting function of tanhyp

testing we implement different initial oscillation voltage on the capacitor (200 – 300 – 600 – 900 V), thus the four half B-H loops show in different shapes, however the Br and Hc locate on the same position. It indicates that the energy stored in the components won`t shift the reset gain. So this measured value under same energizing condition qualified as the permeability to evaluate the component performance, together with apparent permeability. Care needs to be taken for interpretation of coercive force, the demagnetization is included, percolative behavior for composite for internal demagnetization factor (micro, meso agglomerates) for large filling factor, and external demagnetization factor of core shape, in this particular investigation, toroidal shape is taken.

Last but not least, the comparison between each demagnetization curve is illustrated in Figure 8. In Figure 8 (a), an overviewed demagnetization curve comparison is given, from which it is found that the saturation process for each configuration finally merge into a vacuum permeability. Actually, the core with the single largest air-gap "feigned" larger inductance, at beginning and comes into saturation at latest. The demagnetization factor of this configuration is effectively different as others, the more incremetal parts distributed along the circumference, the closer it convergents to fixed value, this is illustrated in Figure 8(b).

All these new observation indicates that though the distribute air-gap cores are challenging to be modelled, but based on the damp-oscillation method, the features can be unearthed and qualified for further analysis. Besides, with the similar measurement method, the temperature dependence features and the aging effect can be also conducted for the distributed air-gap cores. In fact, the potential and the performance of the distribute air-gap core are still waiting for further development. Last but not least, the quality factor, which can reflect the loss performance for the magnetic components, can also be measured with the proposed method [3].

Summary
Bs&T Damp-Oscillation Solution brings validation method two parameter under large excitation; apparent and sheared permeability, to characterize the magnetic designed with discretely distributed multi gapped toroidal cores with larger ratio lg/le ~ 10-2. With the measurement set-up, new features, new design reference and new modelling method are on the way to face the emerging power & energy electronics applications.

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Improved Power Magnetics for High-frequency Applications

Increasing operation frequencies require an improvement of magnetic power materials and their design process, especially regarding loss determination.

By Michael Schmidhuber, Christoph Drexler and Michael Baumann, SUMIDA Components & Modules GmbH

Motivation

Miniaturization of electrical devices became a focus of research and development over the last decades. Especially in mobile customer electronics or automotive applications, an increasing demand for volume optimized devices can be recognized.

The progressing trend means new challenges for the developers regarding magnetic devices because they often are the bulkiest components in electrical applications. Although several more elegant approaches to the optimization of magnetic devices are known, the most used method is the increase of the application's operating frequency. With the continuous improvement of wide band gap semiconductor power devices the usage of operations frequencies within the lower MHz-range becomes more and more established, especially in resonant power converters. To prevent a further increase of the gap between the technology level of semiconductor and magnetic devices, which already are a significant bottleneck regarding size, losses and thermal behavior, the improvement of magnetic components is essential. For this purpose, new ferrite materials are needed. Their development is challenging due to the large number of relevant material properties, such as saturation flux density, high frequency losses, thermal behavior and mechanical stability. Furthermore, economical aspects regarding the market introduction of new materials have to be considered.

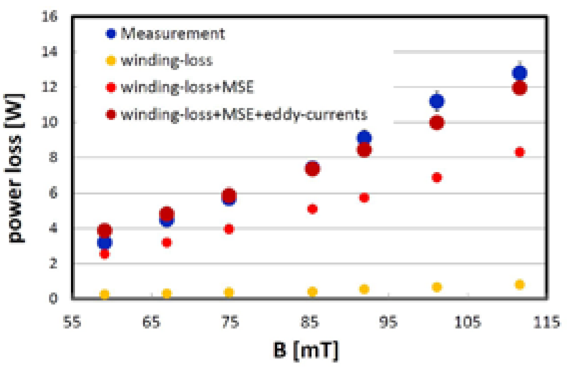

Figure 1: Measured (blue) and simulated (dark red) losses with respect to the flux density.
Yellow and red correspond to the winding losses and the core-losses due to the modified Steinmetz-equation. The maximum temperature of the cores decreases from right to left.

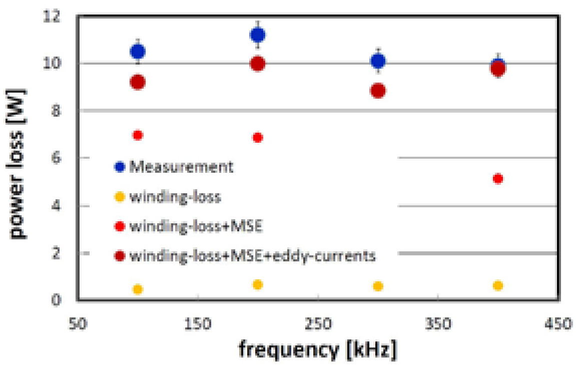

Figure 2: Measured (blue) and simulated (dark red) losses with respect to the frequency.

Another aspect is the improvement of the design process of magnetic devices, especially regarding their loss determination. Most academic optimization methods are too time-consuming and require high level mathematic methods, not always suitable for developers. An adjustment to an industry-orientated approach with a sufficient precision and speed is recommended and will be further improved.

New magnetic material

To ensure a high performance at operating frequencies within the higher kHz-range up to the lower MHz-range a new magnetic material SUMIDA Fi337 was manufactured. It is a power MnZn-ferrite, which is suitable for high frequencies in a range of 0.5 MHz up to 2.5 MHz. More detailed information is presented in [1] and [2].

Industry-orientated loss calculation

Loss determination is almost the most important factor within the design process of a magnetic device and the basis of the component's optimization regarding its size, efficiency and thermal management. Various methods of loss determination and component optimization were published and discussed. However, most of them are suitable for academic applications because of their high precision that causes large time expenditure.

In [3] an industry-orientated loss determination for high-frequency ferrite materials is presented and discussed. It bases on a FEM-simulation using JMAG from JSOL-Corporation but can be realized with any other 3D-FEM-software. For pre- and post-processing, self-written scripts in OCTAVE and C# were used. To generate reliable results, realistic current wave forms based on the component's load in its application were replicated.

After the FEM-simulation was executed the loss-density of each mesh element was calculated in a post-processing routine using the Modified Steinmetz Equation (MSE). The needed coefficients were extracted from representative loss tables based on the values which are given in the datasheet of the ferrite. After calculating the Steinmetz-losses another post-processing routine was executed to calculate the eddy-current losses of each FEM-element also based on datasheet parameters. The results of both calculations are the core losses of the magnetic component.

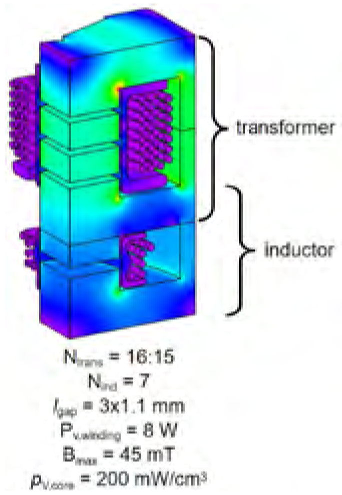

Figure 3: 3D-FEM-Simulation of the optimized LLC-transformer with integrated resonance inductor for a 1 MHz automotive application.

To determine the overall losses of the device a semi-analytical approach based on [4] was used. The RMS-, skin- and proximity-losses were calculated as described in [5] using the realistic currents waveforms of the FEM-simulation. The results of the calculations are the winding losses of the magnetic component.

To generate realistic results of the core and winding losses a thermal simulation was executed using a transient thermal solver of JMAG. The final core and winding losses of the device were calculated in an iterative process using the combination of magnetic simulations, pre- and post-processing calculations and thermal simulations until thermal equilibrium is reached.

The results of the industry-orientated loss calculation have been verified by calorimetric measurements using a non-commercial calorimeter as it is presented in [3]. A comparison of the measured and calculated losses shows a sufficient precision of this practical approach, as it is shown in Figure 1 und 2. However, the relative error increases with lower flux densities, lower temperatures and higher frequencies. A detailed discussion of the results is given in [3].

Application example

To test the new magnetic material and the presented industry-orientated loss calculation, a 1 MHz LLC-transformer with an integrated resonance inductor was designed in collaboration with project partners as a part of a national funded project. For this design PQ 50-cores made of the new material SUMIDA Fi337 have been used. After a first design using conventional loss calculation methods the design was improved by the use of the presented loss determination. A 3D-FEM-simulation of the optimized design is shown in Figure 3. Thereby, optimization and design of the final prototype could be executed virtually in a timeframe of one day. According to [3] it was the first demonstration of a high-frequency ferrite in an automotive application at 1 MHz.

Summary and Outlook

Because of miniaturization of electrical devices and new wide band gap semiconductor power devices the application's operating frequency increases. Magnetic components tend to be a bottleneck in the design process because they usually are the bulkiest components. To close the gap between the technology level of semiconductors and magnetic devices, the improvement of magnetic components must be enforced. The development of new high-frequency ferrite materials together with industry-orientated design routines proved auspicious.

Both approaches, the new material Fi337 and the simplified software based loss determination, were combined and tested in a 1 MHz LLC-transformer with an integrated resonance inductor for automotive application.

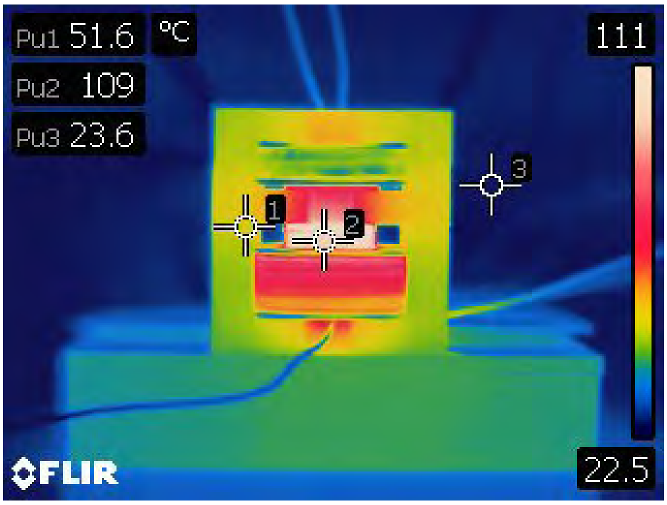

Figure 4: Thermal measurement of the optimized LLC-transformer prototype.

Further developments towards a fully automated digital design environment or the use in collaboration with artificial neuronal networks (ANN) are conceivable to achieve even more precision.

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Efficient Power GaN Technology and Packaging Innovations Delivers a Winning Combination

Gallium nitride for power applications has moved out of the development phase and into the mainstream. No longer is it a niche 'exotic' technology to be discussed in esoteric papers at academic conferences, it is being used in many power applications and being designed in widely for volume growth.

By Dr. Dilder Chowdhury, Director, Strategic Marketing, Power GaN Technology at Nexperia

Of course, the technology – like all others – is being, and will continue to be, constantly refined, leading to significant performance enhancements. It is also important to consider the chip packaging as this can greatly enhance – or compromise – device performance.

The time is right for Wide Band Gap technology

The world is changing. A greater awareness of our environmental responsibilities has led to EU Eco-design Directive and Energy Labelling Regulation and societal demand for less polluting technologies. Therefore, there is a move by all industries – especially power-hungry sectors such as automotive, communications and servers where 24/7 operation is required to move to electrification and even higher efficiency power conversion.

Traditional silicon technologies have performed beyond the wildest dreams of their inventors for 70 years and will continue to be a mainstay of many systems way into the predictable future. But in power applications, both silicon FETs and IGBTs are limited in switching speed, and it is harder and harder to make any significant steps in increasing efficiency.

This is why wide bandgap (WBG) semiconductors have emerged into the mainstream. Power GaN technology and specifically power GaN-on-silicon (GaN-on-Si) High Electron Mobility Transistor (HEMT) technology is today delivering on its long-discussed promise to provide the high-power performance and high frequency switching that many applications clearly require and can take the benefit to move to next level.

Commercial availability of GaN

In 2020, Nexperia launched its first-generation of commercially available power GaN products. Cascode mode devices were offered in leaded TO-247 packages. Just ahead of the PCIM show in 2021, the company announced volume availability of its second-generation 650 V power GaN FET device family, offering significant performance advantages over previous technologies and competitive devices. With RDS(on) down to 35 mΩ (typical), the new power GaN FETs target single phase AC/DC and DC/DC industrial switched mode power supplies (SMPS), ranging from 2 kW to 10 kW, especially server and telecom power supplies that must meet 80 PLUS® Titanium efficiency regulations. The devices are also an excellent fit for solar inverters and servo drives in the same power range.

Nexperia is making significant performance improvements that not only lowered the RDS(on), but also result in better switching Figure Of Merit (FOM) and lower capacitances, leading to improved efficiency and power density. The company is also investigating ways to achieve further optimization going forward with efficient designs to enable more efficient use of die space and higher breakdown voltages, as well as other improvements to drive yields up and costs down.

Cascode provides stability and ease of use

Nexperia's cascode power GaN FET structure has an effective gate rating of ± 20 V (as good as existing silicon super-junction technology) and can be driven by standard cost-effective gate drivers with a simple 0-10 or 12 V drive voltage with lower current compared to SiC while offering high gate threshold voltage of 4V for immunity against false turn on.

Packaging plays a crucial role

As systems move to higher switching frequencies to improve efficiency, the limitations of traditional power packages (TO-220 / TO-247 and D2PAK-7) have become increasingly obvious. To maximize

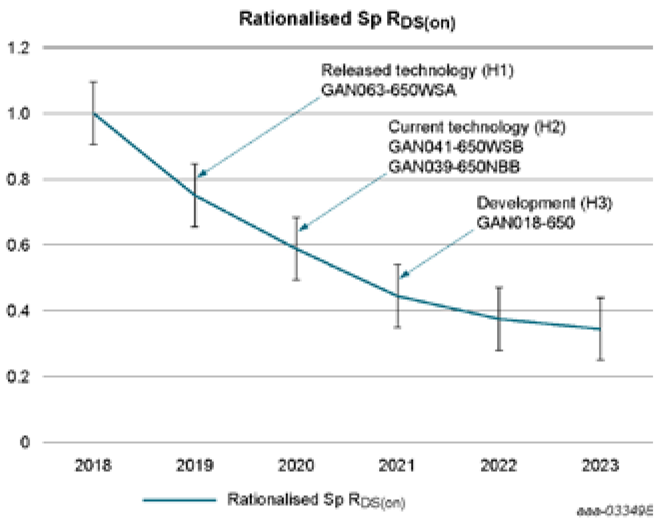

Figure 1: Rationalised Sp $R_{DS(on)}$

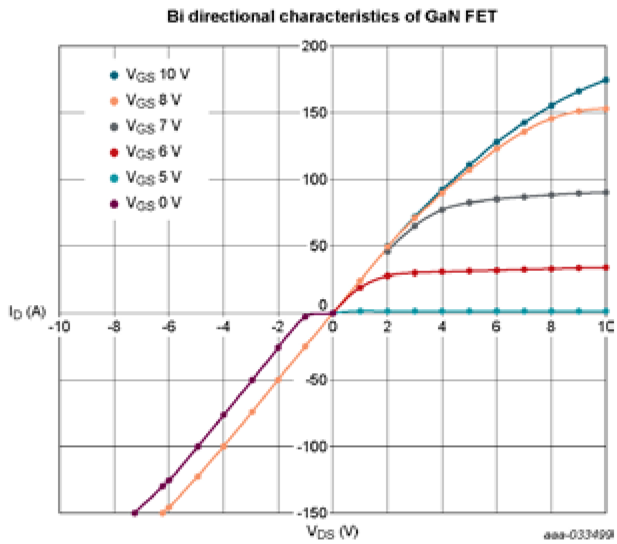

Figure 2: Bi-directional characteristics of GaN FET


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the benefits of high-voltage WBG semiconductors, new packages are required. As the innovators of copper-clip package (CCPAK) technology, Nexperia brings almost 20 years' experience of producing high-quality, high-robustness SMD packaging to its high voltage power GaN FET portfolio.

The new CCPAK package is completely free of wires and has been designed to optimize both electrical and thermal performance.

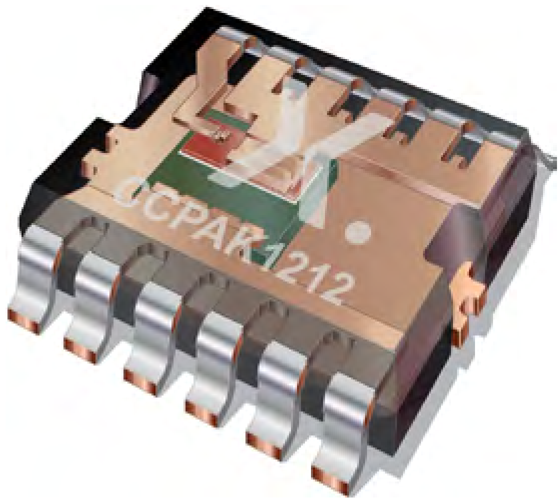

Figure 3: Internal arrangement of CCPAK1212

CCPAK delivers many benefits, firstly size. The CCPAK1212 is compact measuring 144 mm^2 (Solder pad design 168 mm^2) with a low 2.5 mm profile. This is less than a quarter (21.4 %) the body size of a TO-247 and 10 % smaller than the D2PAK-7. This enables significantly higher power density systems to be developed. Also, the CCPAK1212's exposed gull-wing leads facilitate easy optical inspection and enhance board-level reliability.

Electrically, the internal copper clip delivers many benefits. With no internal wire-bonds, the CCPAK enables significantly lower inductances than leaded packages. The table below highlights the comparison of CCPAK1212 and TO-247 operating at 100 MHz, which results in a total loop inductance of 2.37 nH compared to almost 14 nH. The copper-clip package also helps deliver ultra-low package resistance and a thermal resistance of < 0.5 K/W.

Inductance	CCPAK1212 (nH)	TO-247 (nH)
G_MOS_L	1.92	8.19
G_GAN_L	0.53	1.18
S_MOS_L	0.38	0.74
Common_L	0.55	5.92
D_GaN_L	1.44	5.13

Figure 4: Self-inductance @ frequency 100 MHz

Thermal challenge

Thermal management is a constant headache for power applications, becoming ever more difficult to address as power levels and circuit density both increase.

Combining power GaN-on-silicon technology with CCPAK packaging addresses this challenge. Nexperia's 650 V high-power FETs in CCPAK are rated for use at 175 °C, and offers a low typical $R_{th(j-mb)}$ (<0.3 K/W) for optimal cooling. This is shown in thermal simulations (Figure 5) when dissipating 37 W, where in comparison to a TO-247 (Rth = 0.7 °C/W) the CCPAK has a Rth of just 0.173 °C/W. The result is that the CCPAK1212 can comfortably manage over 300 W of power dissipation.

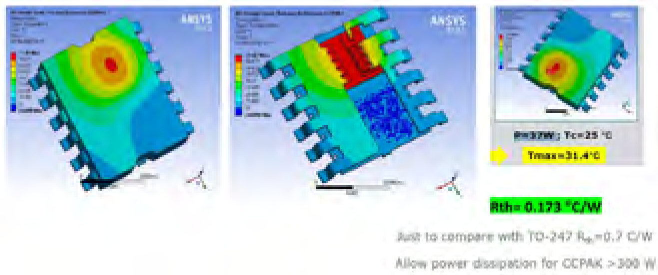

Figure 5: Thermal simulation power GaN FET

For even greater thermal performance, CCPAK1212i "flips" the internal connections, permitting top side cooling and providing a system solution for hard switching topologies or where high ambient temperatures are a concern.

Half-bridge demonstrates GaN FET advantage

The basic building block for most topologies - AC/DC PFC stage, DC/DC converter, or traction inverter - is a half-bridge. If we compare gallium nitride FETs to silicon FETs in a simple boost converter, the superior performance of the power GaN device is clearly shown.

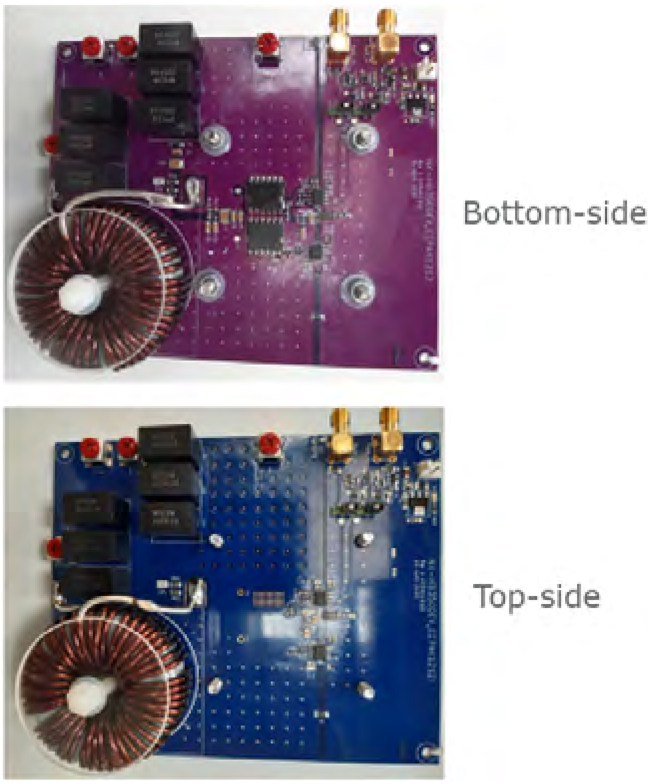

Figure 6: Half bridge demo board top and block diagram

The half-bridge demo in Figure 6 uses Nexperia's top-side cooled GAN039-650NTB delivering 400 VIN and 230 VOUT at 100 kHz with 57.4 % duty configuration operating at an ambient temperature of 23.1 °C. The resulting efficiency results are impressive. At 2 to 3 kW, or the typical operating range for current industrial PSUs, efficiencies are in excess of 99%. To put this in perspective, Titanium is the most demanding of the 80 PLUS® specifications, requiring greater than 91 % efficiency under full load conditions (>96% at 50% load). Therefore, the Nexperia 650 V power GaN FETs provide the efficiency and power density boost that server, storage and telecom PSUs designs require. In fact, the power GaN FETs continue to deliver high efficiencies of 98 % and above even beyond 6 kW.

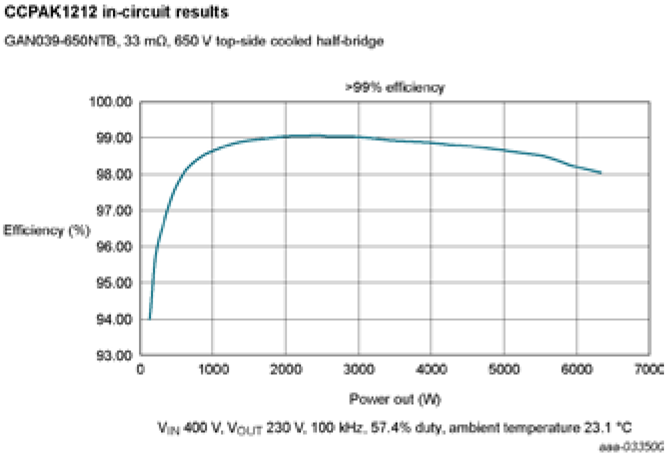

Figure 7: Half bridge demo efficiency

For servo drives, lower motor loss and lower noise are the result of improved current waveforms and the bottom-cooled GAN039-650NBB showcases the fast soft switching offered by these devices. In a 400 V_{DC} buck-mode set-up with a low-side V_{DS} for I_D of 20 A, the spike, overshoot, negative undershoot and ringing are almost negligible during both the turn-on and turn-off. This provides a significant advantage in terms of noise and any silicon related Qrr issues.

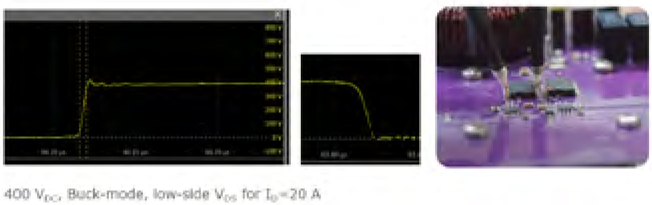

Figure 8: CCPAK1212 switching waveform

Conclusion

As designers increasingly look to wide bandgap (WBG) technology they need also to consider the availability of efficient packaging solutions such as Nexperia's all copper-clip CCPAK in order to take full advantage of the new power GaN semiconductor FETs. By delivering increased power conversion efficiency and fast, hard and soft switching Nexperia's power GaN technology in CCPAK is enabling automotive, telecoms and server companies to address growing requirements for a more sustainable future.

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Optimizing the Frequency Properties of Silicon IGBTs for Operation with SiC Schottky Diodes in Hybrid Modules

This article proposes a method to obtain optimal properties of silicon fast IGBT chips designed for joint operation with SiC SBD in hybrid modules. The optimal doses of proton irradiation as well as optimal static and dynamic properties of 1200V IGBT are determined for hybrid modules used in DC/DC converters at operating frequency of up to 50 kHz.

By Alexey Surma, Dmitry Titushkin, Denis Malyy, Vladimir Verevkin, and Kirill Volobuev, Proton-Electrotex, Russia

Introduction

One of the most promising directions in the evolution of high-spec auxiliary power sources in terms of power semiconductors is related to the use of "hybrid" semiconductor switches based on silicon IGBTs and SiC Schottky diodes. The use of Schottky diodes makes it possible to drastically reduce the frequency-dependent component of the power loss in the diode, to reduce the turn-on energy losses in the IGBT, and to expand the safe operation area of the switch elements in modes typical for power electronics. Using a silicon IGBT allows to optimize the cost of the device.

This requirement to reduce the frequency-dependent component of the loss power highlights the need to improve the frequency properties of the IGBT, since it is this element that limits the frequency response of the entire hybrid switch.

Various aspects of optimizing silicon IGBTs using proton irradiation technology to improve their frequency response are discussed below.

Experimental Samples

The experiment was based on samples of Trench Field Stop IGBT chips rated for blocking voltage up to 1200 V and nominal current up to 200 A having a thickness of 125 μm.

The frequency properties of the IGBT were improved by means of proton irradiation, the related technology was described in detail in [1]. The dose of proton irradiation varied, making it possible to obtain chips with various combinations of static and dynamic properties. The path length of hydrogen atoms remained the same.

The experimental IGBTs were designed to operate together with SiC Schottky diodes in hybrid (Si / SiC) modules.

Experimental modules were tested for the following properties:

- IGBT collector-emitter saturation voltage ($V_{c\ sat}$) at the temperature of 25 and 150°C, collector current I_c = 0.25 x I_{nom} and I_c = I_{nom}, and the voltage across the gate 15 V;
- energy of IGBT turn-on losses E_{on}, energy of IGBT turn-off losses E_{off}. Measurement conditions: temperature 25 and 150°C; collector-emitter voltage 600V; gate-emitter voltage ± 15V; resistance in the gate circuit 2.2 Ohm; stray inductance in the DC circuit of the tester unit below 35 nH; collector current from 0.4 x I_{nom} to 1.5 x I_{nom}. Stray inductance of the module structure made around 20 nH.

Dosage Relations of Vce, Eon, Eoff

Typical relations between $V_{ce\ sat}$, E_{on}, E_{off} of the IGBT and the dose (integral flux - Φ) of protons are shown on Figures 1, 2.

The $V_{ce\ sat}$ relation can be reliably approximated by a linear function:

$$V_{cesat}(\Phi) \approx V_{00} + K_{v0} \cdot \Phi \quad (1)$$

In similar fashion to (1) it is possible to approximate the dosage relations between the current and components of piecewise-linear approximation of the $V_{ce\ sat}$ relation: cut-off voltage (V_{T0}) and dynamic resistance r_T:

$$V_{T0}(\Phi) \approx V_{T00} + K_{T00} \cdot \Phi \quad (2)$$
$$r_T(\Phi) \approx r_{T00} + K_{rT0} \cdot \Phi$$

Figure 2 demonstrates that the dosage relation for E_{on} is almost absent for SiC SBD modules, and the E_{on} value measured in "nominal" mode described above (E_{on}^{nom}) is rather low.

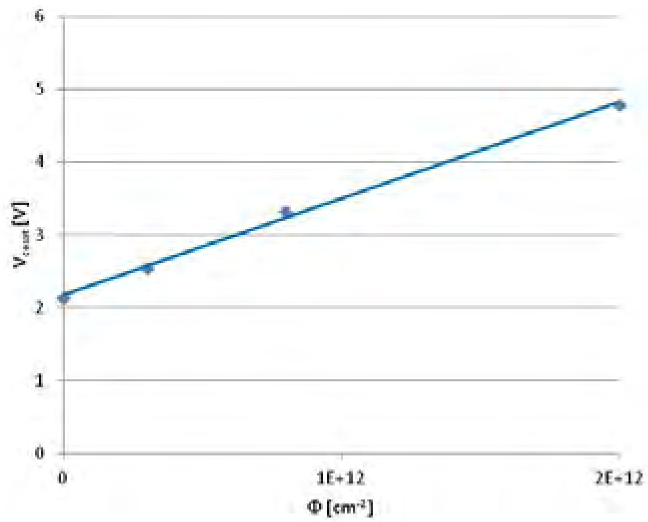

Figure 1: Typical relation between V_{cesat} and dosage. I_c=I_{nom}=200 A, Tj=150 C.

Analysis of the relation between Eoff and dosage shows that it can be approximated with a relation:

$$E_{off}^{nom} \approx E_{off0} + \frac{E_{off1}}{1 + \Phi/\Phi_1} \quad (3)$$

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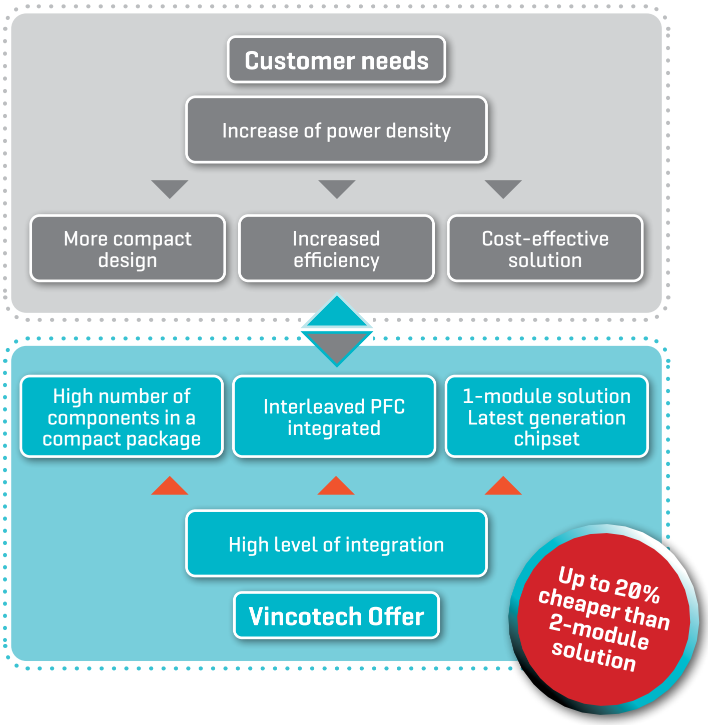

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where E_{off}^{nom} is E_{on} value measured in “nominal mode” described above, E_{off0} – component of loss energy that does not depend on irradiation treatment,
E_{off1} – component of loss energy that depends on irradiation treatment,
ϕ_1 – constant.

Relations between E_{on} / E_{off} and current/voltage are roughly directly proportional:

$$E_{on}(\Phi; I_c, V_{ce}) \approx E_{on}^{nom}(\Phi) \cdot \frac{I_c}{I_c^{nom}} \cdot \frac{V_{ce}}{V_{ce}^{0.5nom}}$$
$$E_{off}(\Phi; I_c, V_{ce}) \approx E_{off}^{nom}(\Phi) \cdot \frac{I_c}{I_c^{nom}} \cdot \frac{V_{ce}}{V_{ce}^{0.5nom}} \qquad (4)$$

where I_c^{nom} = 200 A is the nominal collector current,
$V_c^{0.5nom}$ = 600 V is the collector-emitter voltage measured in nominal mode.

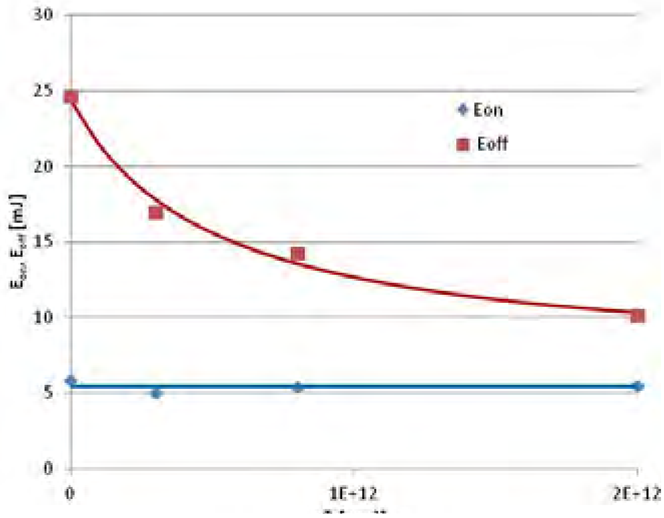

Figure 2: Typical relation between Eon / Eoff and dosage. Ic=Icnom=200 A, Tj=150 C

Approach to Optimization

The loss of power at the IGBT (Ploss) consists of "static" and "dynamic" components. "Static" one is mainly caused by the flow of collector current through a turned-on device and depends on the current and voltage of the collector-emitter saturation (V_{cesat}), but is not affected by the frequency. "Dynamic" component is caused by the dissipation of energy in transient processes of turning-on and turning-off and is directly proportional to frequency (f).

The technology to improve the frequency properties (in this case, proton irradiation) makes it possible to reduce the dynamic component of the loss power. However, it achieves it at the cost of increasing the static component, and while the former decreases monotonically, the latter increases monotonically along with increasing the radiation dose [1, 2].

Thus, we can obtain a family of dependencies between loss power and frequency at various radiation doses for any specific operating mode of the switch, similar to that shown in Figure 3. The envelope of this family, shown in Figure 3 with the red line, is in fact the limit line showing the lowest loss power for a switch of the given design and technological version operating in a particular mode. Each point of this limit line corresponds to a certain optimal dose of proton irradiation allowing to obtain the minimum loss power when operating the switch at a given frequency. This optimal radiation dosage can be determined from the condition of a local minimum of energy losses:

dPloss(F; f, Ic, Vce)/dF=0 (5)

Knowing the relation between the dosage of proton irradiation and such IGBT properties as V_{ce} (V_{T0}, r_T), E_{on}, E_{off}, it is trivial to construct a specific limit line and determine the minimal loss power of a switch at specific frequency, the required proton irradiation dosage and optimal values of V_{ce}, E_{on}, E_{off} for that dosage.

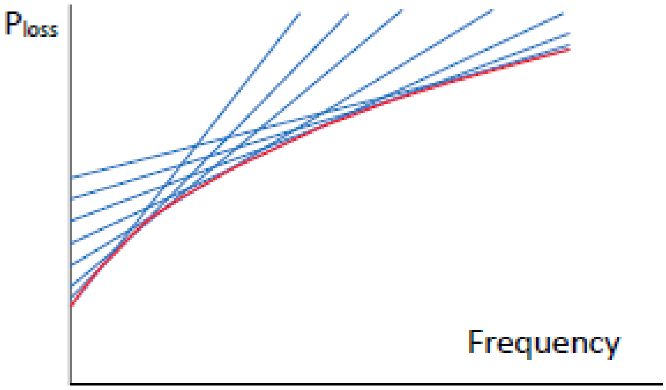

Figure 3: Optimal loss power

Finding the Optimal Properties of Hybrid Switch Operating in an Auxiliary Power Source

Let us find the optimal properties of IGBT for a hybrid chopper switch used in a step-down DC/DC converter with the following properties: DC input voltage 560 V, DC output voltage 300 V, output current up to 100 A. Using the relation (5) and taking into account (2), (3), (4) it is easy to obtain a formula linking the value of optimal irradiation dosage (ϕ_{opt}) to frequency and values of the collector current and voltage:

$$\Phi_{opt} = \Phi_1 \cdot \left[\sqrt{\frac{f}{\theta} \cdot \frac{V_{ce}}{V_{ce}^{0.5nom}} \cdot \frac{E_{off\,1}}{\Phi_1 \cdot I_c^{nom} \left(K_{rT0} + I_c \cdot K_{rT0} \right)}} - 1 \right] \qquad (6)$$

where Θ = 0.54 is the current fill factor for an IGBT used in the converter described above.

Figure 4 shows relations between ϕ_{opt} and frequency for various I_c/I_c^{nom}.

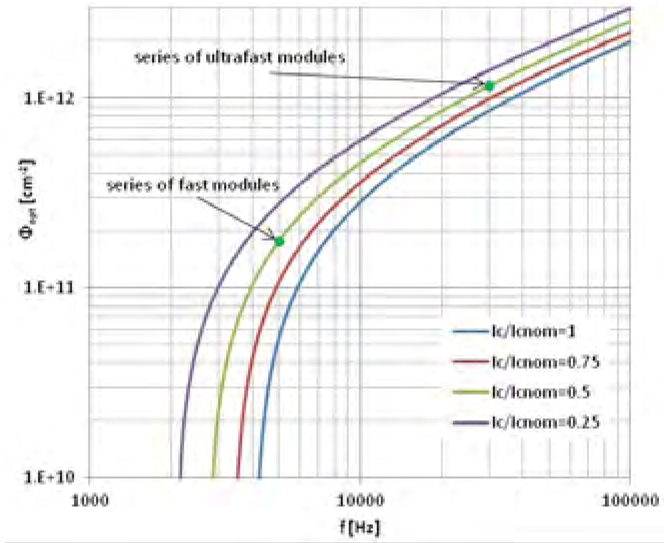

Figure 4: Relation between ϕ_{opt} and frequency.

Figure 5 shows the limit line of minimal loss power at an IGBT obtained using relation Fopt at I_c/I_c^{nom} = 0.5. It shows that this line in the frequency range up to 50 kHz can be reliably approximated with relations between frequency and loss power of two module series – fast and ultrafast. Their IGBT irradiation dosages are marked with dots on Figure 4. The Figure shows that using the

FAST series is optimal for frequencies up to 12 kHz and ULTRAFAST series for frequencies above 12 kHz. In both cases the maximum operating frequency of a device is limited by the maximal power of heat removed by a heatsink and resulting temperature of the module baseplate (liquid cooling was selected for this example).

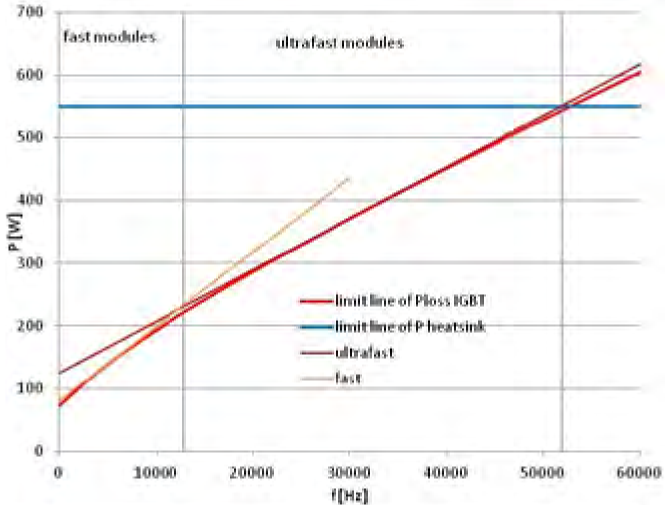

Figure 5: Limit line of a minimal loss power at an IGBT and its approximations by relations between frequency and IGBT loss power for two module series – fast and ultrafast.

If we accept 100A as the nominal current of the above-mentioned hybrid modules, the typical IGBT properties at 150 °C will be as follows:

- for the fast series – V_{cesat} = 1.62 V, E_{on} = 2.75 mJ, E_{off} = 10.0 mJ;
- for the ultrafast series – V_{cesa}t = 2.5 V, E_{on} = 2.75 mJ, E_{off} = 6.0 mJ.

Conclusion

We proposed a method to determine the optimal properties of fast silicon IGBT chips intended for joint operation with SiC SBD in hybrid modules. The optimal doses of proton irradiation as well as optimal static and dynamic properties of 1200V IGBT are determined for hybrid modules used in DC/DC converters with an operating frequency of up to 50 kHz. It should be noted that using IGBTs of a different design and with a different technology of increasing the speed, as well as changing the topology and operating mode of the converter will, of course, lead to a change in numerical values of the parameters and constants used in this method. However, it can be expected that the structure of the proposed formulas will not change.

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Digital PFC + LLC Combo Controller Helps Fast-Charge Adapters Enter the New Age

Fast-charge technology has developed rapidly in the last few years due to the exponential increase in power demand for mobile devices. In late 2020, cell phone market leaders (such as Apple, Xiaomi, and Samsung) started to abandon in-box adapters for cell phones. This change stimulated another boom for the demand of aftermarket adapters, and also confirmed two trends for the fast-charging adapter market.

By Siran Wang, Technical Marketing and Application Engineering Manager, Monolithic Power Systems

The first trend was the demand for multiple-port adapters. Conventional cell phone in-box adapters were designed with a single USB port, regardless of how much power the adapter could deliver. The traditional "one phone, one adapter" concept became less relevant once there was no longer an in-box adapter, as customers started to prefer adapters designed with multiple USB ports. Day-to-day life requires numerous electrical devices (e.g. cell phones, tablets, and notebooks), and whether a consumer is at home or traveling, a single adapter that can simultaneously power multiple devices is the preferred charging method (see Figure 1).

Figure 1: 100W Adapter with 3C1A USB Ports

The second trend was adapters suited for higher power levels that often exceed 100W. The power levels of most adapters have already increased due to the development of fast-charge technology. USB PD protocol allows up to 20V of charging voltage and 5A of charging current.

So far, the majority of in-box adapters in the market are still below 65W due to considerations such as the cost for high-volume products and the practical charging requirements for single portable devices.

However, many aftermarket multiple-port adapters exceed traditional limitations, because higher power is necessary to charge multiple devices. For multiple-port adapters, a higher cost is accepted because it can charge multiple devices. As a result, high-power adapters with rated power exceeding 100W are becoming mainstream products.

The single-stage flyback has been the most popular solution for adapters up to 65W. Especially for single-port fast-charge adapters with a wide input and output voltage range, flyback solutions can adapt to these voltage combinations without requiring an additional DC/DC power stage. However, based on the trends discussed above, the market is demanding an evolution in fast-charge adapter solutions.

First, there are mandatory power factor regulations on power supplies in most regions, so power factor correction (PFC) is necessary on the front end as the rated power exceeds a certain level. Second, it is very difficult for flyback solutions to meet the high efficiency and power density requirements for applications exceeding 100W.

Because multiple-port adapters require each port to be able to adjust the output voltage independently, each port must have its own DC/DC stage. This means that the primary power supply only needs to provide a fixed output voltage instead of an adjustable voltage. All of these differences make a two-stage PFC + LLC combo controller a more suitable solution for high-power adapters with multiple ports. LLC is a resonant converter that can achieve zero-voltage switching (ZVS) across a wide load range. With PFC on the input and DC/DC at the output, an LLC solution can achieve much better efficiency and power density than a flyback solution. Figure 2 shows a PFC + LLC solution.

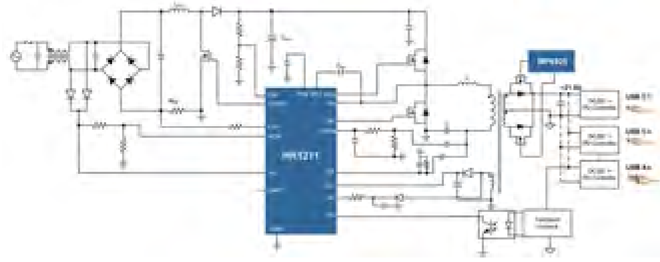

Figure 2: Typical PFC + LLC Controller Solution Based on the HR1211

As an example, we'll look at the HR1211 from MPS, a digital PFC + LLC combo controller that is suitable for high-power multi-port PD adapter designs.

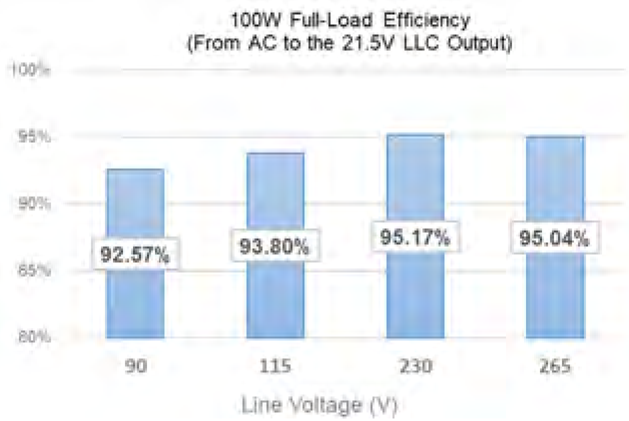

Figure 3: Full-Load Efficiency in the HR1211 Based on a 100W Design

This PFC + LLC combo controller is an ideal solution for multi-port adapters. A hybrid control scheme such as that in the HR1211 allows for continuous conduction mode (CCM) and discontinuous conduction mode (DCM) in the PFC stage. Under full loads, CCM reduces conduction loss (especially at the low-line input) and the inductor size requirement. At the same time, the LLC stage implements current mode control with adaptive dead time tracking technology to guarantee ZVS operation with minimal dead time under any conditions. This minimizes the LLC converter's switching and conduction loss. These features are essential to achieve high efficiency and high power density. In an actual 100W PD adapter with 3C1A USB ports, the full load efficiency from AC to the LLC output can be close to 95% (see Figure 3).

As a result, a 100W high-power adapter can be implemented in a very small form factor (76mmx61mmx29mm). At the same time, the temperature rise can be easily controlled. Figure 4 shows that this solution's maximum temperature is 77°C at the continuous full-load operating condition of 20V/5A.

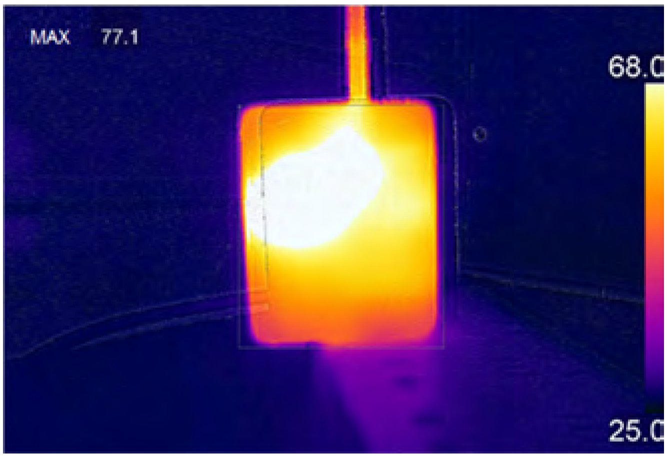

Figure 4: Thermal Performance at a Continuous 20V/5A Output

The HR1211's proprietary control scheme can also achieve superior light-load performance. As the load decreases, the solution gradually changes its PFC operation from CCM to DCM with a reduced switching frequency. LLC control implements skip mode and burst mode to reduce the equivalent switching frequency of the LLC converter under light loads, which then reduces the switching loss.

Figure 5 shows the efficiency from a 10% load to a full load at one of the USB Type-C outputs when the output voltage is 20V. A PFC + LLC combo can achieve average efficiencies at 88.3% and 89% for high lines and low lines, respectively, which easily meets worldwide efficiency regulations.

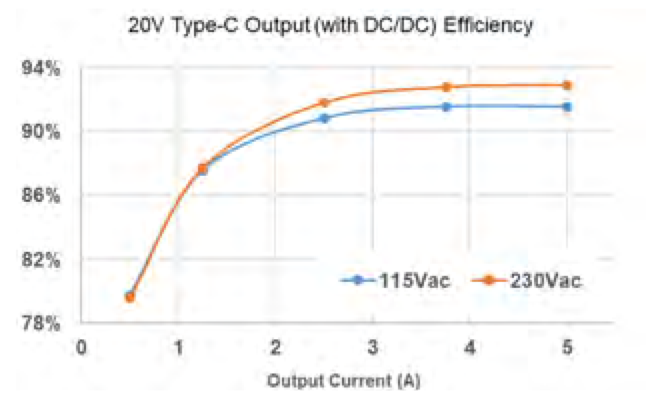

Figure 5: USB Type-C Output Efficiency

An additional benefit of this solution is the design flexibility achieved through digital implementation. Although the external circuits are quite simple, the HR1211 has rich programmability due to the chip's digital core and the multiple-time programmable (MTP) memory. All of the key parameters, switching characteristics, regulation and production levels, and transition thresholds are among the different operation modes that can be programmed through a UART-based communication interface and a graphic user interface (GUI).

Figure 6: HR1211 GUI

With this digital flexibility, any kind of performance, such as efficiency, ripple, noise, protection behaviors, can be easily optimized for a given design (see Figure 6). This is particularly important for a fast-evolving market like that of high-power fast-charge adapters. Whenever there is demand on the market of a new power specification, form factor, or performance regulation, PFC + LLC combo controllers can quickly adapt.

Fast-charge adapters are constantly evolving, and the market is seeing in influx in demands for high-power adapters exceeding 100W, as well as new adapter models with multiple USB PD ports. Digital PFC + LLC controller solutions like the HR1211 are vital to meeting this demand. Their excellent efficiency, performance, power density, and flexibility will help the adapter market enter a new age.

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Bipolar, Bidirectional DC-to-DC Supply Sources and Sinks Current from 5 V to 24 V Input

Most electronic systems depend on power voltage rails that are either positive or negative, but a few applications require individual rails that can be both. In these situations, positive or negative power is supplied by the same terminal - that is, the output voltage of the supply can be adjusted through its entire voltage range, smoothly transitioning across polarity.

By Victor Khasiev, Senior Applications Engineer, Analog Devices

For instance, some automotive and audio applications require, in addition to traditional voltage sources, power supplies that can function as a load and sinking current from the output terminals. Regenerative braking in automotive systems is one example. Single terminal, bipolar power supplies are documented, but solutions that can operate during input voltage drops, such as cold crank conditions, while continuing to provide bidirectional functionality are not. This article presents a solution immune to input voltage changes while generating power and enabling reverse current flow, that is, from output to input.

Bipolar, Bidirectional Power Supply Circuit

Figure 1 shows a 2-stage power supply, which centers around a 4-quadrant controller (stage 2), U1. This 4-quadrant converter is fed by an intermediate bus converter, VINTER (stage 1), supplying an output voltage in a min-max range of 12 V to 24 V, nominally 12 V to 16 V, matching the nominal voltage range of the standard automotive battery rail. The output of the complete 2-stage converter is ±10 V delivering a 3 A current to the load. The output voltage is controlled by the voltage source CONTROL signal at the CTRL pin of controller U1.

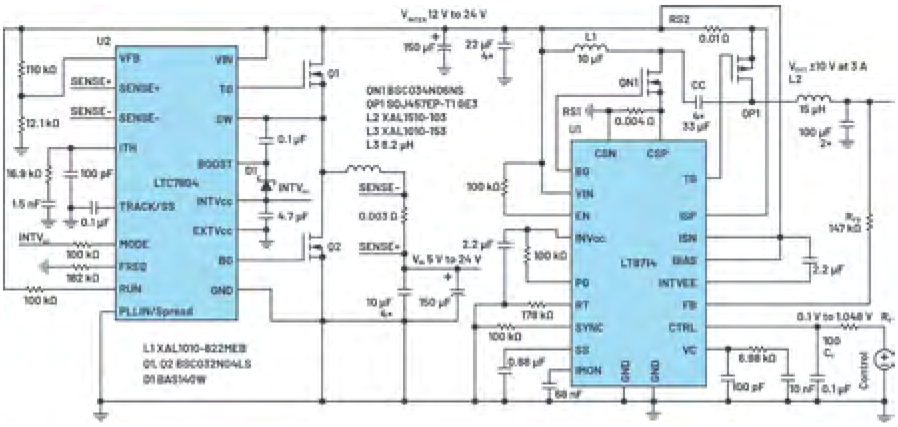


Figure 1: Electrical schematic of bipolar, bidirectional, 2-terminal power supply: V_{IN} = 5 V to 24 V, V_{OUT} = ±10 V at 3 A.

The low-pass filter CF, RF alleviates sharp changes in control voltage. The power train includes two MOSFETs, N-channel QN1, and P-channel QP1; two discrete inductors, L1 and L2; and an output filter. The choice of two discrete inductors instead of a single coupled inductor extends the range of suitable magnetics and allows the use of previously approved and tested chokes. The output filter is composed exclusively of ceramic capacitors because of the dual polarity nature of the output.

The input voltage range of the full 2-stage converter is 5 V to 24 V, to cover cold cranking voltage drops in automotive electronics and brownouts in industrial applications. The boost converter (stage 1), based on controller U2, maintains the voltage of the intermediate bus at or above 12 V whenever the converter is enabled. The power train of the boost converter includes inductor L3 and MOSFETs Q1 and Q2. The 2-stage arrangement allows normal operation of the downstream 4-quadrant converter to deliver ±10 V to the load at all operational conditions.

How It Works when the Bipolar Supply Sources Current

The oscillogram in Figure 2 shows the circuit of Figure 1 in action. When an input voltage is applied at VIN, the boost converter regulates its output, V_{INTER}, to 12 V if the input falls below this level. If V_{IN} exceeds the 12 V typical for a nominal 12 V automotive rail, then the boost converter enters Pass-ThruTM mode or wire mode. In this mode, the top MOSFET Q1 is enhanced at 100% duty cycle, always on operation, so no switching occurs—the voltage, V_{INTER}, applied to a 4-quadrant converter remains relatively stable at a level equal to V_{IN}.

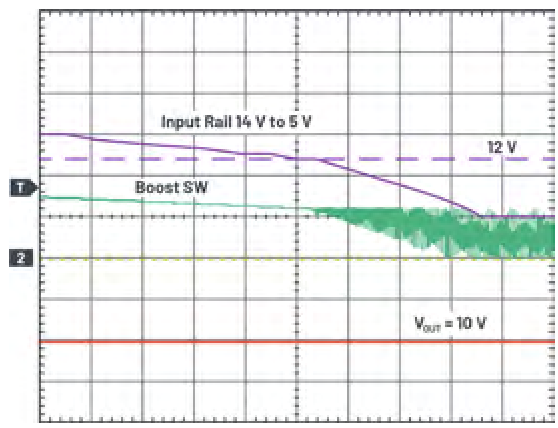


Figure 2: Waveforms showing V_{IN} dropping from 14 V to 5 V. V_{IN} = 5 V/div, V_{OUT} = 5 V/div, boost SW = 10 V/div, and the time scale is 200 µs/div.

This approach greatly increases system efficiency over a typical 2-stage device (namely, a boost converter followed by buck/inverting). This is because efficiency in Pass-Thru mode, where the system will spend most of its time, can be near 100%, essentially turning the power system into a single-stage converter. If the input voltage drops below the 12 V level - for example, during a cold cranking event - then the boost converter resumes switching to regulate V_{INTER} to 12 V. This approach allows the 4-quadrant converter to deliver ±10 V, even when facing sharp drops of the input voltage.

When the control voltage is at its maximum—in this case, 1.048 V—the converter output is +10 V. If the control voltage is at its minimum (100 mV), the converter output is –10 V. Control voltage vs. output voltage is shown in Figure 3, where the control voltage is a 60 Hz sinusoidal signal frequency with a peak-to-peak amplitude of 0.9048 V. The resulting converter output is a correspondingly 60 Hz sine wave with a peak-to-peak amplitude of 20 V. The output smoothly changes from –10 V to +10 V.

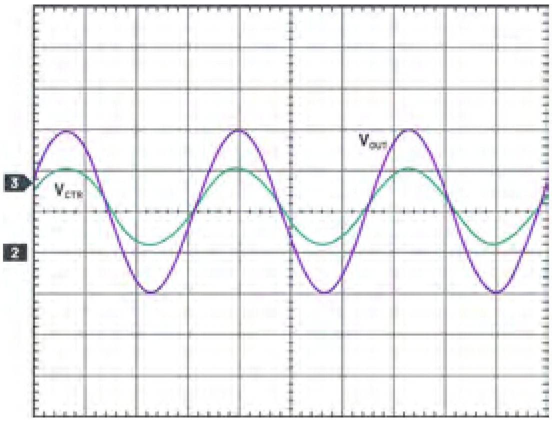


Figure 3: Waveforms of sine wave output as function of the sine control signal. V_{CTRL}= 0.5 V/div, V_{OUT} = 5 V/div, and the time scale is 5 ms/div.

In this mode of operation, the 4-quadrant converter regulates the output voltage. The output voltage is sensed by U1 through the resistor R_{FB} at its FB pin. The voltage at that pin is compared to the control voltage, and from that comparison, the converter's duty cycle—that is, the gate signal on QN1—is adjusted to keep the output voltage in regulation. If V_{INTER}, CONTROL, or V_{OUT} changes, the duty cycle is modulated to regulate the output accordingly. MOSFET QP1 switches in sync with QN1 for synchronous rectification to further maximize efficiency, as shown in Figure 4.

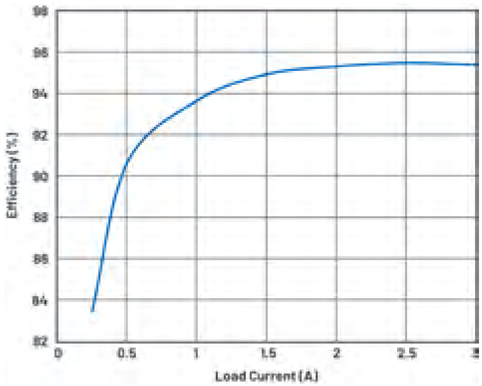


Figure 4: Efficiency vs. load current.

How It Works when the Bipolar Supply Becomes the Load: It Sinks Current

This 2-stage regulator can operate as a current source or a current sink. In current sink mode, current and power flow in reverse from the output, V_{OUT}, to the input, V_{IN}. This is important for automotive electronics and some audio systems. For the purposes of settling on verbiage when describing this mode, V_{OUT} will now be referred to as the input and V_{IN} will now be referred to as the output. Furthermore, this article only considers applications where V_{INTER} bus voltage is equal to or greater than the minimum 12 V.

During reverse current flow, the 4-quadrant converter regulates output current that passes from V_{OUT} to V_{IN}; the converter does not regulate voltage in this mode. The 4-quadrant controller senses output current as the voltage drop across the sense resistor, RS2 in Figure 1, and regulates its duty cycle to keep this voltage drop at a set value, 50 mV, for this solution.

As a 4-quadrant converter generates voltage on the V_{INTER} bus that exceeds the specified minimum, the boost converter enters Pass-Thru mode with top MOSFET Q1 always on and delivers the preset value of the output current to V_{IN} (load) terminals with the smallest losses possible.

This mode of operation was benchtop verified and tested. To do so, the V_{OUT} of the circuit in Figure 1 was connected to a lab power supply set to 12.5 V and the V_{IN} to an electronic load, with the current through the converter set to 4.5 A. The thermal image of the 4-quadrant converter is shown in Figure 5.

Figure 5: Thermal image of the 4-quadrant converter power train in load (reverse current) mode. A 4.5 A current flows from V_{OUT} terminals to V_{IN} from a 12.5 V source at V_{OUT}.

Figure 6 shows a photo of the converter itself, composed of two demo circuits from ADI soldered together: namely an off-the-shelf DC2846A boost converter demonstration circuit and the DC2240A 4-quadrant converter demo circuit.

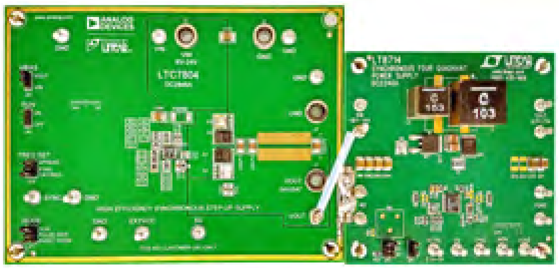


Figure 6: Photo of the test fixture produced by soldering together two off-the-shelf demo boards from ADI. On the left, LTC7804 (DC2846A). On the right, LT8714 (DC2240A).

Component Selection and Power Train Calculations

The two controllers selected for this application were chosen for high performance, efficiency, and ease of use in their relatively specialized functions. The Power by Linear™ LT8714 is an easy to use 4-quadrant controller, featuring high efficiency synchronous rectification. The LTC7804 synchronous boost converter includes an internal charge pump, providing an efficient, switching free, Pass-Thru, 100% duty cycle mode of operation.

Power Train Calculations	
$V_{INTER} = 1.2 \times \lvert V_{OUT} \rvert$	Set minimum V_{INTER} value
$D_{4Q} = \frac{V_{INTER} + V_{OUT}}{2 \times V_{INTER} + V_{OUT}}$	4-quadrant duty cycle
$I_{AVG} = I_{OUT} \times \frac{D_{4Q}}{\eta \times (1 - D_{4Q})}$	Average L1 current η = efficiency
$I_{L1} = I_{AVG} + \frac{\Delta I}{2}$	Peak current in L1
$I_{L2} = I_{OUT} + \frac{\Delta I}{2}$	Peak current in L1
$V_Q = 2 \times V_{INTER} + V_{OUT}$	QN1 and QP1 voltage stress

Table 1. 4-Quadrant Converter Power Train Calculations

What follows is a formulaic analysis of stresses on the power train component and preliminary components selection. For deeper understanding and details of functionality, please refer to the LTspice® models for these devices.

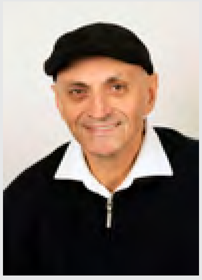
Control Circuit Calculations	
$V_{CTRN} = 0.1\ \text{V}$	Control voltage for minimum negative V_{OUT}
$R_{FB} = \dfrac{[7.25\ \text{k}\Omega \times (-V_{OUT} - V_{CTRN})]}{(V_{CTRN} - 0.6065\ \text{V})}$	Set feedback resistor R_{FB}; select nearest standard value of R_{FB}
$V_{CTRP} = \dfrac{+V_{OUT} + 83.7\ \mu\text{A} \times R_{FB}}{1 + \dfrac{R_{FB}}{7.25\ \text{k}\Omega}}$	Control voltage for maximum positive V_{OUT}

Table 2. 4-Quadrant Converter Control Circuit Calculations

$D_{BOOST} = \dfrac{V_{INTER} - V_{IN}}{V_{INTER}}$	Boost duty cycle, for $V_{IN} < V_{INTER}$

*Table 3. Boost Converter Calculations**
**Q1, Q2 voltage stress is defined by the maximum value V_{INTER} or V_{IN}.*

About the Author



Victor Khasiev is a senior applications engineer at ADI with extensive experience in power electronics both in ac-to-dc and dc-to-dc conversion. He holds two patents and has written multiple articles. These articles relate to the use of ADI semiconductors in automotive and industrial applications. They cover step-up, step-down, SEPIC, positive-to-negative, negative-to-negative, flyback, forward converters, and bidirectional backup supplies. His patents include efficient power factor correction solutions and advanced gate drivers. Victor enjoys supporting ADI customers: answering questions about ADI products, design and verification of power supply schematics, layout of the print circuit boards, troubleshooting, and participating in testing final systems.

Numerical Example

Here is a numerical example, using the previous formulas applied to a converter generating ±10 V at 3 A, 200 kHz switching frequency, and 90% efficiency:
$V_{INTER} = 12$ V
$D_{4Q} = 0.647$ V

Based on the max current limit vs. the duty cycle plot in the LT8714 data sheet,
$V_{CSP} = 57$ mV for given D_{4Q}.
$R_{S1} = 0.63 \times V_{CSP}/I_{OUT} \times (1 - D_{4Q}) = 0.004\ \Omega$
$R_{S2} = (50\ \text{mV}/1.5) \times I_{OUT} = 0.01\ \Omega$
L1 is selected as 10 µH and L2 as 15 µH
$I_{L1} = 6.1$ A; $I_{L2} = 4.3$ A
$V_Q = 58$ V (at maximum V_{IN} of 24 V)
$V_{CTRN} = 0.1$ V
$V_{CTRP} = 1.048$ V
$R_{FB} = 147$ kΩ
Q1, Q2 voltage stress is 24 V

Conclusion

The converter presented in this article is a high performance solution for a bipolar, bidirectional power supply. A few specific features contribute to the performance of the overall solution: synchronous rectification yields high efficiency, and the simple, dedicated control scheme makes for an easy interface to any type of host processor and external control circuitry. This particular solution solves the problem of unstable input voltages, including fast transients, and guarantees stable output voltage in all operating conditions. The devices chosen for the solution maximize efficiency and ease of design. The LT8714, for instance, enables easy design of bipolar, bidirectional power supplies. The LTC7804 enables near-100% efficiency operation as an intermediate supply in automotive and industrial environments.

www.analog.com

Power Supply Cuts Costs for Your Business

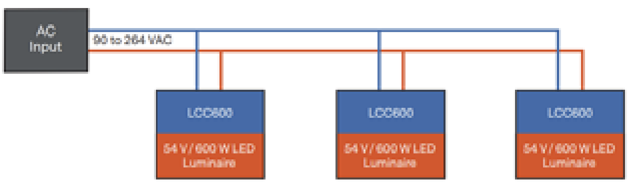
The Artesyn iHP series of power systems has, since its release in 2017, been well renowned for providing accuracy, resolution and stability as either a programmable voltage or current source in both medical and industrial settings. Artesyn's parent company Advanced Energy, in a recent study, certified these business gains by observing their product's effects on operating expenses and capital expenditure in the horticultural sector and their findings are telling of how the iHP Series can improve the bottom line for your business.

By Emma Claridge, Components Bureau

The Study

The Artesyn line of products from Advanced Energy were designed specifically for driving high-power horticultural lighting fixtures and the name of the game here is minimising power consumption whilst maximising performance to keep systems powerful and efficient. The difficulties for horticultural lighting stems from how crucial the control of light sources in ensuring high yields for farms. In the past, artificial lighting would require individual control systems for each luminaire as each power supply would need to precisely control the current to ensure the light is emitted at the correct wavelength to stimulate growth. The installation costs and cooling expenses would drive capital and operating expenditure through the roof!

In conventional power distributions, the heat generated by both the driver/power supply and the luminaire would need to be taken into account for cooling calculations, driving down that bottom line:



The iHP power supplies position themselves as a central current source to drive an array of LED luminaires. Using a large centralized current source outside growth areas and distributing power directly to all the luminaires leads to massive CAPEX savings as it eliminates the "doubling up" of power infrastructure. OPEX gains can also be had, as the current source can be placed outside of the environment-control area, allowing heat conversation to be controlled independently from the plants' temperature control.

The ability of the iHP to supply higher voltages than individual control systems allows for reductions in installation costs with less insulation needed for wires, reducing wire size and cooling needs.

Artesyn observed the effects of their products in the US horticulture market, and the centralized power delivery model and found that using the iHP Series in LED grow light farms yielded a saving of $110k per year. This shows that the total CAPEX of these farms was recovered within three years of operation – this isn't just the difference between the costs, but the entire power CAPEX for the whole system.

According to the manufacturer, utilising AE's system allows end users to reduce their power conversion costs by as much as 50 percent, significantly lower installation and operating costs and increase the quality of crop yield.

In a statement released in December 2020, Joe Voyles, VP for Industrial Marketing at Advance Energy spoke of the iHP revolutionary gains for the horticulture industry: "We are transforming our customers' operations by both reducing the amount of needed equipment and improving the efficiency of the lighting systems, thereby reducing cost and energy spend. Not only do these innovative new products increase the efficiency and quality of fruit and vegetable production, but they also open the door to establishing indoor farming facilities in harsh environments anywhere in the world."

The Product

The iHP is a highly configurable and intelligent high power system designed specifically for unrivalled control and accuracy in both medical and industrial applications. Providing up to 24 kW in 3 kW increments, the iHP provides both the resolution and the high-power output needed for your critical application. With up to eight outputs, this power supply is perfect as a central node in any power delivery system and the ability to control the system both through analogue and digital methods affords engineers easy access for configuration.

Figure 2: Digital control affords greater levels of scalability, as multiple iHP systems can be controlled simultaneously as routines and power variations can be synced or altered from one cloud-based access point.

Using Artesyn's high level PowerPro configurable GUI, end users can seamlessly control and monitor all functions, including input and output variations, monitor system temperature and set time routines using a graphic script creation engine.

Using an iHP system as a centralised power supply allows for simpler installation and makes servicing and repair much easier. The outputs can be configured as voltage or current sources and customised to the application's requirements. Outside of LED growth lighting, the iHP is perfect for medical settings, like pharmaceutical production where the programmable nature of the iHP allows for great precision to ensure safety and efficiency. Safety approvals secured by Advanced Energy eliminate the need for an isolation transformer in medical equipment. The power rack house EMC filtering and digital front-end power factor correction circuits – allowing system designers to maintain the level of reactive power consumption and decrease the likelihood of power instability and equipment failure.

The modular design for output modules allows application specific modular development. Precision modules in development help provide low noise output for critical laboratory equipment.

For use with semiconductor processing equipment, AE have developed this product to meet the SEMI F47 standard, whereas the compact size and multi-rack paralleling capabilities makes the iHP perfect for large Megawatt installations for chemical processing or high-powered laser applications.

Billing itself as the heavyweight backbone to a highly configurable and efficient power delivery system, the iHP's modular flexibility accelerates the speed of design cycles, shortens development time and allows for greater scalability, qualities that make it perfect for system designers as their next central PSU.

www.componentsbureau.com/artesyn-ihp

SiC Intelligent Power Modules Platform Expanded

CISSOID is adding to its growing platform of 3-Phase Silicon Carbide (SiC) MOSFET Intelligent Power Module (IPM) products by introducing liquid-cooled modules for E-mobility tailored for lower switching losses or for higher power. The company is also introducing a module based on a lightweight AlSiC flat baseplate that meets the demand for natural convection or forced cooling in aerospace and in dedicated industrial applications. These products integrate a 3-Phase SiC MOSFET module with a powerful gate driver. Two liquid-cooled power modules based on a pin fin baseplate are rated for 1200V blocking voltages and for 340A to 550A Maximum Continuous Currents. The On Resistance ranges from 2.53mOhms to 4.19mOhms depending on current rating. The total switching energies are as low as 7.48mJ (Eon) and 7.39mJ (Eoff) at 600V/300A. The co-design of the power module and the gate driver enables optimizing the IPMs for lowest switching energies by carefully tuning dV/dt and controlling voltage overshoots inherent to fast switching. The new air cooled module is designed for applications where liquid cooling is not an option, like aerospace electromechanical

actuators and power converters, for example. This module is rated for a blocking voltage of 1200V and a Maximum Continuous Current of 340A. The On resistance is equal to 3.25mOms. Turn-on and turn-off switching energies are respectively 8.42mJ and 7.05mJ at 600V and 300A. The power module is cooled down through an AlSiC flat baseplate.

www.cissoid.com

Expanded Lineup of Shunt Resistors

ROHM developed the GMR320 series of shunt resistors featuring a rated power of 10W. GMR320 series is the largest rated power product in ROHM high-power low-ohmic GMR series lineup designed for high power applications in the automotive, industrial equipment, and home appliances.

Recent years have seen an increasing of requirement in the automotive and industrial fields for lower power consumption in higher power applications. This in turn requires shunt resistors that support high power and high accuracy current detection to achieve high efficiency operation in a variety of applications. ROHM's GMR and PSR series shunt resistors provide highly accurate current detection even at high power, making them ideal for high power applications in the automotive, industrial and consumer sectors. The GMR320 series is offered in a resistance value range from 5mΩ to 100mΩ and a rated power of 10W, making them ideal for automotive engine ECUs and headlamps as well as motors and power supplies for industrial equipment and home appliances. Unique structure and optimized materials allow the GMR320 series to reduce surface temperature rise by 23% over standard products, ensuring high ruggedness against overcurrent loads even though it has the smallest size among 10W class resistors in the market . In addition, a high performance metal alloy for the resistive material provides low Temperature Coefficient of Resistance (TCR), that makes it reliable and highly accurate current detection possible even in the low resistance values.

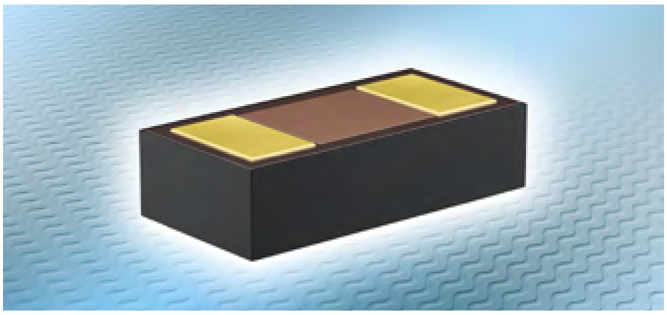
www.rohm.com

Small TVS Diodes for Effective ESD Protection

TDK Corporation has released tiny high-power TVS diodes for ESD protection, extending its portfolio of components for bi-directional overvoltage protection of I/O interfaces. The space requirement of the so-called chip scale package (CSP) is just 400 x 200 µm2 (CSP01005) or 600 x 300 µm2 (CSP0201), while the package height of just 100 µm is also very low.

The new TVS diode types are designed for an operating voltage of 5 V and a response voltage of 6.8 V. The clamping voltages of the components are 7.2 V at a peak pulse current of 8 A or 8 V at a peak pulse current of 16 A. The TVS diodes differ in their parasitic capacitances: Type SD0201SL-GP101 (ordering code B74121G0050M060) has a capacitance of 12 pF, while the SD01005SL-GP101 type (B74111G0050M060) has a capacitance value of just 5 pF. Other features include the short response time and low leakage current of just 2 nA at 3.3 V.

The protective components are designed in accordance with IEC 61000-4-2 for an ESD contact discharge of up to 24 kV, exceeding standard requirements. They can withstand a high surge current



load of up to 8 A according to IEC 61000-4-5 (8/20 µs), despite their low size.

The TVS diodes are suitable for various IoT, smart home, and Industry 4.0 applications. Due to their minimal dimensions, the new protective components are ideal for wearables, smartphones, notebooks, tablets, smartwatches or even hearing aids.

www.tdk-electronics.tdk.com

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DS20006490A. MEC2368A-ENG-02-21

Power Supply with Medical Certification

Mascot has further extended its Blueline portfolio of power supplies with the addition of the switch mode 3920 external PSU. The 3920 is medically certified in accordance with EN 60601-1 edition 3.1 (safety) and EN 60601-1-2 edition 4 (EMC) and has been designed to meet global power conversion requirements. Working with universal AC line voltages from 90V to 264V, the high-efficiency 3920 offers continuous output power up to 180W. Possible applications include medical computer systems, healthcare, laboratory and medical devices such as incubators, blood analysers, DNA equipment, ultrasound systems, diagnostics units and medication dispensers, and other applications such as communications systems and security devices. The 3920 range combines high quality and performance, with competitive pricing and compliance with the latest eco-design specifications (CoC Tier 2, DoE level VI, CEC, MEPS) adopted in the EU and North America. CE-marked and bearing global UL Certification, the range delivers a complete turnkey solution to product designers. It comes in four standard versions delivering fixed outputs of 12, 24, 36 and 48V. Other versions and customised units with special plugs and cords can be supplied on request. All units are fitted with short-circuit protection as standard.

www.mascot.no

Automated Microchip Testing

esmo group has rolled out upgrades and additional features for the talos 2021 system. First launched in 2019, the talos engineering handler is a reliable and easy-to-use handling system for semiconductor test applications, and is esmo's solution to the industry's need to cost-effectively test increasingly compact and complex devices within a shorter period of time. At the core of the talos engineer handler is its state-of-the-art active thermal control system (ATC), which allows manufacturers to carry out multiple test temperature cycles and achieve the highest temperature accuracy.

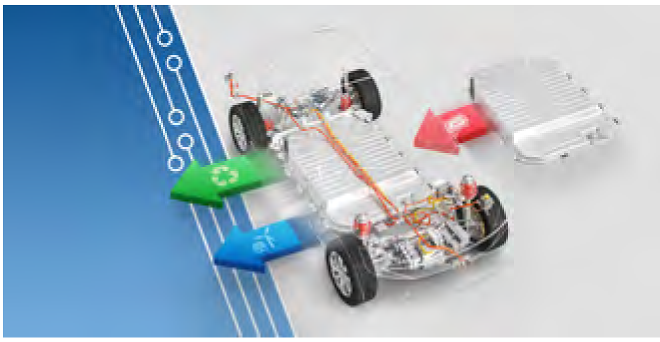
"Our talos engineering handler provides semiconductor companies with the most stringent quality control and assurance, ensuring products are tested to specification," shared Josef Weinberger, Business Unit Manager (semicon). "A highly flexible and cost-effective test system, the talos platform helps manufacturers achieve faster time-to-yield with higher overall equipment efficiency. Furthermore, its remote control and monitoring feature also allows customers to remotely manage and conduct device handling." The talos system supports the testing of devices with any site pitch dimension, which allows semiconductor companies to use already existing production load boards and sockets seamlessly. Its tray or tube loading and unloading feature also makes it possible for manufacturers to run the talos system in a mixed media operation. As such, loading trays, tubes, and tapes can be combined with their unloading counterparts, and devices can even be sorted from one media to another, such as from tube to tray.

www.esmo-group.com

Line of Regenerative Power Supplies and Electronic Loads

In response to demand driven by the rapidly expanding electrical vehicle market, EA Elektro-Automatik has developed a range of products for the entire spectrum of battery recycling – from battery testing/recharge to second life to final recycling. E-mobility is booming. But with increasing operating time, the lithium-ion batteries used become less effective and need to be replaced in the vehicle. The old batteries then begin a second life or are finally recycled and completely discharged.

EA offers a wide ranging product line for initial battery production, recharging, second life test and final recycling. Its bidirectional power supply EA-PSB 10000 and regenerative electronic load EA-ELR 10000 provide safe and sustainable preparation of discarded batteries – with 96% regeneration efficiency. If the storage capacity of the lithium-ion battery systems is no longer sufficient for use in e-vehicles, residual capacities may well be available for second-life use as energy storage for solar power or wind energy. With the EA-PSB 10000 bidirectional power supply, the batteries are tested for their remaining capacity by charging them to almost 100% and then discharging them again.



At 30kW in a 4U package, the EA-PSB 10000 bidirectional power supply offers the highest power density on the market. Up to 1.92 MW is possible in a rack system, which means that mass testing is also possible without any problems. In addition, EA-PSB 10000 can seamlessly switch between operation as source and sink, which offers additional time savings.

www.elektroautomatik.com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Linear Accuracy in the Basic Power Supply Class

Rohde & Schwarz continues to expand its range of basic power supplies with the R&S NGA100 series. The R&S NGA100 is available in four models, providing a choice of single and dual outputs with up to 35 V/6 A per output, or 100 V/2 A per output. Single output models supply up to 40 W, dual output models up to 80 W power. The dual model outputs can be combined to provide up to 200 V or 12 A. Rohde & Schwarz has implemented a linear design throughout the output circuits of the R&S NGA100 which significantly improves performance compared to the switched-mode circuits frequently found in basic power supplies. The resulting higher accuracy means engineers can be confident of supplying exactly the right power level without any need for an additional multimeter. The standard level of readback resolution, 1 mV/100 µA, is enhanced for currents under 200 mA to a resolution of 1 µA, ideal to test low current levels typical for IoT applications in standby and sleep mode. The R&S NGA100 also has the necessary dynamic range for power and current spikes when switched to active mode.

www.rohde-schwarz.com

Fuse Switch Disconnector for a Networked Future

Mersen presents a vertical NH fuse switch disconnector as an addition to the Multivert® series. The Multivert i-Xtensio offers even more user convenience and adaptability while retaining all functions of existing fuse switch disconnectors from Mersen. It is designed for an increased installation depth of 150mm, features a user-friendly mounting solution for current transformers on the back and is available in two sizes – size 2, 400A and size 3, 630A.

The product is suitable for power distribution in cable distribution cabinets, transformer substations and feeder pillars in commercial and industrial systems. The Multivert® i-Xtensio was designed to meet Mersen's exceptionally high safety standards: Current transformer covers on the sides achieve IP20 protection against electric shock to ensure maximum safety during installation and servicing. Cables can be connected via bolts, insert nuts or V-terminals. Safe switching under load in accordance with IEC 60947-3 is ensured.

With the Multivert® i-Xtensio, Mersen now has 2 available designs on the market of NH Fuse Switch Disconnectors: space-saving standard compact design and i-Xtensio design, which is compatible with all installations systems and enables the easy integration of current transformers.

The NH fuse switch disconnector is ideal for future IoT solutions, since it is fully compatible to Smart Modbus monitoring modules developed by Mersen, one of the world's leading manufacturers of innovative technical solutions.

www.ep-de.mersen.com

DC-DC Converter for Compact IT Equipment

ABB's MicroDLynx IITM DC-DC converters help meet the power needs of demanding, data-hungry applications, providing highly accurate voltage regulation in a compact, 232-mm2 footprint – with a power density of 167 A/in2. "When you look at the sheer computing power required in today's data-intensive applications – from cloud computing, artificial intelligence (AI) and 5G, to the Industrial Internet of Things (IIoT) and high-speed networking – every square millimeter of board space that can be utilized for processing power is precious," said Vesa Jokitulppo, senior product manager at ABB Power Conversion. The power modules provide the precision power required for equipment including high-speed switches and routers, AI processors, application-specific integrated circuits (ASICs), high-current field programmable gate array (FPGA) processors, and ARM-based processors – and it does so in a small footprint that frees up valuable space for additional computing capacity and functionality.

In addition to the MicroDLynx II DC-DC converters, ABB has announced a new version of its proven Digital Power Insight software tool. The Digital Power Insight software integrates with ABB's digital products – including AC-DC and DC-DC power supplies, digital bus converters, and point-of-load/voltage regulator modules – enabling communication between the power supplies and customer end-use equipment via a PMBus interface. This allows customers to easily select the right product for their application need and to test different options, digitally.

www.electrification.us.abb.com

Square Leaded DC-Link Capacitor Series

Rated for operation at up to 105°C ambient, UL 810 listed, compact size dc-link capacitor series CBB 138 DS from Jianghai covers the voltage range from 450 ~ 1200V while the capacitance comprises values from 1 ~ 120µF. The advanced, self-healing polypropylene

dielectric in conjunction with the in-house heavy edge metallization result in superior ripple current capability while being compact in size. The 2- and 4-pin PCB-mount types in a UL 94 V-0 recognized, square plastic encapsulation yield low serial inductance and best volumetric efficiency. This makes the capacitors an ideal choice for demanding industrial applications, e.g. frequency converters and power supplies. The design of the IEC 61071 compliant series can be adapted to provide customized solutions

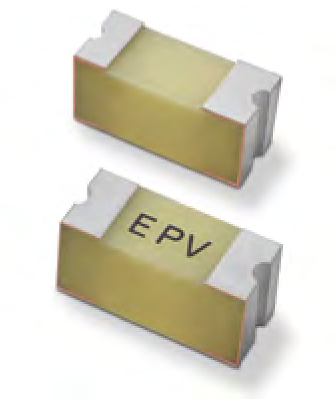
www.jianghai-europe.com

Photovoltaic Fuses Provide Rugged Circuit Protection

Littelfuse announced the 400PV Fuse series, a 2410 size, surface mount design (SMD) circuit protection component that offers low resistance for photovoltaic (PV) applications.

The 400PV is specifically designed to address the latest trend in solar roofing by enabling PV shingles that integrate both the shingles with the PV cells while incorporating protection that meets the UL 248-19 standard for PV applications. This new development helps eliminate mounting separate solar panels over the existing roofing, allowing the use of the new integrated PV shingles to serve in a dual function – as the protective roofing material while collecting electricity to power the building.

"The 400PV Fuse series innovation enables the next generation of smart home designs to utilize photovoltaic roof shingles to power up everything in a house that requires power," said Boris Golubovic, Vice President, Marketing and Strategy at Littelfuse. "The protection provided by these PV fuses help ensure the operational longevity, maintenance convenience, and safety of solar home and building applications."



www.littelfuse.com

High-current Inductor for POL Regulators

With improvements in its internal design, the latest model of WE-HCF-SMT high-current inductors from Würth Elektronik sets new standards in its class. WE-HCF in the 2010 design offers significantly better characteristics than previously available inductors in this size: inductance values up to 2 µH and saturation currents up to 25% higher than comparable products in the market. The magnetically shielded flat wire coil with MnZn core impresses with a low resistance of 0.84 mΩ and low core losses. The recommended 3-pin contacting ensures mechanical stability of the WE-HCF, which is designed for an operating temperature of -40 to +125 °C. Potential applications include POL regulators for FPGA, ASIC and GPU, high-efficiency DC/DC converters, high-current switching power supplies, forward converters, half-bridge and full-bridge converters, as well as battery chargers and solar inverters. WE-HCF 2010 is available immediately from stock with no minimum order quantity. Würth Elektronik will provide free samples to developers upon request.

www.we-online.com

AEC-Q101 Approved Trench Schottky Rectifiers

Nexperia extended its portfolio of Trench Schottky rectifiers with devices rated at up to 100 V and 20 A. The parts feature excellent switching behavior and leading thermal performance. They are available in Nexperia's Clip Bond FlatPower (CFP) packages which have a much smaller footprint than SMA/SMB/SMC components.

Trench technology results in low leakage and also greatly reduces the charge, Qrr, stored in the device. Therefore, Trench Schottky rectifiers deliver very fast switching, cutting both the switching losses of the rectifier and the losses that are induced in the MOSFET in the same commutation cell – a configuration that is commonly used in asynchronous switch-mode power converters. Nexperia's PMEGxxxTx devices additionally provide a wide safe operating area (SOA), delivering an extra safety margin and reducing the risk of thermal runaway compared to parts currently available. Jan Fischer, Nexperia's product manager comments: "Nexperia's Trench Schottky rectifiers combine low forward voltage and very low Qrr to enable best efficiency at high switching speeds as needed in switch-mode power converters. Automotive applications including LED lighting, in particular, will benefit from the wide SOA of our parts." Nexperia is investing in its portfolio of Trench Schottky rectifiers, now offering 32 devices from 40 V to 100 V and up to 15 A in volume production. A further 17 parts, including the 20 A types, are sampling.

www.nexperia.com

Software for Control and Tuning of ICs in BLDC Motor Drives

Power Integrations released its Motor-Expert software, an embedded "C" code application, library and control GUI that enables designers using the company's BridgeSwitch brushless DC (BLDC) motor driver ICs to precisely control and tune single-phase motors. BLDC motors are widely used in modern, high-efficiency appliances such as compressors, fans and water pumps in domestic appliances, and for ceiling fans and room air conditioning systems. The Motor-Expert software features accurate speed and current control loop functions. The modularity and flexibility of the API-based software architecture enables new use cases and functions to be added and allows users to port the software to their favorite microcontroller or combine with other code in a system CPU. The software meets static (MISRA) and dynamic performance profiling covering latency, jitter and execution time. It requires only 14 kB code memory and 5 kB SRAM, suiting it to microcontrollers with small memory capabilities. The BridgeSwitch motor drive IC can pair with 3 V and 5 V MCUs and removes the need for an external shunt resistor. The BridgeSwitch integrated half-bridge IC family dramatically simplifies the development and production of high-voltage, inverter-driven single- or multi-phase PM and BLDC motor drives. The superior efficiency and distributed thermal footprint architecture of BridgeSwitch motor drives eliminates the need for

a heatsink, reducing system cost and weight. Built-in hardware motor overcurrent protection enhances safety and reliability, and simplifies IEC 60335-01 and IEC 60730-01 certification, significantly reducing time-to-market.

www.power.com

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