ISSN: 1863-5598

ZKZ 64717
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# Bodo´s Power Systems®

Electronics in Motion and Conversion

July 2019

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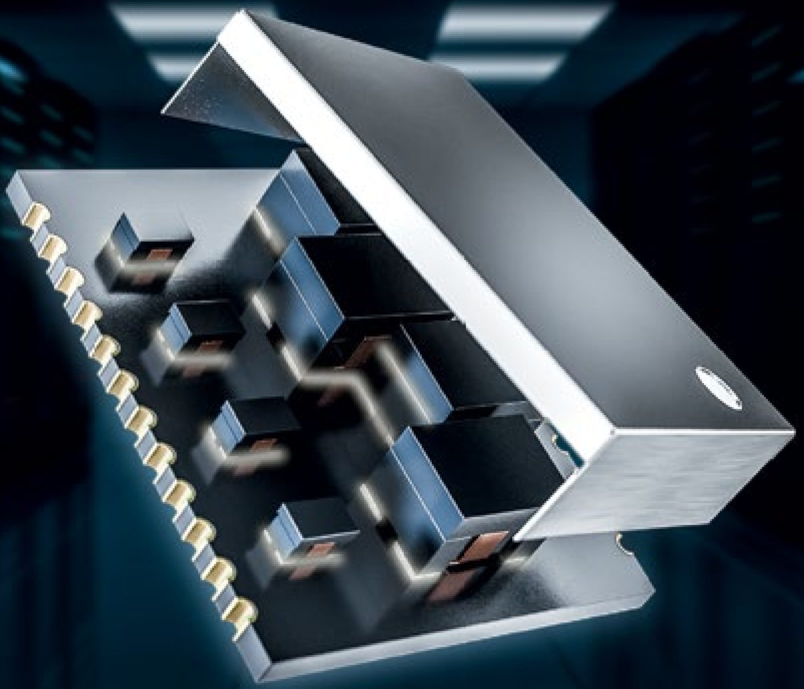
## CONTENT

# The Gallery



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

**Printing by:**
Brühlsche Universitätsdruckerei GmbH
& Co KG; 35396 Gießen, Germany

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# Let's Keep Trade Free!

I'm sure many of you are enjoying, or about to enjoy, a well-earned holiday season – I'm wishing everyone the rest they need to be ready for the remainder of the year! For me, the beautiful country of Denmark has always been a good holiday destination. When away, I remember very well how it was to call home - stuffing dozens of coins into the phone box and experiencing a really bad connection. Today, helped by the abolition of roaming charges in most European countries, phone calls are easy. We are always close to our families and friends through various channels. It is nice to see that even members of the older generation have quickly learned to enjoy frequent communication.

Working at Bodo's means one thing above all else: communication with people and companies from all over the planet! Our customers can be found from Russia to India, from Japan to Canada, everywhere in Europe, in China and the US. I am worried by the threats to free international trade in the news these days. Surely the benefits of global trade and cooperation in research and development should be available to everyone. The world has become so small as a result of technological advances that no one can afford to be marginalized - all should benefit.

We are very happy every month to give talented and established authors the opportunity to present their information globally. Their latest results are made available to a broad audience. And we attach great importance to imparting basic knowledge to young engineers. In this issue, the renowned expert Dr.-Ing. Artur Seibt, from Vienna, takes on this task once again and describes relationships between component size and thermal management, and some of the associated practical issues. Our readers can benefit from his extensive experience. The ubiquitous hot topic of Wide Band Gap Transistors is included - certainly worth reading, though it will take some time.

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. They publish our content exclusively on 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:**
Have you ever thought about changing the way you travel to work? Could an e-bike be an option? I've been using mine for two months now and it has turned out to be one of the best decisions in a long time!

Best Regards

Holger Moscheik

## Events

**IPFA 2019**
Hangzhou, China, July 2-5
www.ipfa-ieee.org

**SEMICON West 2019**
San Francisco, CA, USA, July 9-11
www.semiconwest.org

**Thermal Management 2019**
Denver, CO, USA, August 7-8
www.thermalconference.com

**GBF ASIA 2019**
Guangzhou, China, August 16-18
www.battery-expo.com

**EPE ECCE 2019**
Genova, Italy, September 2-5
www.epe2019.com

**SPS Middle East 2019**
Dubai, UAE, September 3-4
www.spsautomationme.com

**EU PVSEC 2019**
Marseille, France, September 9-13
www.photovoltaic-conference.com

**EV Tech Expo 2019**
Novi, MI, USA, September 10-12
evtechexpo.com

**PCNS 2019**
Bucharest, Romania, September 10-13
www.passive-components.eu/pcns

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# Inducted into the ISPSD Hall of Fame 2019

Efficient Power Conversion (EPC) Corporation proudly announces that Dr. Alex Lidow, CEO and co-founder, is inducted into the ISPSD Hall of Fame 2019. This prestigious honor is bestowed upon an honored contributor to advancing power semiconductor technology and sustaining the success of ISPSD. This Hall of Fame award was announced on May 20th, 2019 at 31st IEEE International Symposium on Power Semiconductor Devices and ICs (ISPSD) 2019 at the Marriott Parkview Hotel, Shanghai, China. On thanking the ISPSD committee regarding his induction, Dr. Lidow said, “This is a great honor. I share this honor with Tom Herman, with whom I undertook the foundational work on the power MOSFET, and with my co-founders at EPC, Joe Cao and Bob Beach, who had the courage to join me on our mission to develop gallium nitride power devices to crush silicon. I look forward to continue working with our customers who are innovating new designs with GaN.” Dr. John Shen, advisory committee chair said, “We are very pleased to have Alex inducted into the Hall of Fame this year. Contributions to our semiconductor industry have been most important in furthering our betterment of the whole world, as well as changing the way we live. We will continue to achieve further contributions, only through our inductees’ unremitting efforts in innovating and contributing to power semiconductor technology, which is indispensable in our daily lives.”

**www.epc-co.com**

# Strengthening and Accelerating its Path of Growth

Infineon Technologies and Cypress Semiconductor Corporation announced that the companies have signed a definitive agreement under which Infineon will acquire Cypress for US$23.85 per share in cash, corresponding to an enterprise value of €9.0 billion. Reinhard Ploss, CEO of Infineon, said: “The planned acquisition of Cypress is a landmark step in Infineon’s strategic development. We will strengthen and accelerate our profitable growth and put our business on a broader basis. With this transaction, we will be able to offer our customers the most comprehensive portfolio for linking the real with the digital world. This will open up additional growth potential in the automotive, industrial and Internet of Things sectors. This transaction also makes our business model even more resilient.”

Hassane El-Khoury, President and CEO of Cypress, said: “The Cypress team is excited to join forces with Infineon to capitalize on the multi-billion dollar opportunities from the massive rise in connectivity and computing requirements of the next technology waves. This announcement is not only a testament to the strength of our team in delivering industry-leading solutions worldwide, but also to what can be realized from uniting our two great companies. Jointly, we will enable more secure, seamless connections, and provide more complete hardware and software sets to strengthen our customers’ products and technologies in their end markets.”

Infineon + CYPRESS
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Strengthening the link between
the real and the digital world

**www.infineon.com**

# New Brand Identity

LEM is proud to announce the launch of its new group brand identity. The changes come at an exciting time in LEM’s evolution and coincide with new prospects for the business. “Today is the starting point of a refreshed LEM. Given the changes in our markets, the time is right to improve the visibility of LEM with all of our stakeholders” commented Frank Rehfeld, Chief Executive Officer at LEM. The new group brand identity aims to improve LEM’s visibility and clearly define the LEM story for customers, suppliers, associates and employees. The logo has been refreshed and includes a tag line which reflects LEM’s “Life, Energy, Motion” strapline.

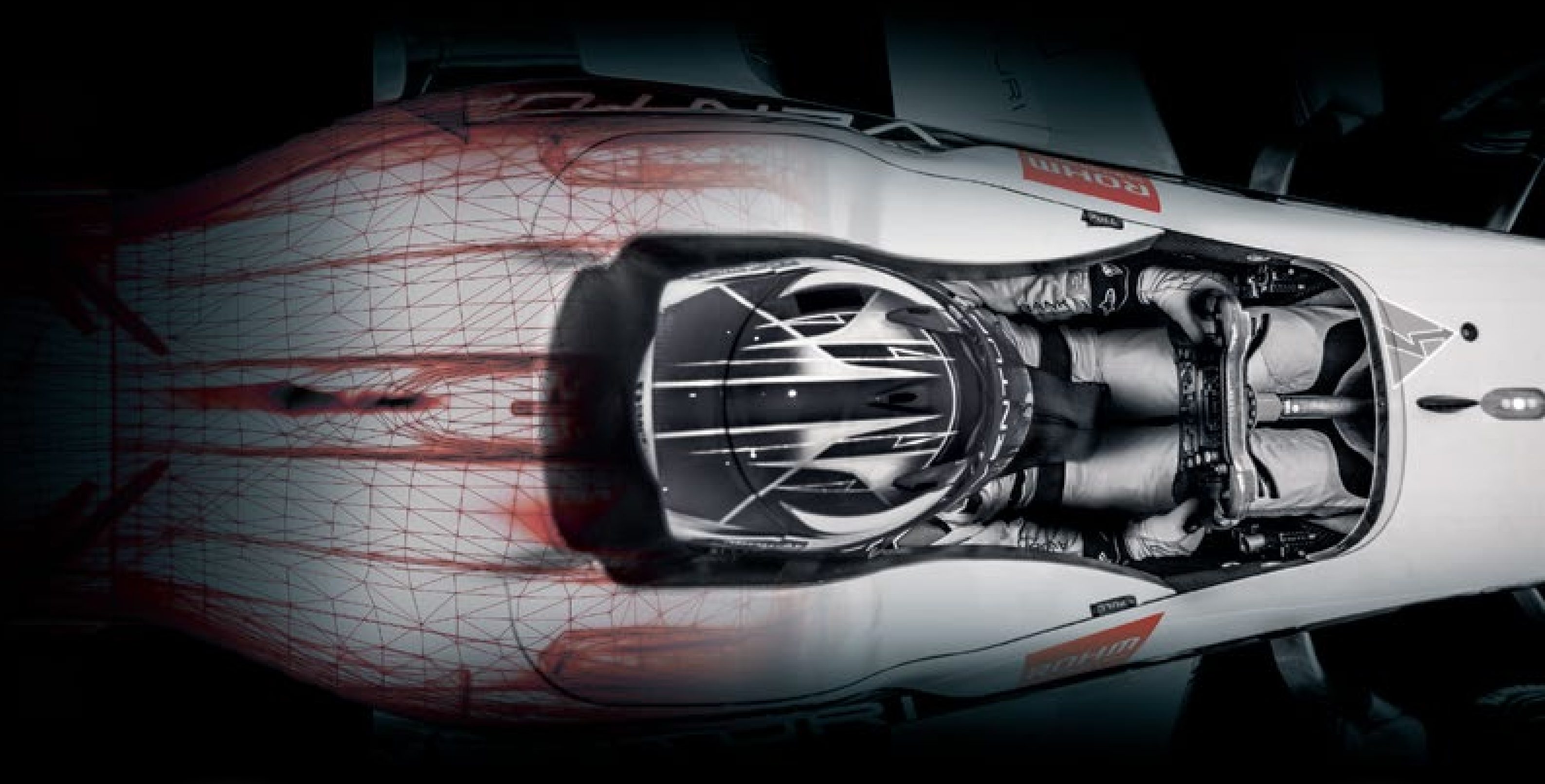
Life: How many of us desire life unplugged? Even brief downtimes can be quite unsettling. We love the ease, convenience, colour, brightness, speed, mobility, on-command, real-time connectedness that electricity provides.

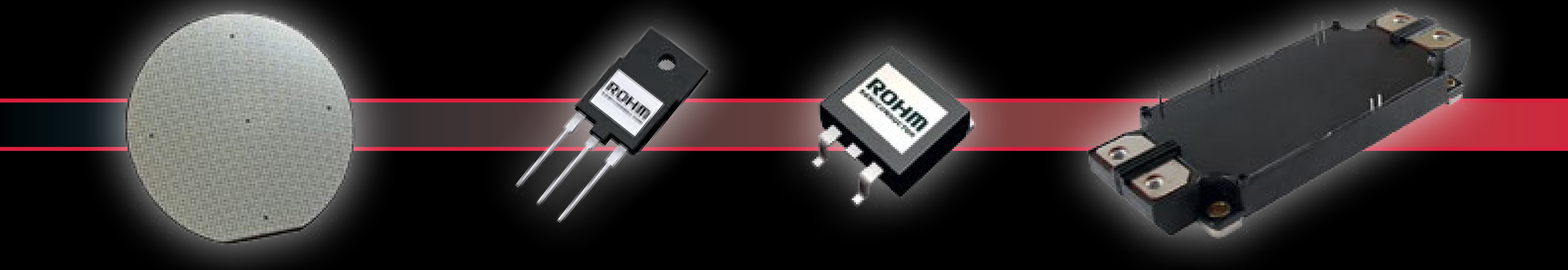
Energy: Smart grids, microturbines, wind and solar power all provide affordable and clean energy which is critical for a sustainable future. LEM is addressing this challenge by developing sensors that meet the most demanding standards of accuracy and safety, whilst adapting to higher power densities in battery and charging systems.

Motion: Train, trams, buses, conventional cars, green cars, elevators. The world’s demand for electrical motion is ever increasing. LEM provides sensor solutions for mobility applications which can play a remote or close role in our everyday lives.

LEM
Life Energy Motion

**www.lem.com**





# Proton-Electrotex at PCIM Europe 2019

To stay relevant on the modern fast-paced market, it is essential for every company to monitor the latest trends and offer its customers competitive products and technologies. To achieve it, we participate in the most significant global events. This time Proton-Electrotex took part in the main annual event of the power electronics industry – PCIM Europe 2019. Year after year this event remains a great opportunity to get in touch with technicians, designers, partners and buyers operating in the electronics industry. In 2019 PCIM Europe once again surpassed the market's high expectations. Proton-Electrotex takes part in this event for 20 years and traditionally presents its latest research and new products there. Besides, we showcase samples of existing portfolio already known to our customers. This time Proton-Electrotex has presented single-component diode and thyristor modules with a 50-mm wide baseplate (type B0). The Lead Research Engineer of Proton-Electrotex D. Malyy successfully presented his research "Fast Switching yet Cost Effective: Ultra-Fast IGBT Modules Compete SiC in High-Frequency Applications", while the New Technology Engineer D. Titushkin held a poster session "High Voltage Thyristors with Self-protection Elements in Cases Beyond Safe Operation Mode".

**www.proton-electrotex.com**

# European Research Project Launches in Dresden

The European cooperation project Power2Power has started. Over the coming three years, 43 partners from eight countries will research and develop innovative power semiconductors with more power density and energy efficiency. Power semiconductors are needed in all stages of energy conversion: generation, transmission, and use. More efficient semiconductors make a major contribution towards reducing carbon dioxide emissions in spite of the world's growing energy needs. Universities, research institutes, small and medium-sized companies and international corporations are involved in this cooperation. Infineon Technologies Dresden GmbH & Co. KG is coordinating this project. "Collaboration across different levels of the supply chain is a basis for the success of the European microelectronics industry," said Dr. Reinhard Ploss, CEO of Infineon Technologies AG. "We are also pursuing this approach in the Power2Power cooperation project. In collaboration with our partners, we will be working on new power semiconductors and system architectures with higher energy efficiency. Our goal is: more power from less energy."

The volume of the Power2Power project will be approximately €74 million. Two thirds of this will be allotted to the German partners. The European Union is funding the cooperation within the scope of the ECSEL (Electronic Components and Systems for European Leadership) program. Funding from Germany will be provided by the Federal Ministry of Education and Research and from the two states of Saxony and Thuringia. The partners from the other seven countries are also being sponsored by their national authorities.

**www.infineon.com/power2power**

# Honoring Distribution Partners in Europe

TDK Europe has once again honored its best distribution partners for TDK and EPCOS components. The TDK European Distribution Award 2018 was presented in the three categories of high-service distribution, international volume distribution and local distribution. The gold award went to Digi-Key Electronics, Avnet Abacus and to the Polish distributor Elhurt Spółka. This is the sixth time that these awards have been presented in Europe. "All three recipients of the gold award are repeat winners from last year," says Dietmar Jaeger, head of the TDK's Global Sales Distribution. "This constant excellent performance shows that our program is stable and successful."

The highest score this year was attained by Digi-Key Electronics Europe, therefore recognized with a gold award in the high-service distribution category. Hermann Reiter, head of Global Strategic Business Development & Supplier Management at Digi-Key, emphasizes, "The TDK Senten Manten Award is a perfect reflection of the way we do business every day. At Digi-Key Electronics we live the motto 'A thousand things done right every day.' This motivates us to strive for outstanding achievements every single day. We thank the TDK team for the fifth award in a row and our customers for their trust."

**www.tdk-electronics.tdk.com**

# Battery Tech Trade Expo Will Run at Silverstone

BATTERY TECH EXPO

The Battery industry is on the cusp of a power revolution with big technology companies investing heavily in the next generation of battery development and energy storage. The Battery Tech Expo UK runs 26th March 2020 Silverstone | The Wing | Silverstone Circuit | NN12 8TN a major UK hub of the high tech industrial sector and will bring together professionals from across the advanced battery technology industry. The event will provide a unique opportunity to showcase the latest products, technologies and services covering the Battery Management Systems, EV Battery, Battery Storage, Battery Development/ Discovery, Commercial and Mobile Power Device sectors.The Battery industry is on the cusp of a power revolution with big technology companies investing heavily in the next generation of battery development and energy storage.

**www.batterytechexpo.co.uk**

# PEMD 2020 Call for Papers

Bring your latest research to over 450 experts in Power Electronics, Machines and Drives at #PEMD2020. PEMD delivers the latest practical innovations, technical developments and new theoretical research across the breadth of power electronics, machines and drives. Authors also have their work indexed on IET Inspec and Ei Compendex, and submitted to IEEE Xplore. Plus you'll get a discounted rate to attend the conference. Key conference themes are power electronics, machines, drives and control, transportation, energy systems and advanced manufacturing. Submit your paper by 13 September at

**www.theiet.org/pemd**

# LpS 2019 Line-Up and Event Program

LpS 2019
LED professional SYMPOSIUM +EXPO

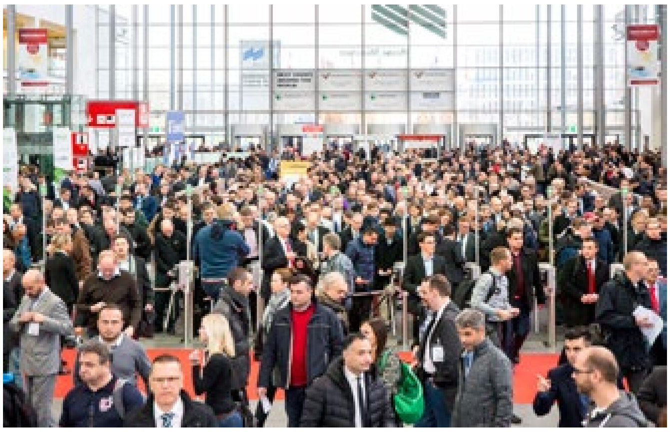
The LpS 2019 (LED professional Symposium +Expo) is proud to reveal this year's speaker line-up and event program, for what is set to be another outstanding year for the conference. Joining over 1700 delegates and 100 exhibitors in Bregenz this year will be global experts from industry and research, across multiple lighting applications such as Human Centric Lighting, Transportation, Agricultural, Healthcare and many more. These chosen specialists will be sharing their future visions, innovative technologies, trend insights and research findings in over 100 carefully selected lectures.

LpS is the leading international lighting technologies event for design, testing and production of lighting systems, controls and equipment, showcasing state of the art lighting designs and products. The conference has a long heritage and a trusted reputation for being the event that brings together the very best light technologies experts from around the world. LpS 2019 is supported by Lifud, Nichia, Seoul Semiconductor and Tridonic and is co-located with the 3rd Trends in Lighting Event and the 1st DALI Summit 2019 from the Digital Illumination Interface Alliance (DiiA).

**www.led-professional-symposium.com**

# productronica Helps to Attract Young Professionals

From November 12 to 15, 2019, productronica will present the entire value creation chain for the electronics production industry in Munich. The motto for the world's leading trade fair for electronics development and production will be "Accelerating Innovation." This year's event will focus on a range of topics including smart maintenance and attracting young professionals to the industry. This year too, SEMICON Europe will take place alongside productronica as it did two years ago.



According to the latest VDMA Business Climate Index, the manufacturers of electronics production equipment are expecting turnover to grow by 1.0 percent in 2019. In 2020, the sector is expecting growth of 1.4 percent. Asia accounts for almost half of all turnover, making it the biggest market for electronics mechanical engineering. It is followed by Germany with 25 percent and the European market with around 18 percent. Falk Senger, Managing Director of Messe München, sees these figures as a positive sign for productronica 2019: "Electronics production is still in good financial shape. We're therefore optimistic that we'll have a successful trade fair and productronica will live up to its reputation as the world's leading trade fair with numerous international exhibitors and visitors this year too."

**www.productronica.com**

# Silicon Carbide Partner for the Volkswagen FAST Program

Cree, Inc. has been selected as the exclusive silicon carbide partner for the Volkswagen Group's "Future Automotive Supply Tracks" Initiative (FAST). The aim of FAST is to work together to implement technical innovations quicker than before and to realize global vehicle projects even more efficiently and effectively. "The Volkswagen Group has committed to launch almost 70 new electric models in the next ten years, which is up from our pledge of 50 and increases the projected number of vehicles to be built on the Group's electric platforms from 15 million to 22 million in that timeframe. An effective network is our key to success. Our FAST partners are our strategic partners, each of them outstanding in their respective field. We want to shape the automotive future together," said Mr. Michael Baecker, Head of Volkswagen Purchasing Connectivity.

This agreement connects two simultaneous revolutions: the automotive industry's move from internal combustion engines to EVs and the growing adoption of silicon carbide in the semiconductor market. It also drives innovation for both parties, enabling the Volkswagen Group to better serve their customers.

The use of silicon carbide accelerates the automotive industry's transformation to electric vehicles, enabling greater system efficiencies that result in electric cars with longer range and faster charging, while reducing cost, lowering weight and conserving space.

**www.cree.com**

# Call for Technical Session Papers

APEC 2020 continues the long-standing tradition of addressing issues of immediate and long-term interest to the practicing power electronic engineer. Outstanding technical content is provided at one of the lowest registration costs of any IEEE conference.

| | |
|---|---|
| July 19, 2019 | Deadline for submission of digests |
| October 16, 2019 | Notification that a paper was accepted or declined |
| November 22, 2019 | Final papers and author registrations are due |

Submission Requirements: Prospective authors are asked to submit a digest explaining the problem that will be addressed by the paper, the major results, and how this is different from the closest existing literature. Papers presented at APEC must be original material and not have been previously presented or published. The principal criteria in selecting digests will be the usefulness of the work to the practicing power electronic professional. Reviewers value evidence of completed experimental work. Authors should obtain any necessary company and governmental clearance prior to submission of digests.

Please visit http://www.apec-conf.org/conference/presenters for all details on digest and final manuscript format and to submit your paper.

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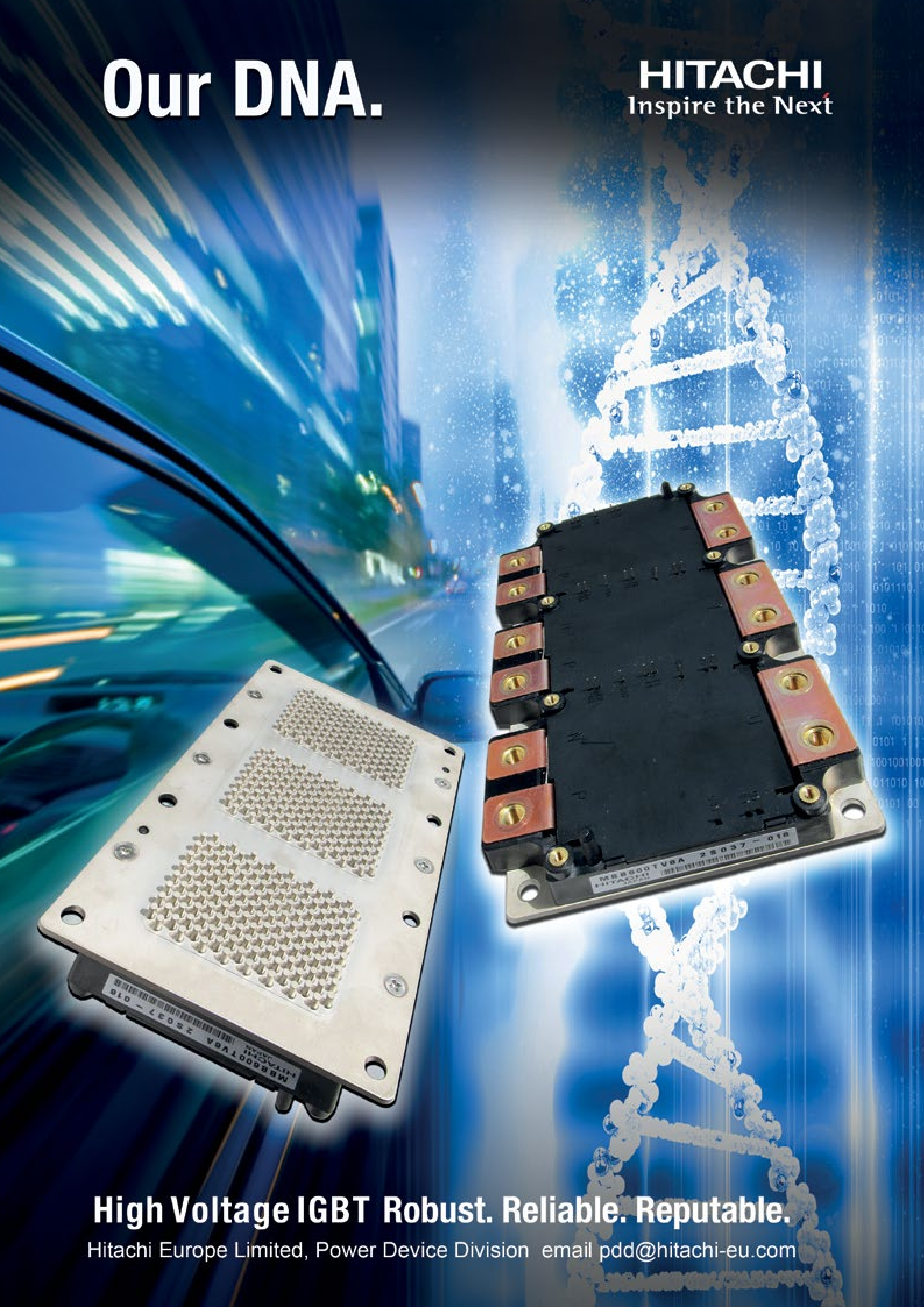


# Isolated Gate Drivers with Integrated Sensing for IGBTs and SiC MOSFETs

*New gate drivers from TI provide advanced monitoring and protection while improving total system efficiency in automotive and industrial applications*

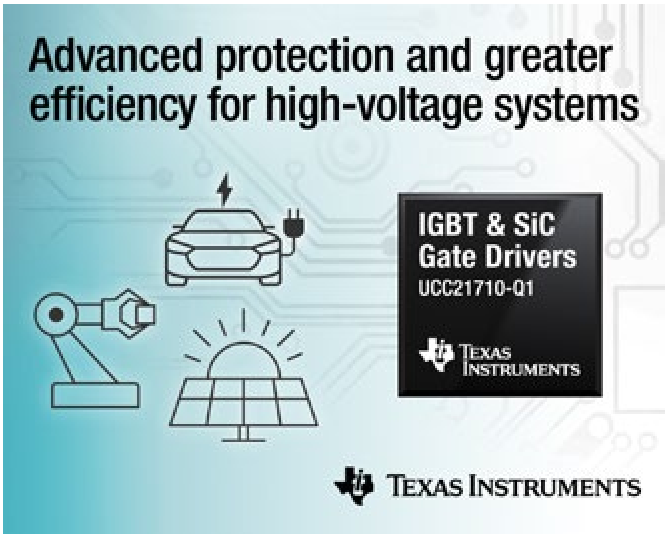
Texas Instruments (TI) recently introduced several isolated gate drivers that provide unparalleled levels of monitoring and protection for high-voltage systems. The UCC21710-Q1 and UCC21732-Q1 and UCC21750 enable designers to create smaller, more efficient and higher-performing designs in traction inverters, onboard chargers, solar inverters and motor drives. For more information, see www.ti.com/UCC21710-Q1-preu, www.ti.com/UCC21732-Q1-preu and www.ti.com/UCC21750-preu.

The devices are the industry’s first to offer integrated sensing features for insulated-gate bipolar transistors (IGBTs) and silicon carbide (SiC) metal-oxide semiconductor field-effect transistors (MOSFETs) to simplify designs and enable greater system reliability in applications operating up to 1.5 KVRMS. With integrated components, the devices provide fast detection time to protect against overcurrent events while ensuring safe system shutdown.

Utilizing capacitive isolation technology, the UCC21710-Q1, UCC21732-Q1 and UCC21750 maximize insulation barrier lifetimes while providing high reinforced isolation ratings, fast data speeds and high-density packaging.

Key features and benefits of TI’s UCC21710-Q1, UCC21732-Q1 and UCC21750 products

- Enhanced system performance: The new isolated gate drivers’ high peak drive strength of ±10 A maximize switching behavior and reduce losses, while 200 ns of overcurrent detection enables fast system protection.
- Strengthened system-level reliability: The UCC217xx family extends insulation barrier lifetimes with capacitive isolation technology and industry-leading reinforced isolation ratings with surge immunity up to 12.8 kV. Additionally, the devices ensure accurate data communication with common-mode transient immunity (CMTI) of more than 150 V/ns.
- Reduced system size: The gate drivers eliminate external components with integrated buffers and sensors while providing accurate temperature, current or voltage sensing, with an isolated analog-to-pulse-width modulation sensor to simplify system-level diagnostics and prevent switch failures.



**Package, availability and pricing**

Pre-production samples of the UCC21710-Q1, UCC21732-Q1 and UCC21750 gate drivers are available now in the TI store. The table lists pricing and package type.

Find out more about TI’s UCC21710-Q1, UCC21732-Q1 and UCC21750 gate drivers

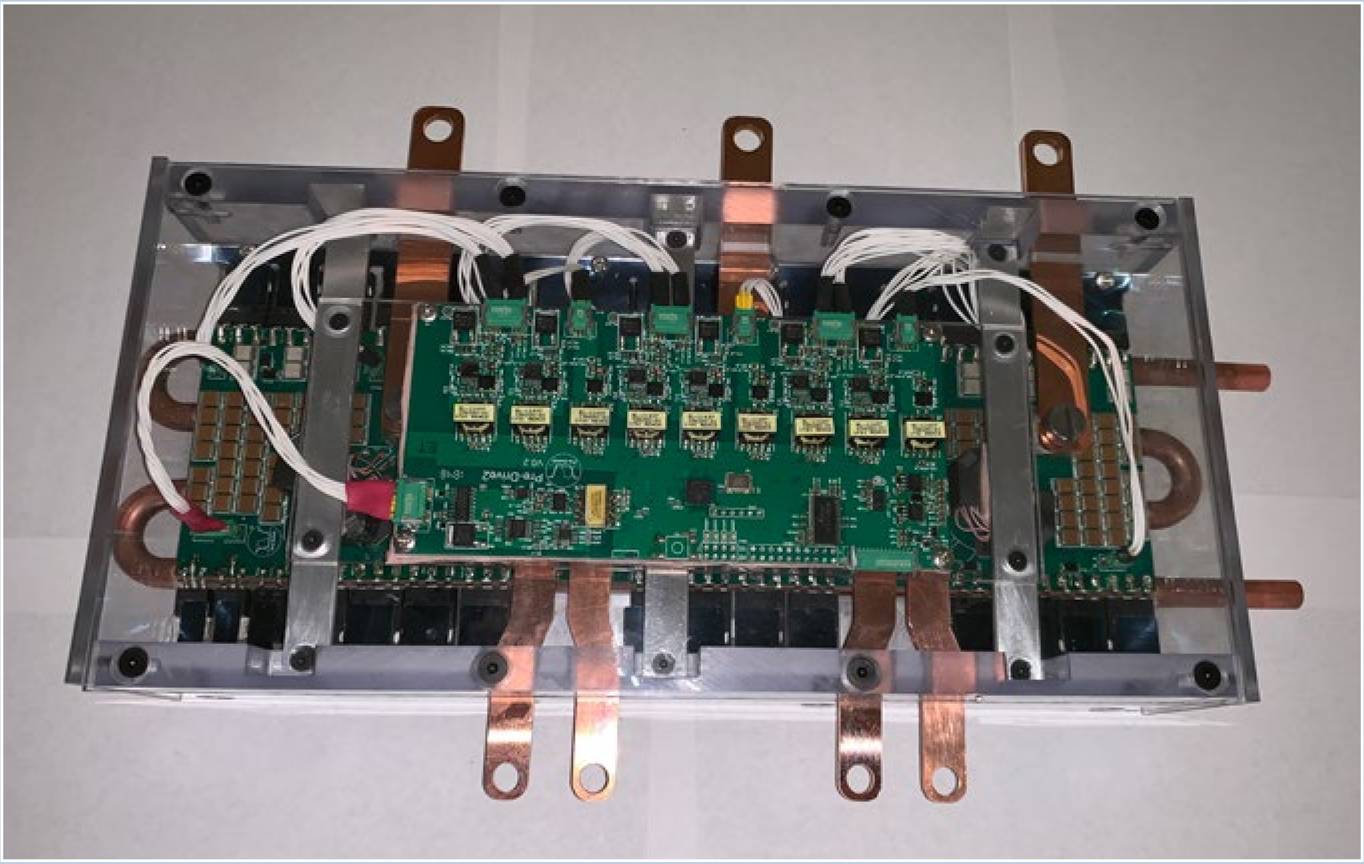
- Read the white papers, “Impact of an isolated gate driver” and “Silicon carbide gate drivers – a disruptive technology in power electronics.”
- Download the application note, “Understanding the short-circuit protection for silicon carbide MOSFETs.”
- Watch the four-part video training series, “How high-voltage isolation technology works.”

**www.ti.com**

| Product | Package type | Price (1,000-unit quantities) | Order now from the TI store | Evaluation module |
|---|---|---|---|---|
| UCC21710-Q1 | 16-pin plastic small-outline integrated circuit (SOIC) | US$4.00 | PUCC21710QDWQ1 | UCC21710QDWEVM-025 |
| UCC21732-Q1 | 16-pin plastic SOIC | US$4.00 | PUCC21732QDWQ1 | UCC21732QDWEVM-025 |
| UCC21750 | 16-pin plastic SOIC | US$3.48 | PUCC21750DW | UCC21750QDWEVM-025 |

# 200kW SiC Inverter Evaluation System

## *AI-Based Solution to Hidden Inverter Challenges also Suits Solar, Wind & Traction Applications Above 100kW*



Pre-Switch, Inc. announced its CleanWave 200kW silicon carbide (SiC) automotive inverter evaluation system that enables power design engineers to investigate the accuracy of the company's soft switching architecture and platform over varying load, temperature, device tolerance and degradation conditions. Pre-Switch's platform, including the Pre-Drive™3 controller board, powered by the

Pre-Flex™ FPGA, and RPG gate driver board, virtually eliminates switching losses, enabling fast switching at 100kHz, significantly improving low torque motor efficiency. High switching frequency also reduces motor copper and iron losses. For electric vehicles this results in a massive increase in range of 5-12%. The soft-switching solution also benefits industrial motors, solar, wind and traction applications or any other power converter requirement greater than 100kW that is looking to reduce costs and improve efficiency. Comments Bruce T. Renouard, CEO, Pre-Switch: "With Pre-Switch, critical design challenges hindering EV adoption, have been solved. Previously, the limited switching frequency of inverters resulted in a distortion of the output power sine wave causing excessive motor inefficiencies. Our CleanWave inverter evaluation system – which is available to pre-order now – uses Artificial Intelligence (AI) to constantly-adjust the relative timing of elements within the switching system required to force a resonance to offset the current and voltage wave forms – thereby minimizing switching losses and increasing EV range."

Pre-Switch's forced-resonant soft-switching topology replaces the traditional IGBT driver or silicon carbide driver with a common intelligent controller board, Pre-Drive3, and a specific plug-in RPG (Resonant Power Gate) module optimized for the customer's chosen SiC or IGBT package. The Pre-Switch architecture increases efficiency and range, while reducing size and weight. A video explaining the technology and its application to EVs is available at: https://www.youtube.com/watch?v=VN2sp0D79oc&t=82s

**www.pre-switch.com**

# Smart Solutions to Accelerate Design

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- Efficiently create differentiated designs with flexible peripherals and functions
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MICROCHIP

# Win a Microchip SAM L21 Xplained Pro Evaluation Kit

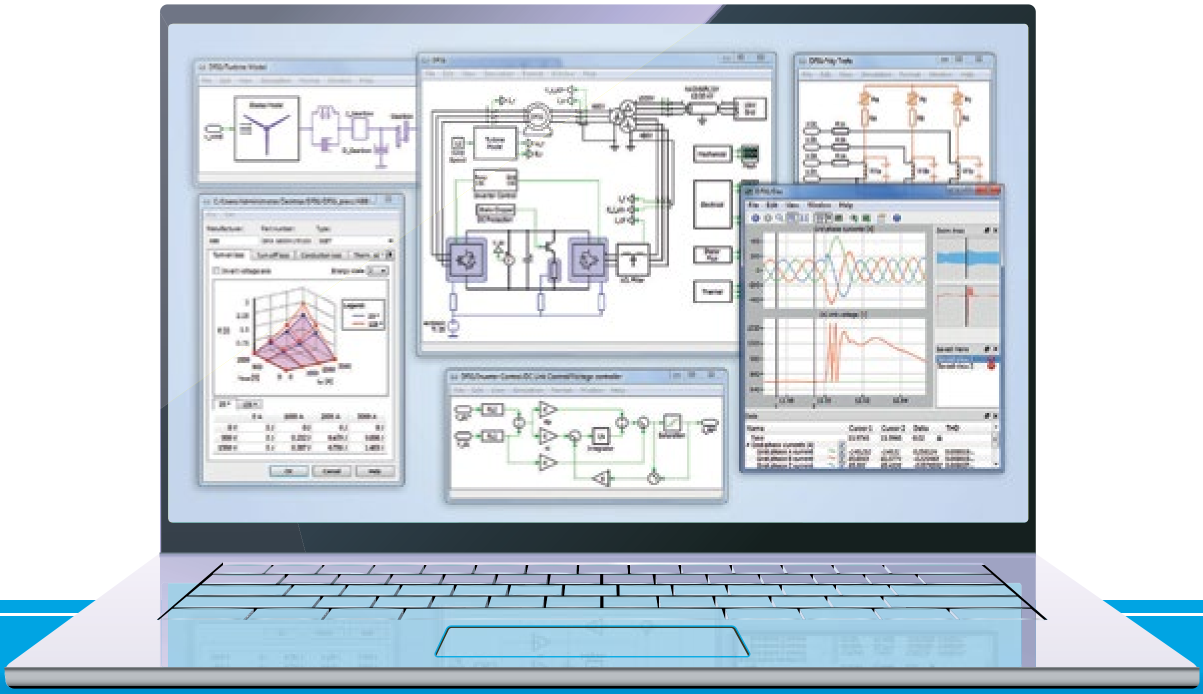
*Win a Microchip SAM L21 Xplained Pro Evaluation Kit (ATSAML21-XPRO-B) from Bodo's Power.*

The SAM L21 Xplained Pro evaluation kit is for evaluating and prototyping with the ultra-low power SAM L21 ARM® Cortex®-M0+ based microcontrollers.  Microchip SAM L family of microcontrollers are built with innovative picoPower® Technology to deliver best-in-class low power consumption down to 25 µA/MHz in active mode, under 100nA in sleep mode and fast wake-up times of 1.2uS. These MCUs have achieved EEMBC certified ULPMark Score of 410, which is the highest score for an ARM® Cortex®-M23 or ARM® Cortex®- M0+ class device. In addition to ultra-low-power capabilities, these devices feature enhanced Peripheral Touch Controller, chip-level robust security, ARM®TrustZone® Technology, AES, Full Speed USB host and device, Event System and Sleepwalking, 12-bit analog, built in opAmps and much more.

A rich set of peripherals, flexibility and ease-of-use combined with Ultra low power consumption make the SAM L21 ARM Cortex-M0+ based microcontroller series ideal for IoT, wireless, and any system that needs large memories and ultra-low power consumption. The SAM L21 is designed for simple and intuitive migration between SAM L devices with identical peripheral modules, compatible code and a linear address map and is compatible with the SAM D family of general-purpose MCUs.

For your chance to win a Microchip SAM L21 Xplained Pro Evaluation Kit, visit http://page.microchip.com/Bodos-Power-SAM-L21.html and enter your details in the online entry form.

**www.microchip.com**



# Wide Band Gap Devices are Mature

## *Both SiC and GaN have started to take more market*

*The demand for better efficiency in systems can only be achieved with better semiconductors that have less loss in conduction and switching in respect to established devices in silicon.*

*By Bodo Arlt, publishing editor of Bodo's Power Systems*

Our world demands more and more communication and transport and electronics is the key element to drive this. So, the consumption of energy is growing, and any wasted power energy needs to be avoided. The wide band gap devices have now reached a level to be the first source for this new design.

The benefits are in hand to save losses and get systems much more efficient and also shrink the physical size as we can now go to higher switching with the result of smaller passive components.
Specifically, the transformer and inductors can be much smaller.

My podium at PCIM Europe was a 'speed dating presentation' of the leading industry what we have achieved so far. The session took its traditional place during the afternoon of the second day and first to present were the SiC manufactures highlighting their progress which was followed by the GaN manufactures.

The following draws a short highlight of each presentation. For more details or to contact the companies who took part I have included the URLs.

**www.mitsubishielectric.com**

Mitsubishi as a SiC chip and module manufacture showed reliability information for SiC MOSFETs.
2nd generation SiC MOSFETs with JFET doping showed no significant shifts during HTGB tests. ( +/- 20 V, 150°C 1000 h test ).
Wolfspeed in addition to SiC chip and device manufacture announced a significant capacity planning for new investment into production equipment. Wolfspeed is now focusing into automotive power train. Reliability in automotive is a mandatory subject.

**www.wolfspeed.com**

Rohm is building a new fab in Japan to serve the market demand. Automotive is one focus in addition to transportation and wind power. There are 96 parts in mass production at Rohm.

**www.rohm.com**

United SiC is filling out the widest discrete SiC offering. A special focus at United SiC is the SiC cascode device. Also, here is the electric automobile one focus that is served beside IT infrastructure and renewables.

**www.unitedsic.com**

Infineon is claiming the broadest portfolio of CoolSiC MOSFET modules in Easy package in the market. Targeted areas are automotive with the infrastructure for charging and traction.
Photovoltaic is also mentioned.

**www.infineon.com**

WeEn semiconductors is offering SiC 1200 volt diodes. WeEn SiC diodes are designed by a team of experts pioneering this technology for over 10 years.

**www.ween-semi.com**

GeneSiC's presented SiC MOSFET and Schottky MPS rectifiers performance.
SiC MOSFET successfully conducts a single-pulse avalanche energy (EAS) of 1.07 J (14.1 J/cm2 normalized to the total chip size), at a peak drain current of 5.5 A, and drain voltage of 5100 V.

**www.genesicsemi.com**

Littelfuse showed SiC MOSFETs stable under unclamped inductive switching.
Maximum UIS capability scales with die active area:
$E_{AV}$=1000 mJ for 1200V, 80 mOhm (~10 J/cm$^2$).
No parametric change observed for:
Single shots of 80% of Max UIS.
100k shots of 25% of Max UIS

**www.littelfuse.com**

ON semiconductor will have completed Silicon Carbide vertical integration by 2020
SiC power modules will continue release during 2019.
First Company to release SiC technology on 6” wafers in 2015.

**www.onsemi.com**

Here is the extract from GaN device progress:
EPC demonstrated with eGaN replacing MOSFETs in 48 V DC-DC applications like cloud computing, artificial intelligence & deep learning, mild-hybrid cars & trucks.
eGaN technology is changing the World and improving rapidly.

**www.epc-co.com**

Infineon presented the CoolGaN product roadmap.
More than 20,000 systems in the field (40,000 CoolGaNTM devices) have not caused any field failures < MTBF > 30 X 106 Hours (limited by current operating hours) >.
This compliments Infineon Technologies cumulative equivalent of 26 x109 device hours of biased life operation.
Normal and abnormal peak currents must be limited to stay within GaN max ratings.

**www.Infineon.com/GaN**

Navitas has the world’s first GaNFast™ power ICs and the ICs are much faster than any discrete solution up to 40MHz switching, 5x higher density & 20% lower system cost.
World’s smallest Charger 42W (30W-C + 18W-A) + Battery Pack (5,000 mAhr)(31.5 x 85.5 x 81.5 mm)

**www.navitassemi.com**

GaN Systems has GaN-on-Silicon transistors for the power conversion market. GaN Systems is serving industry’s most extensive and highest-performance products with enhancement mode devices of 100V & 650V for industry-best performance.

**www.gansystems.com**

Exagan had shown GaN technology & System level product solution.
Their G-FET™ series demonstrates robustness and performance.
The component features include the embedded driver with digital control signals, the slew-rate adjustment for EMI, full protections (OCP, TSD, UVLO) with digital fault reporting, auto-diagnostic for safe operation and accurate peak current sensing (3%@500 mA).

**www.exagan.com**

Transphorm presented the two main categories that are driving the adoption.
First the competitive advancement: differentiating their product lines to outperform the competition. Second the market disruption: today’s available technology is unable to meet end customer’s needs.
Transphorm GaN is in high volume production.

**www.transphormusa.com**

Texas Instruments has presented the LMG341x with transient overvoltage capability for surge robustness. This is analogous to the avalanche rating of silicon.
Complete GaN, driver and protection in single package for
fast and easy system design.

**www.ti.com**

ON Semiconductor provides a unique Ecosystem focused around WBG solutions
The GaN HEMTs geared towards ruggedness and speed. GaN drivers are for reliable and fast switching and SPICE based Physical Models for HEMTs.

**www.onsemi.com**

We can generally state that GaN is serving higher voltages up to line voltages in Europe. SiC is able to have capability for several kilo volts. The challenge is to get the acceptance to the broad range of designers. Therefore, I have the WBG Power Conference, together with AspenCore, taking place in Munich in December and I will share further details of this event with you soon. Wide band gap semiconductors will continue to be part of solutions for future design.

**www.bodospower.com**

# The Next Step: Sintering is the Key to Future Power Electronics

*In modern power electronics applications, requirements are becoming more demanding. Soldered connections are reaching their limits. Sintering is increasingly becoming indispensable. Dennis Ang, sintering expert at Heraeus, knows what challenges the new technology introduces and what users must consider when making the transition.*

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

Q: What is the significance of sintering for modern power electronics?

Manufacturers of power electronics still rely on soldering. Standard power electronics modules are typically assembled by soldering with lead-free SnAg solder and wire-bonded with thick aluminum wire. In these techniques, the simple handling, low material costs and flexible integration into various processes offer an advantage. But what is enough for many standard applications is reaching its limits in modern technologies. This is because the demands made by new applications such as electromobility or renewable energies have risen enormously. Even a perfect solder joint may no longer meet the requirements. The materials used must support higher power densities and switching frequencies, and at the same time, the demands on the reliability of high-performance electronic modules are growing. Automobile manufacturers, for example, require the supplier industry to make products with a service life of at least 15 years or 250,000 km. Sintering with silver offers a solution. It also can overcome higher operation temperature restriction. A solid material until 961 °C, silver has a significantly higher melting point than tin-based, lead-free solders. Incorporating filler technologies, sinter supports higher thermal operating temperatures of more than 250 °C, as they remain thermomechanically stable and show almost no signs of aging. This is what makes high operating temperatures possible in modern power electronics. The silver particles of the sinter paste densify by means of diffusion processes. When heated above 230 °C and together with applied pressure of between 5 MPa and 30 MPa the density increases. The pressure ensures that porous areas in the compound layer are reduced, which is particularly important for large-area semiconductors.

Q: What experience does Heraeus have with sintering?

In the field of sintering, we have gained comprehensive know-how from more than a decade of experience in working with this technology. As a result, we have developed and refined an extensive range of solutions for a wide variety of applications. We have also developed a performance material portfolio covering almost every aspect related to improve device robustness – from various DCB substrates, sinter pastes optimized for copper surface and aluminum-copper bonding wires. Of course, we also share our accumulated experience with our customers - through comprehensive advice and hands-on experience in our application center in Hanau. Here we simulate their sintering processes and we offer sinter seminars and hands-on training to get to know the technology.

To establish the use of sintering in the production of high-performance electronics, the technology group Heraeus has accelerated a further development step. A die connection to a microchip substrate can already be made with sintering, but the core problem is surface contacting. Many years of expertise in material and bonding techniques such as sintering have resulted in several patented solutions for the manufacture of electronic modules -- from DCB substrates for a wide variety of applications to the most resilient wires made of the latest materials to sinter pastes to reliably hold all components together. We know almost every aspect of sintering and offer both products and advice. We don't just want to supply individual parts; we always have the holistic solution in mind.

Q: What difficulties arise when switching from soldering to sintering?

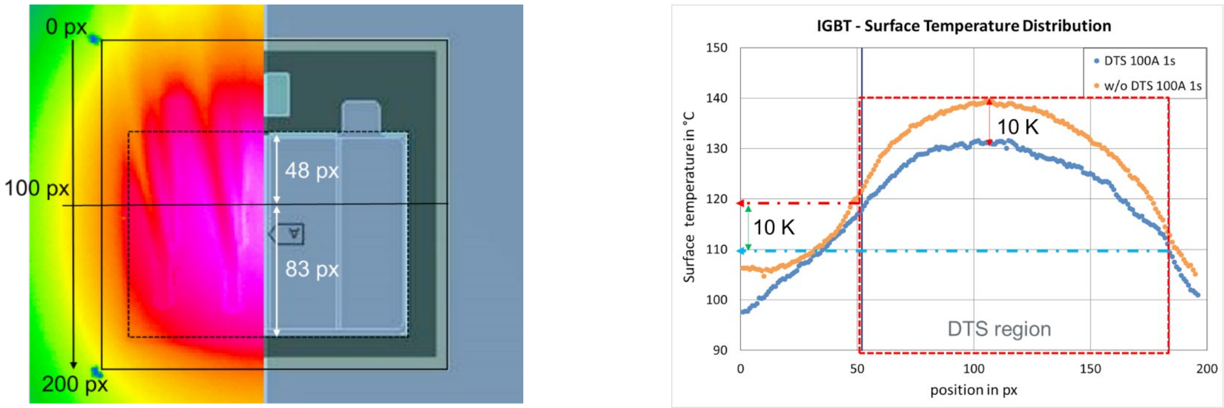


*Figure 1: Fewer Hot Spots: The excellent thermal and electrical conductivities of the Cu foil and the Ag sintered layer ensure a lower temperature distribution on the top side of the chip, as this comparison of heat distribution with and without DTS shows.*

TRAIN

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series 7G

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**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

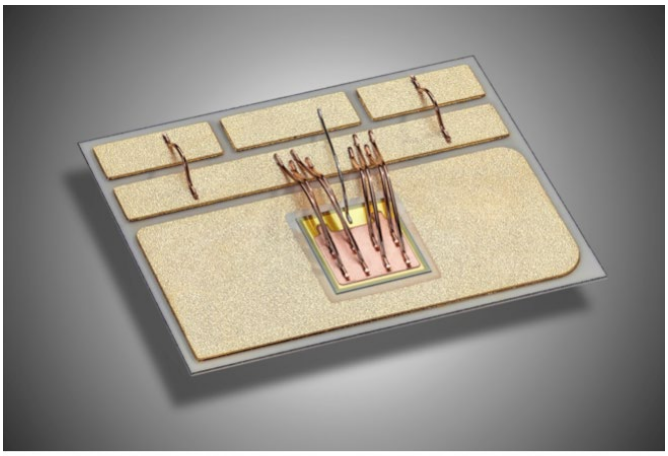
**RoHS compliance**
- Ultrasonic welded terminals
- RoHs compliant solder material

**Over temperature protection**
- Thermal sensor installed

**Easy paralleling**
- HPnC module has a minimized current imbalance
- Easy scalability

Sintering has not yet established itself completely as a technology in power electronic modules despite the outstanding physical properties of sintered layers. This is because sintering requires different machines and processes than soldering. Many manufacturers are reluctant to use the technology due to the complexity of the production changeover, and that converting to the sintering process involves significant investment in new production machines. In addition, the sintering process is still considered to be a complex mechanical engineering process. But these objections are increasingly diminishing, or even disappearing entirely. Sintering will be the standard for high performance material in the future. We are constantly working on making this future possible today - with cost-effective solutions and more easily accessible innovations.

The result of our efforts is the Die Top System (DTS®) - a material system for assembly and connection technology that was developed jointly with the technology company Danfoss and is based on its bond buffer technology. The conversion to new material systems such as DTS requires a manageable amount of investment. Therefore, Heraeus worked toward making its industrialization straightforward. With the pick & place system, chips and copper foils are put in place automatically. Since the sinter paste has already been pre-applied to the copper plate, the paste no longer must be applied by the customer. Furthermore, optional fixation points ensure that the applied copper plates do not slip before sintering, thus speeding up DTS placement during production. Next, chips and copper plates are sintered together. The copper wires are usually applied using thermosonic ball wedge bonding. A key advantage of the DTS is the flexible applicability of the material system. The process can be adapted to any shape. For example, if the chip layout is changed, no new tool is required.



**Die Top System**

*Layout by courtesy of Fraunhofer IISB

*Figure 2: Flexible in use: The DTS enables the use of Cu wires instead of Al, which results in better performance and higher operating temperatures. The process can also be used for a wide variety of substrate layouts.*

A similar approach is followed by clip systems in which metal plates are used instead of wires. However, these also pose further challenges: The additional plates influence the bending stiffness, and the asymmetrical design can cause greater mechanical loads. Furthermore, the clip systems require two sintering processes. By using DTS in the joining process, the connection can be completely produced in one process. Coating systems are also a well-known alternative to DTS. Instead of a copper plate, copper coating is applied to the chip. However, copper coating on both sides is necessary to guarantee the mechanical strength - a complex process to ensure the necessary layer thicknesses of 40 µm.

Q: Which parts of the power electronics benefit from sintering?

Power Modules benefit most from sintering. They operate in the top end drawer of the power spectrum, requiring innovative solutions to enable high operation temperature and improve device lifetime exponentially. An example for this is the automotive market where the future will be autonomous, connected and electric. The proliferation of electronics control systems will intensify these challenges, and the demands on the material are constantly increasing. To meet these scenarios, newly developing power platforms can integrate SiC (silicon carbide) and adopt sinter technology to increase power capacity and overall performance. So sinter technology will primarily benefit automotive electronics systems such as power inverters and onboard chargers to deliver superior performance.

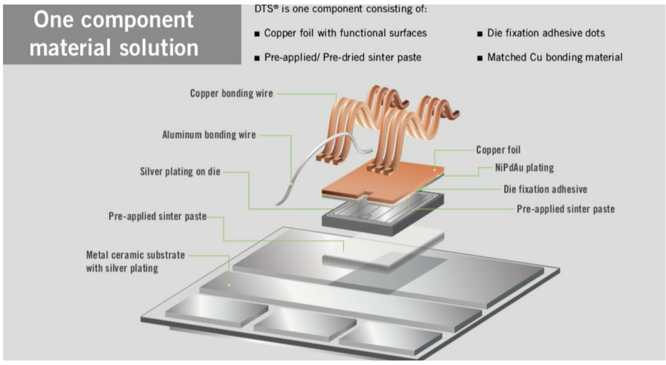


*Figure 3: Structure of the Die Top System*

Q: What advantages does copper wire offer over aluminum?

Compared to soldered chips with aluminum bonding wire, a 50-fold higher number of cycles is achieved before faults occur. At the system level, this was experimentally proven at a temperature swing of DT=130°K. To conduct the heat generated by the chip in a targeted manner, the copper layers are specially structured to produce an optimum topology. The foil protects the chip from the high mechanical loads during wire bonding. Thus, copper bonding wires with much better conductivity can be used instead of the previously used aluminum bonding wires. These make it possible to significantly reduce module derating or to use smaller modules while maintaining the same performance. The challenge: Since copper does not bond sufficiently with the silver contained in the sinter pastes, the Cu plates must be coated with a precious metal (NiAu, NiPdAu or Ag). Heraeus has further

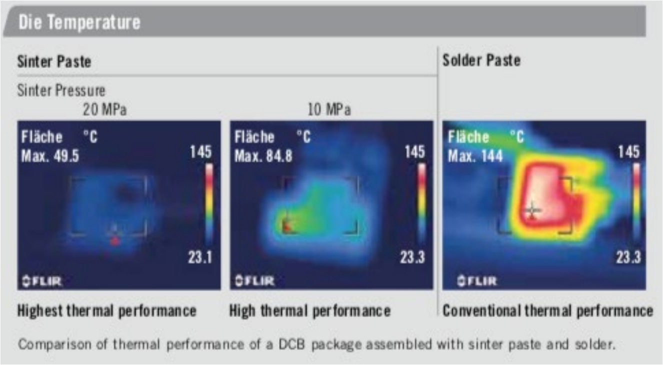


*Figure 4: Better heat distribution: A comparison of the two methods shows that the heat is distributed better with sintered DCBs than with soldered ones.*

developed its sinter pastes for this purpose: A targeted addition of additives ensures that the copper oxide is reduced to copper during the sintering process of the paste, thus optimally diffusing into the sinter layer and creating a solid bond.

Q: What is the future of sintering?

The increasing demand for high-performance electronics along with rising performance requirements for electronic components make the use of modern sintering technology indispensable. The further development of electromobility - in response to technical advances as well as political conditions - is one of the factors driving further growth in the field of high-performance electronics. This can already be seen in the example of China: There, a quota has already been introduced for e-cars and plug-in hybrids, according to which domestic and foreign car manufacturers must meet minimum targets for the share of alternative transmissions in production and sales. In addition to e-mobility, renewable energies are also being promoted in Europe. The use of DTS thus represents an important success factor in competition on the global market. Sintering is indispensable and is the technology of the future needed to achieve this aim.

**www.herae.us/sintering**

**About the Author**

**Dennis Ang, Global Product Manager - Sinter Products, Heraeus Electronics**

Dennis is a well-travelled profession in the field of engineering. At Heraeus Electronics, his area of focus is in power electronics systems where he applies his invaluable industrial knowledge accumulated from past appointments in product development, process engineering and business development to bring to market cutting-edge performance material to energize power electronics industry.

Dennis graduated from Australia with honors in Electrical Engineering and is a Six Sigma Black Belt.

# The Smarter E Europe 2019 Consolidated its Status as Europe's Largest Energy Trade Fair

## *Innovation Platform for the New Energy World*

*In mid-May and in 10 halls of the exhibition grounds, Munich hosted four trade fairs with a common mission: to achieve a clean and modern energy industry. After three successful days, "The smarter E Europe", the innovation platform for the new energy world, draws a positive balance.*

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

From 15 to 17 May 2019, a total of four energy trade fairs took place on the innovation platform: At Intersolar Europe, the world's largest trade fair for the solar industry, the goal was "Connecting Solar Business!" The ees Europe focused on batteries and energy storage systems, the Power2Drive Europe showed the interaction of electric vehicles and environmentally friendly energy supply, and the EM-Power covered the intelligent use of energy in industry and buildings. With a total of 1,354 exhibitors (+15%), 100,000 square metres (1,076,000 square ft, +16%) of exhibition space and around 50,000 visitors (+8%) from 162 countries, The smarter E Europe – just one year after its premiere – proved to be Europe's largest energy platform.

The focus was consistently on the core themes of a sustainable energy sector – from renewable energies to decentralisation, digitisation and sector coupling. Particular attention was paid to intelligent and networked energy systems. In addition, numerous innovative technologies, new business models and forward-looking projects were presented at the accompanying conferences and trade fair forums.

**ees Europe: Trends in batteries and energy storage systems**
More than 450 suppliers of energy storage technology and energy storage systems were represented at Europe's largest and most international exhibition for batteries and energy storage systems ees (electrical energy storage) and the parallel exhibitions. ees Europe also offered a comprehensive accompanying program – from the ees Europe Conference and a range of forums to free, expert-led exhibition tours on a variety of different topics to the presentation of the renowned ees Award. With additional events in San Diego, Bangalore and São Paulo, ees is represented on four continents.

On May 14 and 15, the ees Europe Conference, highlighting and consolidating current industry issues, offered an in-depth program on international storage markets and introduced lucrative business models. Numerous sessions explored the technologies of the future. For example, the session "Quality Assurance for Products and Projects – Safety, Reliability and Performance" addressed key questions in the field of quality assurance for stationary battery storage units. The session was led by Dr. Matthias Vetter, Head of Department for Electrical Energy Storage at the Fraunhofer Institute for Solar Energy Systems ISE in Germany and Chairman of the ees Europe Conference. Vetter stated: "When it comes to achieving a wide-reaching and sustainable market penetration of stationary battery storage systems in the widest possible range of applications – PV battery-based storage units in private, commercial and industrial environments, battery systems for providing primary balancing power, battery storage systems integrated in solar parks and wind farms – the topics of safety and reliability are paramount and create the basis required. But efficiency and effectiveness also have to be addressed for worthwhile application." The session shone a light on all these topics from a technical and economic perspective, described the current status of standards and presented exemplary results from professional practice.

Specialists explained how to guarantee the safety and reliability as well as the efficiency and effectiveness of battery systems. Existing and future standards for certification were also up for discussion. Main topics of the conference were

- Hydrogen production from renewable electricity for energy storage and grid balancing
- Status of power-to-gas and other multi-sector hydrogen activities
- Hydrogen storage and distribution
- Power-to-gas as a facilitator of sector coupling
- Energy and industrial policy aspects – current status in Germany and other EU-States
- Fuel cell systems for CHP and power for industrial, commercial, residential scales and small applications, and
- Latest trends – road/non-road vehicles propulsion

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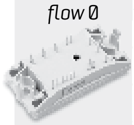
- / Multi-sourced for more freedom of choice, less risk
- / Optional integrated passive components
- / Easy assembly with pre-applied phase change material and Press-fit pins
- / Low-inductive packages to downsize external passive components

| Package | Technology | Voltage | $I_{Cnom}$(A) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 15 | 20-30 | 40-50 | 75-80 | 100 |
| *flow* 0  | IGBT3 | 600 V | | | ■ | ■ | ■ |
| | Si-MOS | 650 V | | ■ | | | |
| | IGBT H5 | 650 V | | ■ | ■ | ■ | |
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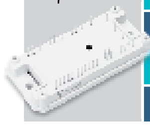
| | SiC-MOS | 1200 V | | ■ | | | |
| | IGBT4 HS | 1200 V | ■ | | ■ | | |
| *flow* 1  | IGBT H5 | 650 V | | | ■ | | ■ |
| | Si-MOS | 650 V | | | ■ | ■ | |
| | IGBT4 HS | 1200 V | | | ■ | ■ | |
| | Trench IGBT | 1200 V | | | ■ | ■ | |
| | SiC-MOS | 1200 V | | | ■ | | |

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In the ees Forum, held under the motto “Innovating energy storage!”, the ees Award finalists’ contributions were introduced and current topics and developments were discussed in sessions such as “Long-term Profitable Energy Storage Technologies,” “Monetizing Solar & Storage,” “Business Models for Commercial Storage Facilities,” “Alternatives to Li-Ion Battery Systems,” “Specialized Distributors for Storage Systems,” “Energy Storage Market Overview” and “Pitches from Start-ups.”

The PV and Battery Production Forum, in another hall, was held in close cooperation with PEM (Chair of Production Engineering of E-Mobility Components) at RWTH Aachen University. Here, the spotlight was on battery production as a trend in technology, automation and process innovation. Christoph Schön from PEM explained, “The discussion explored current innovations which are extremely important for sustainable production in Europe. These range from energy-efficient processing technologies – such as the use of lasers – to a strong machine and plant construction sector with solutions for automated module and pack production to the next generation of battery technologies.”

**Intersolar Europe 2019:Multitalented inverters**

Intersolar Europe 2019 offered unmissable opportunities to exchange ideas with the global market leaders for inverters, presenting innovative solutions and systems which open up entirely new fields of application and help to make the goals and visions of professional users and prosumers a reality. These innovations can also be combined with a whole range of battery systems that were on show at the parallel event ees Europe. In addition, attendees at the two-day Intersolar Europe Conference explored all about the latest developments, from innovations in string inverters to central inverters and PV power plant concepts, at the side event “Power Electronics for Photovoltaics and Battery Systems.”

Thanks to digitalization and the greater needs of the market, inverters are becoming increasingly versatile. From storage devices to electric cars, heating elements to smart home applications and monitoring systems, a variety of components can be seamlessly integrated using inverters. With this wide scope of application, inverters are currently undergoing a highly dynamic innovation process, and have already become real all-rounders. The main trends are for easily installed and modular hybrid inverters, solutions for retrofitting, and string inverters with a high power density for large-scale PV plants which feed into the grid.

Converting direct current solar power into alternating current as efficiently and cost-effectively as possible – this was the task of inverters until just a few years ago. Since then, they have become multitalented. In addition to converting electricity, they are now used to analyze and control solar strings and solar batteries as well as power-to-heat and smart home solutions. They include interfaces for digital communication and are connected to energy management systems which also incorporate electric vehicles, for example. One factor driving this development is the advance of digitalization. This is accompanied by a change in the needs of a new generation of users who produce and use their own power from renewable sources. These prosumers store the solar energy that they produce until they require it for any of a wide range of applications. Modern inverters must be able to meet the needs of this generation.

“It used to be that people would simply feed solar power into the grid and earn money from the feed-in tariff. Today, this tariff is only 10 to 12 € per kWh, while the electricity purchase price is 30 euro cents. For this reason, it is becoming more economical in some cases to install batteries at home” explained Prof. Dr. Bruno Burger, who is responsible for the energy data platform Energy Charts at Fraunhofer ISE. Batteries make it possible to store the cheap, self-generated electricity for consumption later when solar power is not available. Inverter technology is evolving with this trend. “There used to only be feed-in inverters. Now, we have inverters which can be connected to the photovoltaic installation and the batteries.”

Also popular are new storage systems with integrated hybrid inverters, which are particularly suitable for retrofitting existing photovoltaic installations. This is an increasingly important consideration – not least as the EEG feed-in tariffs will gradually expire for older solar installations starting from 2021. The new systems can be connected directly to the household network, independent of the solar installation, and are compatible with batteries from a range of manufacturers. They can be used as an emergency power backup and automatically inform users of any errors via apps or portals.

There have also been innovations in string inverters for large-scale PV installations which feed into the grid. Manufacturers are increasingly designing larger string converters for 1,500VDC with a high power density. The higher voltages from the module array allow for lower currents, reducing the cost of cabling and cooling. The trend here is toward devices which offer increased outputs while remaining compact and efficient. They can often be connected to several solar strings at the same time, and installation tends to take place entirely online via apps and the internal wireless network.

**Power2Drive: EV and PV ensure sustainable eMobility**

The combination of solar energy and electric vehicles enables new, pioneering use concepts for private households and companies alike. One asset of eMobility is how perfectly it can be combined with renewable energy. Electric vehicles can be driven and charging stations can be fed with electricity from PV systems. Ideally, electric vehicles are charged with solar power directly from the owner’s roof. Electric vehicles are notably more efficient than vehicles with combustion engines. A PV system with a capacity of three kilowatts peak in a single-family home in Germany can provide enough power annually to operate an electric car for around 18,000 km (annual average in Germany: 14,000 km) emission free. This will be of particular interest for all those PV system owners who will lose their eligibility for EEG subsidies in 2021 or later, once their installations are more than 20 years old. For them, completely new business models such as the operation of solar filling stations are also in the works, with many suppliers having already developed the necessary software.

**Avoiding grid congestion**

Fraunhofer ISE has developed a household energy management system that optimizes electric vehicle charging to maximize the supply of self-generated power from photovoltaic installations. The system develops and monitors charging schedules, taking into account yield forecasts and the household load. In a field test, this intelligent, foresighted control technology enabled the photovoltaic system to provide 86 percent of the charging power needed on a sunny day. Without the charging algorithm, it would have only achieved 46 percent.

With eMobility, grid congestion can be prevented for the most part through intelligent coordination of renewable energies and storage systems. A current study conducted at the TU Braunschweig has shown that, by employing solar installations connected to battery storage systems, around 60 percent of all homes connected to the power grid in neighbourhoods of private one- and two-family houses can be supplied by their own 11 kW charging stations for electric cars. This significantly relieves stress on the normal power grid. As of now, most new solar power systems are being installed with a battery storage system, according to the German Solar Association (BSW-Solar).

The EV and PV combination was also central focus of this year’s Power2Drive Europe Conference and the Power2Drive Forum. EMobility is headed for a breakthrough. In the coming years, a large number of vehicle models from various manufacturers will enter the market, accompanied by a major expansion of charging infrastructure, making new approaches such as sector coupling financially attractive. “Our mobility of the future has no other option but to become carbon neutral as quickly as possible. Aside from efficient electric drive mechanisms and smaller, lighter electric vehicles, this also requires the most direct possible use of renewable electrical energy”, commented Thomic Ruschmeyer, Chairman of German Association for Solar Mobility (BSM).

The topic “Nascent eMobility Markets: Insight, Analysis and Areas of Opportunity” went into details of select eMobility markets, identifying the regions displaying particular potential, the most important influential factors and provided insight into future forecasts.

**EM-Power: Sector coupling and smart metering**

Beyond the use of sun and wind to generate electricity, climate-friendly alternatives to fossil fuels need to catch on in the heating and transportation sectors as well. Using renewable electricity in these sectors and coupling them as much as possible holds vast potential. EM-Power put the spotlight on professional energy customers.

“Sector coupling not only protects the climate, but paves the way for new technologies to enter the market, boosting the energy sector’s overall innovative power as a result,” said Robert Busch, CEO of the German Association of Energy Market Innovators (bne). “However, sector coupling requires a sound legal framework, which no longer impedes the use of green power in the heating and transportation sectors. Here, top priority must be given to reforming the taxation and levy system and introducing a national carbon price.”

Increased sector coupling allows excess solar power to be used more efficiently and more flexibly in terms of time and place in the form of heat, cooling and driving power. Electric heat pumps and decentralized heat/power-generation units combine the electricity and heating sectors (power-to-heat), while electric vehicles connect the electricity and transportation sectors. At EM-Power exhibitors presented the sector coupling solutions already available on the market at their booths and at the Compact Energy Forum alike.

Smart metering is the buzzword of the hour and a major step forward for the industry, because smart metering systems that can also transfer the data they capture are a key factor in smart energy use. And they hold enormous potential – both for developing a clean energy industry and for energy customers who want smart ways to manage their energy consumption. Smart metering systems make a vital contribution to the energy transition. They enable connection, communication and automation between the people, devices and systems involved, and ensure that all of this is done at the necessary speed. Free – i.e. non-certified – metering systems already offer a wide range of functions and provide consumers and businesses with attractive solutions for self-generation, tenant power models, neighbourhood concepts and e-mobility.

**www.thesmartere.com**

# SiC Technology on Track

*Journalists from all over Europe joined ROHM Semiconductor to enjoy the Formula E Race in Monaco this year.*
*An eventful weekend with interesting insights at the stunning Côte d'Azur.*

*By Holger Moscheik, Junior Editor Bodo's Power Systems*

Formula E began in 2014 and is a city-based racing championship for electric cars. Races take place in cities all around the world, including Berlin, Hong Kong, New York and Paris. Now in its fifth season, the international teams are now using the Gen2 car, which shows some significant improvements in power and range. The most important one being that drivers no longer have to change the car half way through the race due to battery capacity.

ROHM Semiconductor has been an official technology partner of the Monaco based Venturi team since season three, supplying the racing team with SiC power devices. ROHM was the first in the world to successfully mass produce SiC MOSFETs. A major advantage of SiC power devices is significantly higher power conversion efficiency compared with conventional semiconductors. As a result, much less heat is generated during conversion, making it possible to dramatically reduce device size - including the cooling mechanism. Often the key to victory is the performance of the inverter which controls the electricity from the battery and forwards it to the motor. Efficiency is one key factor as the level of battery has to stay in mind permanently.

During the press round table in Monaco, which took place during the race weekend, Susie Wolf, Team Principal of the Venturi Formula E Team, explained the close cooperation between the engineers at the racing team and the ones based in the laboratories of the suppliers. An ongoing exchange of data, experience and knowledge is the prerequisite for improvements. In fact, this is exactly what I learned while talking to the engineers at the ROHM booth during PCIM the previous week. The results and experiences gained out of the races are used in the daily research within the laboratories. This data really helps to understand the behavior of the devices under these tough conditions. You can see parallels to research and development in the automotive industry. Weren't racing championships always used for test and simulation?

The weekend was also a sporting success as Felipe Massa from the Venturi Team reached the third place and secured a place on the podium. A great success in a demanding race where not all participants saw the chequered flag!

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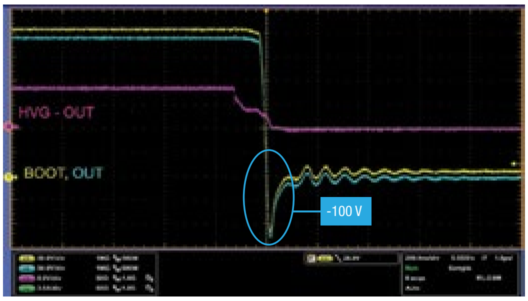

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# PWM Inverter Power Measurement System Required for Evaluating the Efficiency of Advanced Motor Drive Systems

*Measuring power accurately in the inverter switching frequency and its harmonic frequency domain is critical in order to properly evaluate the performance of high efficiency motor drive systems. A power measurement system combining the Hioki Power Analyzer PW6001 that delivers superior performance and a phase shift function with newly developed Hioki AC/DC Current Sensors CT6875 / CT6876 / CT6877 can lead to accurate efficiency evaluation of such systems.*

*By Hiroki Kobayashi, Kenta Ikeda, Koki Nakazawa, Chiaki Yamaura, Masayuki Harano,*
*Hioki E.E. Corporation*

### Foreword

In recent years, against the backdrop of efforts to stem global warming, motor drive systems used for electric vehicles and industrial applications have drawn much attention, and their increasing efficiency has advanced. In the power conversion efficiency and loss evaluation of inverters and motors, which are the key components of motor drive systems, accurate power measurement is critical, and calls for extremely precise current sensors and power analyzers [1]. However, PWM output power includes the switching frequency and its harmonic components in addition to the AC frequency component for driving the motor, making it difficult to accurately measure the power at this switching frequency and its harmonic frequency range. Indeed, to date, there has been no complete system that can accurately measure PWM inverter power.

In this article, we will first show the specifications of a power measurement system required to accurately measure the PWM power of an inverter, focusing on the features of the PWM waveform, and clarify the problems that a power measurement system faces. Next, in order to solve these problems, the extremely superior performance of newly developed current sensors is introduced together with a phase shift technology provided by a power analyzer. Finally, the actual measurement results of the PWM power of an SiC inverter will illustrate the singular effectiveness of this new power measurement system.

### Characteristics of PWM Inverter Waveforms [2]

The principal components of inverter output power include a fundamental frequency component (up to 2 kHz), its harmonic components, the switching frequency (5 kHz to 100 kHz), and its harmonic components. Of those, the fundamental frequency component is dominant. Figure 1 illustrates an inverter output's line voltage waveform, line current waveform, and associated FFT results for a typical motor drive system. Table 1 provides detailed information about the measurement target.

Looking at the voltage FFT results, it is possible to observe the fundamental wave that is the principal component of the line voltage PWM waveform and its harmonics, along with the switching frequency and its harmonic components. A spectrum of at least 0.1% f.s. exists up to approximately 2 MHz.

The fundamental wave, its harmonics, the switching frequency, and its harmonic components can also be observed for the current waveform. However, the observed spectrum at frequencies of 100 kHz and above falls below 0.1% f.s., and the current level falls abruptly as the frequency increases. This phenomenon can be explained by considering the equivalent circuit of a motor that is connected to an inverter as a load (Figure 2). The motor's winding can be thought of as an R-L load consisting of a resistance and inductance connected in series. Consequently, impedance increases at high frequencies, making it harder for current to flow.

Similarly, if we look at the power factor (cos θ) for the power of an R-L load, the power factor approaches a value of 1 when the frequency is low, for example, for the fundamental wave and its harmonics. However, because inductive reactance becomes dominant at high frequencies such as the switching frequency and its harmonics, current exhibits lagging phase, resulting in a low power factor.

The bottom half of Figure 3 provides an enlarged view of the time axis for the PWM inverter output voltage and current waveforms up to the switching frequency region. The voltage waveform is rectangular, while the current waveform is triangular. It is apparent that their phase relationship is characterized by the current's lagging phase, as described above, resulting in a low power factor.

Figure 4 shows the principal components and characteristics of the active power of a PWM inverter output.

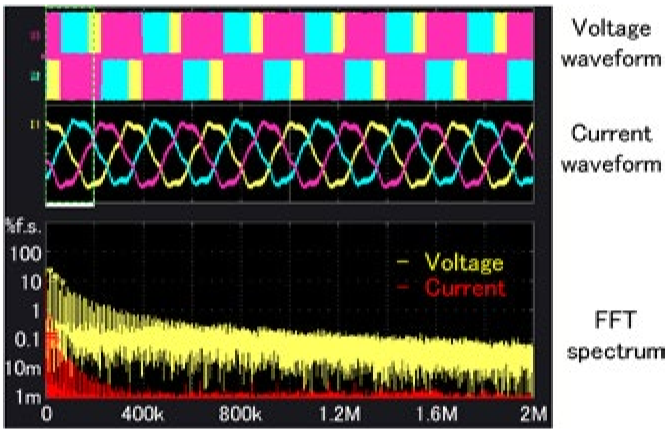

*Figure 1: Waveform and FFT results for an inverter-driven motor (measured with Hioki Power Analyzer PW6001)*

*Table 1: Measurement target specifications*

| Inverter | | Motor | | |
|---|---|---|---|---|
| Switching element | Switching frequency | Inductance | Resistance | Rated power output |
| SiC-MOSFET<br>SCH2080KE<br>(ROHM) | 20 kHz | 3.6 mH | 0.9 Ω | 120 W |

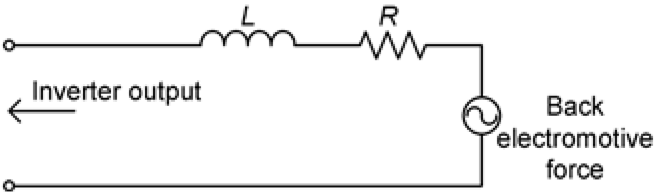

*Figure 2: Motor equivalent circuit (for 1 phase)*

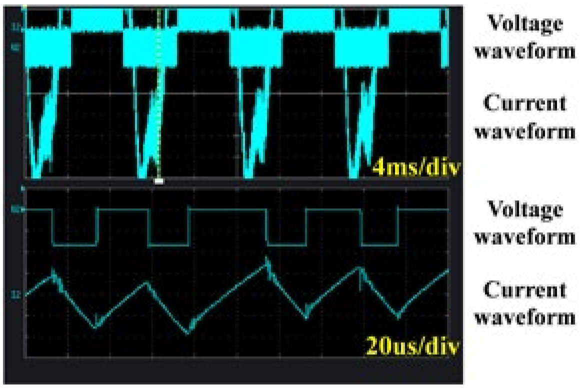

*Figure 3: Enlarged view of inverter output waveforms*

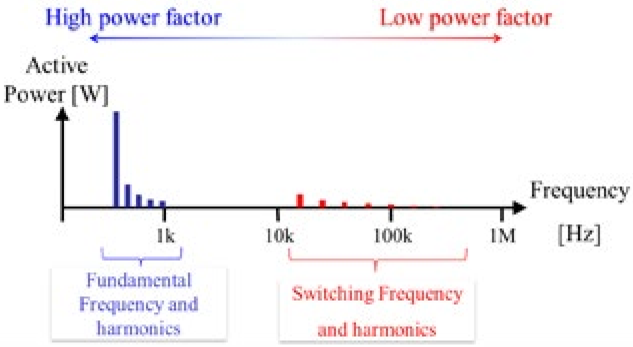

*Figure 4: Principal components and characteristics of a PWM inverter's active power*

**Performance Required for High Precision Measurement of PWM Inverter Power**

This section describes the requirements that a power measuring instrument must satisfy in order to accurately measure PWM inverter power. Based on the characteristics described above, it is important that such an instrument be capable of measuring active power not only for a high-power-factor fundamental wave and its harmonics, but also for a low-power- factor switching frequency and its harmonic components.

Figure 5 illustrates the relationship between phase error and active power error at different power factors. Voltage and current phase error in the measurement circuit has a greater effect on active power at low power factors than at high power factors. Consequently, accurate measurement of active power at the switching frequency and its harmonic components requires both flat amplitude characteristics and flat phase characteristics across a broad frequency band, the latter being particularly important. For power components that consist of a rectangular-wave voltage and triangular-wave current as shown in Figure 3, the frequency band across which the instrument must exhibit flat amplitude and phase characteristics in order to measure efficiency at a precision of 0.1% is likely 5 to 7 times the switching frequency [3].

Suppose that the switching frequency of an IGBT inverter is operated at 10 kHz, the flat amplitude and phase band required to measure the entire PWM inverter power with 0.1% accuracy is approximately 50 to 70 kHz. On the other hand, supposing that the switching frequency of an SiC inverter is operated at 100 kHz, the flat amplitude and phase are required to be around 500 to 700 kHz.

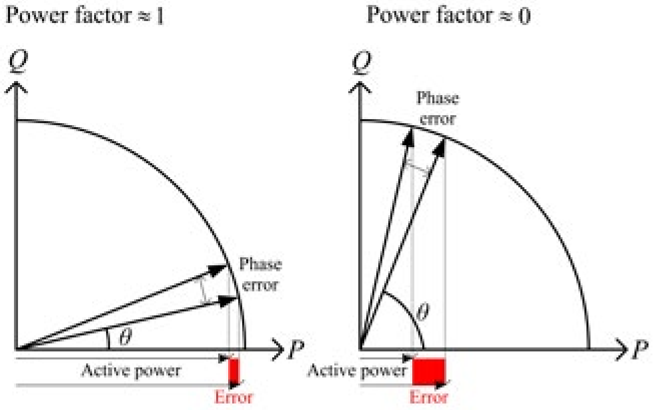

**Figure 5: Relationship between phase error and active power error at different power factors**

**Issues Faced by a Power Measurement System**

The indicator for evaluating flat amplitude and phase performance is the active power frequency characteristics at zero power factor of the power analyzer. Figure 6 shows examples of the active power frequency characteristics at zero power factor of a general power analyzer and the Hioki Power Analyzer PW6001. From Figure 6, in the example of a general power analyzer, even if the measured device is an IGBT inverter, you can see that the analyzer's performance is insufficient to accurately measure the switching frequency and the power of its harmonic components. On the other hand, the Hioki PW6001 has flat characteristics up to 1 MHz, and you can see that both IGBT and SiC PWM inverter power can be accurately measured. Thus, the active power frequency characteristics at zero power factor is an indicator for evaluating the measurement performance of PWM inverter power.

Next, Figure 7 shows an example of the amplitude and phase-frequency characteristics of a conventional 500A rated (DC to 100 kHz) pass-through current sensor. In general, current sensors tend to have increased phase error in high frequency regions due to the characteristics of the sensor's magnetic core and circuit. As mentioned earlier, to measure PWM power accurately, flat amplitude and phase characteristics are required in the frequency band up to about 5 to 7 times the switching frequency. In the example of the current sensor shown in Figure 7, even if the measured device is an IGBT inverter, you can see that the performance is insufficient to accurately measure the switching frequency and the power of its harmonic components.

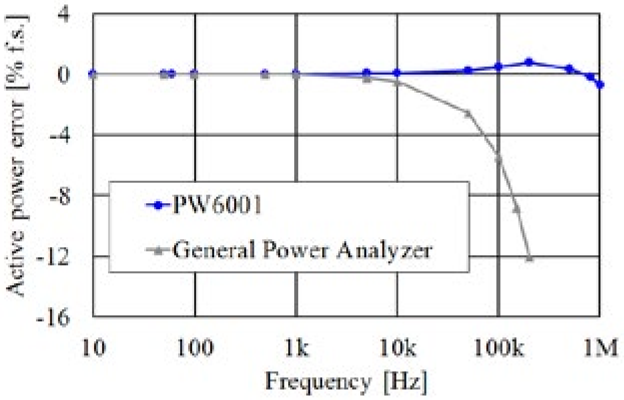

*Figure 6: Example of active power frequency characteristics of the PW6001 Power Analyzer at zero power factor*

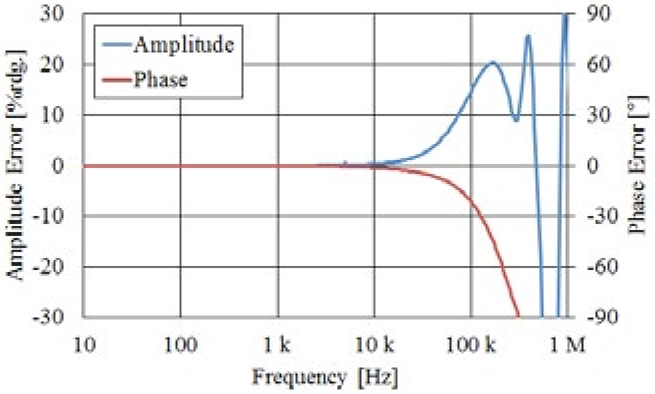

*Figure 7: Example amplitude and phase frequency characteristics of a conventional pass-through current sensor*

Furthermore, in a high frequency switching environment with switching elements, common mode noise tends to be superimposed on the current sensor via the measured device. As an example, in the current waveform zoomed in on the time axis shown in the lower part of Figure 3, high frequency noise synchronized with the switching timing of the voltage is superimposed on the current waveform.

When measuring PWM inverter power, the frequency characteristics of these current sensors and the effects of common mode noise are the main factors that cause measurement accuracy of the active power of the switching frequency and its harmonic components, which have a low power factor, to deteriorate. For this reason, in a PWM inverter power measurement system combining a conventional current sensor and a power analyzer, the effects of measurement error of the switching frequency and its harmonic component are much larger than the effects of measurement error of the fundamental wave and its harmonic component. For this reason, we need to resolve the issue of not being able to accurately measure PWM inverter power.

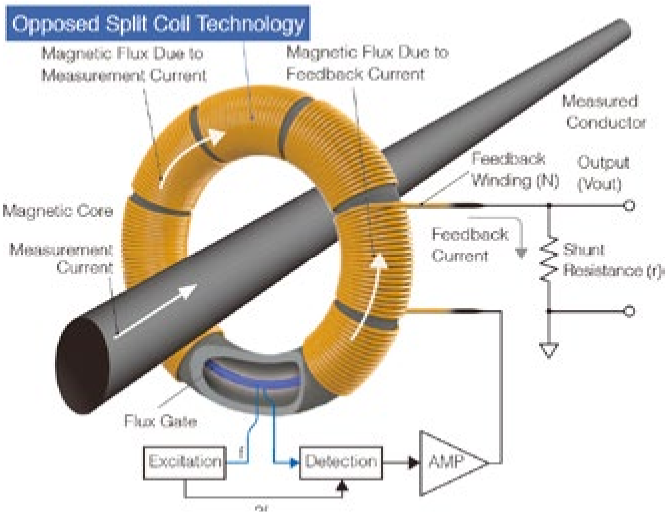

*Figure 8: Operating principle of zero flux method using fluxgate element*

### A Newly Developed Current Sensor and Phase Shift Technology

To solve this problem, Hioki developed three types of AC/DC current sensors with a rated current of 500A, 1000A, and 2000A (Table 2). All of the sensors use the zero flux method with the fluxgate element. Fig. 8 shows the principle of operation. Highly accurate measurement is performed by supplying a feedback current to the feedback winding

| **Model** | **CT6875**<br> | **CT6876**<br> | **CT6877**<br> |
|---|---|---|---|
| **Rated Current** | AC/DC 500 A | AC/DC 1000 A | AC/DC 2000 A |
| **Frequency Band** | DC to 2 MHz | DC to 1.5 MHz | DC to 1 MHz |
| **Basic accuracy** | ±0.04%rdg.±0.008%f.s. | ±0.04%rdg.±0.008%f.s. | ±0.04%rdg.±0.008%f.s. |
| **Measurable conductor size** | ϕ36 mm (1.42 in) or less | ϕ36 mm (1.42 in) or less | ϕ80 mm (3.15 in) or less |
| **Common-mode rejection ratio (100kHz)** | 120 dB or greater | 120 dB or greater | 120 dB or greater |
| **Output voltage** | 4 mV/A | 2 mV/A | 1 mV/A |
| **Offset voltage** | ±15ppm typical | ±15ppm typical | ±10ppm typical |
| **Linearity** | ±5ppm typical | ±5ppm typical | ±10ppm typical |
| **Operating Temperature** | -40°C to 85°C | -40°C to 85°C | -40°C to 85°C |

*Table 2: Main specifications of newly developed current sensors*

(closed loop) so that the magnetic flux generated in the magnetic core is canceled by the alternating current flowing in the measured conductor. A newly developed opposed split coil (coil in which divided windings are arranged opposite each other on a magnetic core to broaden the range of current detection) was adopted as the sensor, and a wide band was realized. In addition, a shield layer was formed inside the case to improve CMRR (Common Mode Rejection Ratio).

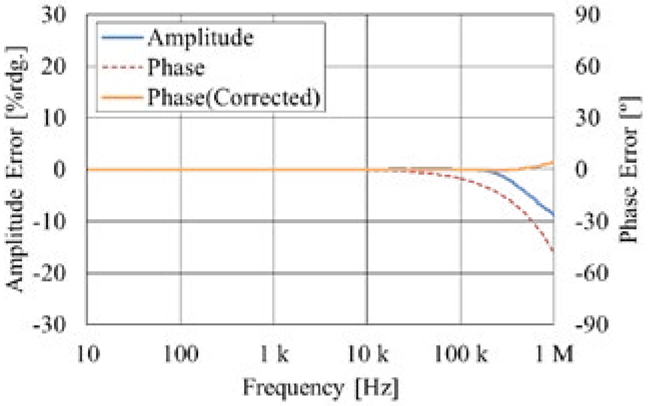

*Figure 9: Example amplitude and phase frequency characteristics of the newly developed Hioki CT6875*

Based on the above technology, the newly developed sensors bear the following distinctive features:

- Wide measurement bandwidth exceeding 1MHz
- Superior linearity that maintains high precision even down to low levels
- High CMRR at wide bandwidths, with almost no effects from common mode noise
- Excellent temperature characteristics that helps achieve high long-term stability

Figure 9 shows an example of the frequency characteristics of the Hioki CT6875 AC/DC Current Sensor rated at 500A. The phase of the frequency characteristics example represents the characteristics when using the current sensor phase shift function [2] available on Hioki Power Analyzer PW6001, in addition to the individual characteristics of the CT6875. When using the phase shift function, we set the phase characteristics value specific to the current sensor in the PW6001 in advance. As a result, the PW6001 measures power in real time while computing phase shift according to the set value. By combining the newly developed current sensor and the PW6001's built-in current sensor phase shift function, it is possible to improve the phase characteristics in the high frequency range at each stage as part of the power measurement system.

Figure 10 shows an example of the CMRR characteristics of the CT6875. CMRR is dramatically improved via the shield inside the sensor case. This can prevent high frequency common mode noise from being superimposed on the current waveform.

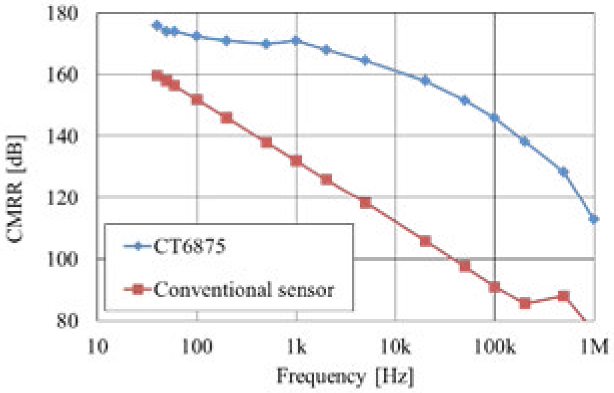

*Figure 10: CMRR-Frequency Characteristics of the CT6875*

Through the improved performance of these current sensors, PWM inverter power can be measured accurately by pairing them with the PW6001.

**Comparison of Actual Measurement Results of PWM Inverter Power**

Using the SiC inverter shown in Table 1 above, we measured and compared the PWM power measured using the PW6001 in combination with the three newly developed current sensors and a conventional pass-through current sensor. The motor's rotational speed and load torque are constant, and the inverter switching frequency is measured under each operating condition of 10kHz to 200kHz. The

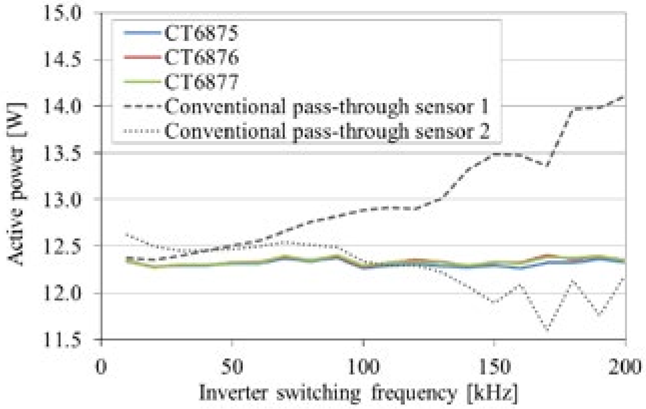

*Figure 11: Sensor comparison when measuring PWM inverter power*

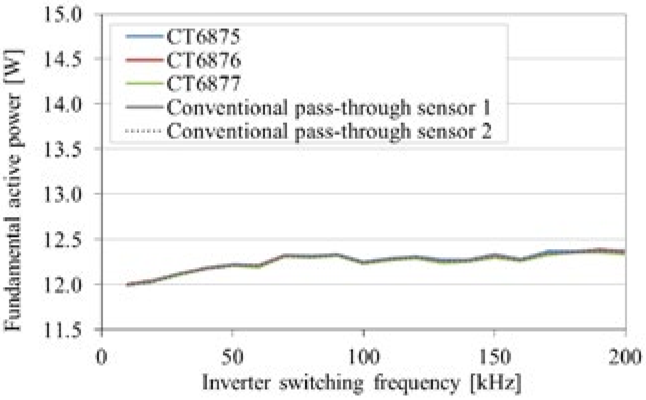

*Figure 12: Sensor comparison of the fundamental wave component of PWM inverter power*

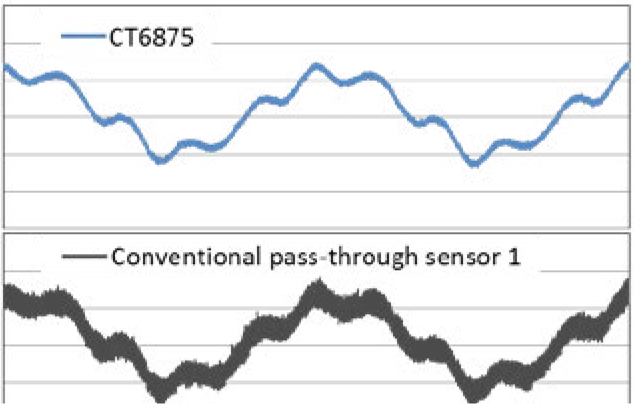

*Figure 13: Comparison of the current waveforms of PWM inverter output*

newly developed current sensors are properly performing under the phase shift settings on the PW6001.

The power measurement results are shown in Figure 11. The new sensors showed almost identical measurement results for all three models at any switching frequency. On the other hand, for the conventional pass-through current sensor, the difference between the measured value and those obtained with the new sensors becomes larger as the switching frequency becomes higher.

On the other hand, Figure 12 shows the comparison of the fundamental power measurements under the same conditions. The fundamental power measurements were almost identical for all models at any switching frequency.

Furthermore, Figure 13 shows the comparison of a current waveform of the PWM inverter output under the operating condition of a 100 kHz switching frequency between the newly developed CT6875 and a conventional pass-through current sensor. Despite measuring the same object, CT6875 achieves it with low noise. The dramatic improvement of the CMRR characteristics is due to the shield inside the sensor case.

From these results, it can be inferred that the significant deviation shown in Figure 11 between the active power measurement values of the three newly developed current sensors and that obtained by the conventional sensor is attributed to the measurement performance in the frequency band of the switching frequency and its harmonic components (amplitude characteristics, phase characteristics, CMRR characteristics).

**Summary**

In this article, we illustrated the importance of measuring power accurately in the inverter switching frequency and its harmonic frequency domain in order to properly evaluate the performance of high efficiency motor drive systems. We also provided measurement examples that showed that a power measurement system combining the Hioki Power Analyzer PW6001 that delivers superior performance and a phase shift function with newly developed Hioki AC/DC Current Sensors CT6875/ CT6876/CT6877 can result in accurate efficiency evaluation of high efficiency motor drive systems that has been difficult until now.

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# Thermal Resistance and Capacitance are Critical Parameters of Power Devices

*Modern power transistor chips shrink continuously, GaN and SiC chips are by nature even smaller than silicon. Thermal resistance and capacitance are impaired.*

*By Dr. – Ing. Artur Seibt, Vienna*

**Definition of the problems**
From its beginnings the semiconductor industry is continuously busy to shrink their chips. Chip size not only is a cost factor, but in the case of power transistors the thermal resistance and capacitance are adversely affected. The smaller contact area between chip and housing increases the thermal resistance junction-to-case Tjc, and the thermal capacitance is reduced due to the lower mass. Newer chips thus run hotter than their predecessors for the same power dissipation, and those chips can not take as much short.term overload either. In SMPS start-up and output overload can impose a sudden increase in power dissipation, the lower the thermal capacitance is the higher the temperature will rise and may reach destructive levels. While older, larger chips took such stresses easily more recent ones may fail. Users are seldomly notified or warned if a chip was shrunk, sometimes a suffix like “A” is added to the type designation, which should ring the alarm bells with engineers. Manufacturers praise the lower electrical capacitances, the faster switching but it is a rarity if they also mention the disadvantages incurred. Often the data sheet remains unchanged although the chips were shrunk.

So it may happen that suddenly transistors from a new shipment fail while such failures of the same type previously never occurred. In such cases prime customers can force the semiconductor manufacturers to continue production of the larger chips, and, although the former type designation was removed from the firm’s catalog it is still available - if one knows this. Sometimes chip shrinking goes along with a change to a less expensive technology which is more delicate and sensitive to overload. In case of sudden, unexplainable failures it is advisable to check first whether these parts came from a new shipment. If yes the next step is to compare new chips with ones from earlier shipments. If these tests confirm that the new ones fail and the old ones not confront the manufacturer with the results and ask whether the chip was altered, and what the date codes of the new ones are. Distributors can then be asked whether they still have old chips in stock. If not, one will be forced to switch to the new type; in order to get a chip which is comparable to the “old” one, it will be necessary to choose a type which is one or two sizes larger than the data sheet implies, the thermal resistance spec should be the guide. This also applies when looking for the right size transistor for a new design. Not only electrically, but also thermally a transistor must be adequate.

In thermal circuits Ohm’s law applies: temperature difference equals voltage, heat flow equals current, and the resistances add up. The vital parameter is junction temperature Tj. The user has no access to the junction and is unable to check its temperature. The manufacturers place test structures like diodes on the chips which accurately measure the temperature. The user has to trust the manufacturers’ data sheet specifications of thermal resistance junction-to-case Tjc, he can only measure the case temperature, but in order to arrive at meaningful results two problems must be solved: how can the temperature of the transistor case be measured if there are high fast pulses like 360 Vpp in 10 ns? And how can the power dissipation of switching transistors be accurately determined?

High fast pulses will disturb most temperature measuring instruments so much that they give false results, also the high capacitance of the probe may disturb the switching. It is therefore necessary to measure immediately after turn-off with a contact probe. The best method of determining the transistor power dissipation is this: first the case temperature of the power transistor is measured, then the transistor is exchanged against a power resistor in the same type case, e.g. TO-220. This resistor is heated up to the same case temperature from a precision supply; and this power is identical to the transistor’s. Attempts at calculating a switching transistor’s power dissipation lead at best to approximate results because switching is very complex. Standard silicon power mosfets are in fact no simple mosfets as the symbol implies but consist of a cascode connection of a power jfet and a mosfet and associated capacitances - which is very seldomly mentioned. Especially turn-off is complicated, and the vital capacitances are nonlinear. Figures 1 and 2 show the true internal structure of power mosfets, small signal mosfets conform to the symbol.

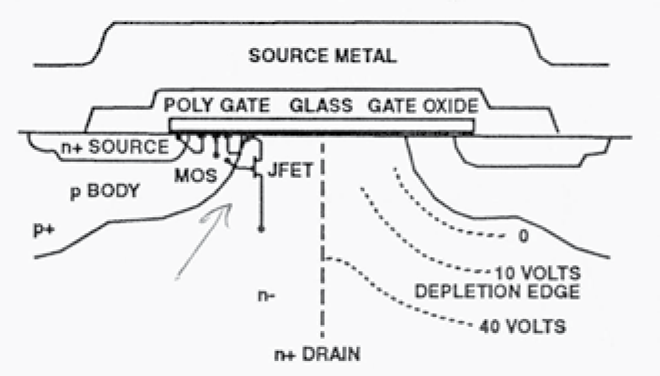
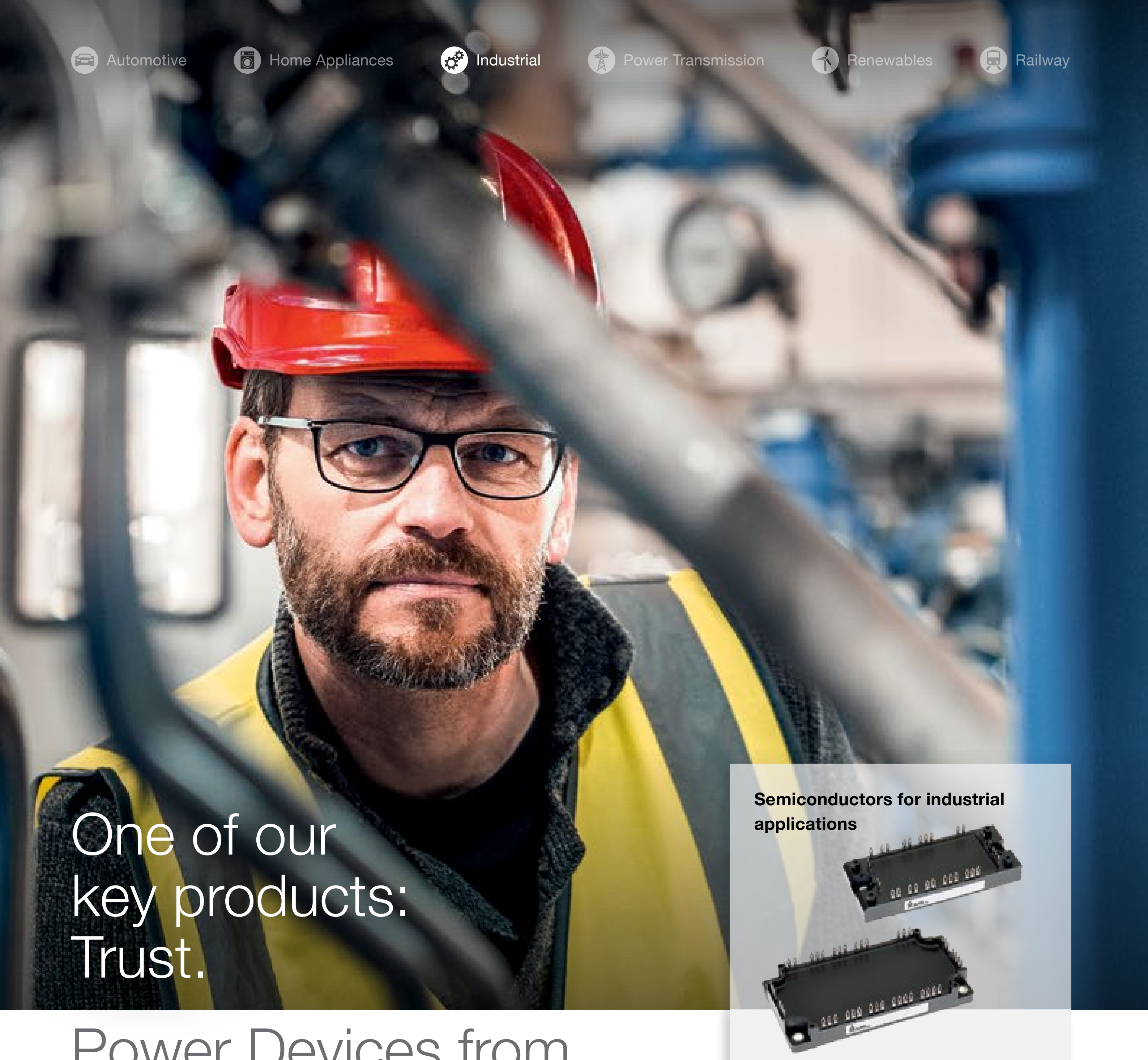


*Figure 1: Cross sectional view of a standard silicon power mosfet shows a cascode connection of a power jfet and a mosfet. Yes, the power device is a jfet.*



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This complex structure explains why it is easy to switch the mosfet on, but the user has no control over the switching off, he can only switch the inside mosfet off, but he has no access to the power jfet, and current will continue to flow alone via the capacitances. In practice the products of the various manufacturers with the identical type designation vary widely in their turn-off behavior. Turn-off happens in stages: the current will fall rather fast to about half, but stay there for times which reach from a few ten ns (good mosfets) to over hundred before it falls to zero. As the voltage will rise quite fast, the product voltage times current can reach destructive levels. Experienced engineers know this and will specify only the products of the manufacturers they tested. In other words: by no means is it acceptable to buy from any manufacturer who produces parts with the same designation. Failures caused by slow turn-off have nothing to do with thermal resistance and capacitance, but it is evident that a large chip will take overloads easier.

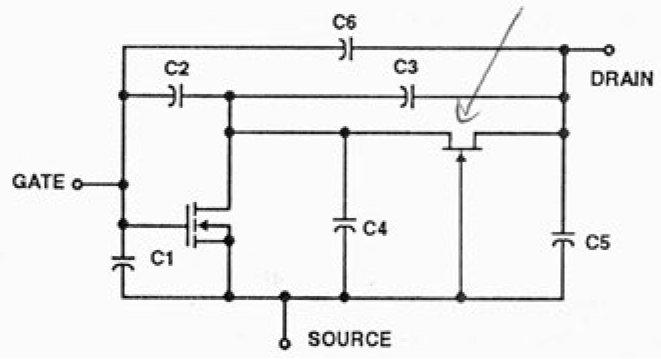

*Figure 2: Equivalent circuit of the above structure. Both drawings are from Harris Semiconductor application notes.*

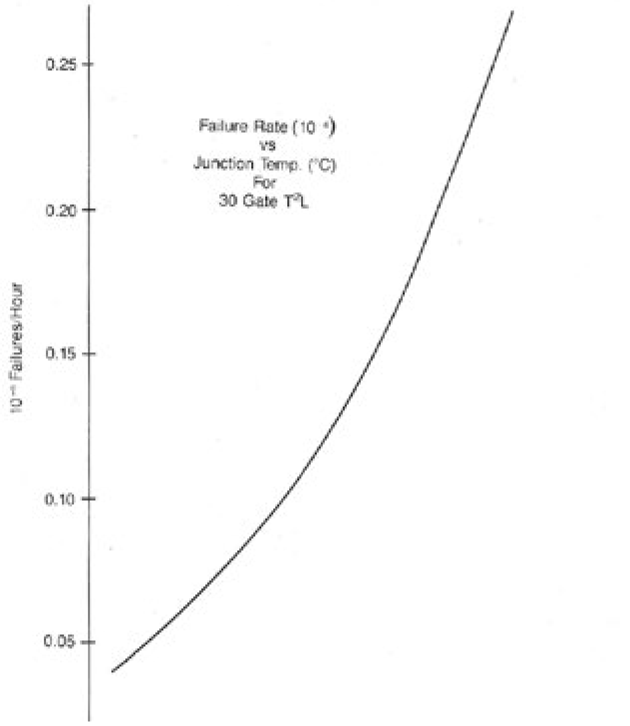

*Figure 3: Dependence of semiconductor life on the junction temperature: 10-6 failures per hour vs. time.*
*It should be noted that there are more influences on the service life, e.g. moisture will influence plastic encapsulated devices. SMD packages are more affected than through-hole devices because there is only a thin layer of plastic*

A frequent misunderstanding concerns the meaning of the "maximum Tj " in the data sheets. By no means is it implied that a component can be operated at or even near this temperature! The manufacturer guarantees only that the part will function up to this temperature, but no more. Quite independent of the maximum junction temperature the law of halving life for every 9 K applies! This is why important users of electronics as a rule prescribe a maximum operating junction temperature like 110 or even 90 C in order to ensure a meaningful service life resp. low failure rates. Applications where such components are stressed close to their maximum ratings, such as in the vicinity of combustion engines in autos are possible because it is often forgotten that an auto is only operated for a few thousand hours in its life, and that the worst operating conditions occur only seldomly, too, e.g. during traffic jams in summer.

The exponential dependence of life on the junction temperature meaans that every degree counts: the cooler a component runs the longer it will function. There are large scale products like smartphones which are designed for two years, but the bulk of electronic products has to last for many years, even up to 15 or even 30 years. The designer can only meet such requirements by operating the components at low junction temperatures.

**Thermal resistance and capacitance**
The newest Coolmos chips became so small that the thermal resistance in TO-220 of some goes up to 2 K/W while the older ones were mostly below 1 K/W. This means e.g., at a power dissipation of 10 W, an increase of 10 degrees C in junction temperature with such new devices over their predecessors.

This problem is no better with the new materials GaN and SiC: these chips are much smaller than silicon chips of the same Rdsons, a fact which is often overlooked. The thermal conductivity of GaN is lower than that of silicon while that of SiC is higher. Both materials take higher temperatures than silicon so that even though the masses are so small the temperature increase in case of short-term overload may rise even above 250 C without causing a failure. Due to plastic package limitations most parts are specified for a continuous Tj of max. 150 C.

Thermal capacitance equals electrical capacitance; it is charged up to a certain temperature by a thermal current like a capacitor which is charged up to a certain voltage by a current. Thermal capacitance is defined by:

$C_{th}$ = V x ρ x $c_p$   V = volume ($m^3$), ρ = density ($kg/m^3$),
$c_p$ = specific heat (J/kgK)

In practice only the product ρxcp counts which does not vary much between materials. Data sheets rarely specify thermal mass resp. capacitance, they show a graph of the thermal impedance vs. time with the single pulse energy as the parameter. The higher the thermal mass, the more short-term overload a chip can take without failure. In SMPS, if soft start is not provided, start-up will overload for a moment because all electrolytics are empty. Simple output current limiting circuits are fairly slow and also cause a momentary overload which is more dangerous because the power devices are already hot.

**Mounting considerations**
Transistor thermal resistance Tjc is a component property, the designer has only influence on the other thermal resistances: case-to-cooling surface and mostly also an insulator. Here quite a few problems are hidden. For the benefit especially of our young engineers the

following hints: Neither the surface of the transistor case nor that of the mounting hardware are flat, also the surface finish is often poor. The actual contact area available for the heat transfer is hence much smaller than the area of the transistor case, causing an increased thermal resistance. Also the method of mounting the transistor influences it substantially. Rivets are completely out. Screws are a solution which has become obsolete for several reasons. Apart from the fact that mounting with screws is labor intensive and expensive, it is only acceptable if the mounting torque is limited and a spring washer is used. Limiting the torque is essential because if the screw is tightened too much the effect shown in Figure 4 will ensue: the case will be lifted so that the contact area is severely reduced.

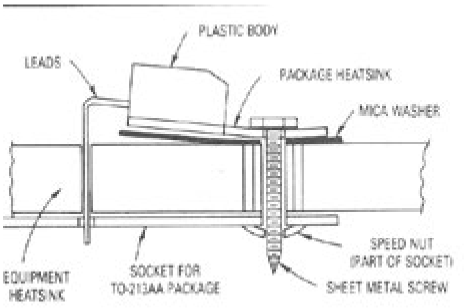

*Figure 4: What happens if the screw is tightened too much: the rather soft case metal will flow, bend and lift the case off, causing a severely reduced contact area and thus increased thermal resistance.*

The professional method uses spring clips which press upon the plastic body; this exerts the pressure where the chip sits and prevents any bending of the case. Also the spring keeps the force up over time even if an insulator softens and yields. A cost saving and effective cooling method is to use a U-shaped aluminum chassis and to arrange all power semiconductors along the circumference of the e.c. board; the spring clips press the components against the side walls of the chassis.

Care must be taken regarding the transistor leads, the material is quite brittle and does not take much bending. If bending is necessary it should be limited to once, and the leads must be supported near the body. Also no mechanical stress must be left on the leads after mounting, otherwise failures are programmed! Connection with wires solves this problem, but is rare because it is expensive and increases lead resistance and inductance.

SMD power devices are a special case because the standard FR-4 material is a very poor heat conductor. The large copper areas shown on the data sheets are never realized in practice. Power dissipations are thus limited to a few watts at best. Higher values require the use of heat sinks.

For heat sinks manufacturers specify thermal resistances, but these are obtained under special testing conditions and thus variables. In any application where the heat sink is mounted otherwise the figure does not apply.

**Interface materials, Insulation**

Most switching transisrors have the drain connected to the tab resp. case. In offline-SMPS the drains are on line potential, high insulation against the cooling surface, mostly the chassis which is connected to safety earth, is required. The insulation between drain and chassis has to fulfill three requirements:1. Insulation good for at least 1 KVrms 50 Hz up to 4 KVrms; also creepage requirements have to be observed, e.g. 8 mm; in case spring clips are used which press upon the body, with TO-220 8 mm can not be realized against the drain, in this case the spring clip must be also insulated. 2. Good thermal conductance, 3. Low capacitance and low dielectric losses. The latter is often overlooked; the high and steep pulses at the drain, e.g. of a PFC switching transistor 360 Vpp in 10 ... 20 ns cause enormous dielectric currents through that insulator which produce dielectric losses in the first place and, secondly, these currents flowing into the chassis generate strong emi. The dielectric losses heat the insulator which goes by undetected because this heat can not be discerned from the heat contributed by the transistor.

The current and the emi disturbances are proportional to the dv/dt, hence faster switching will improve the efficiency somewhat, but cause higher stress on the insulators and increased cost and space for emi filtering components. These days there is much talk about the faster switching of GaN and SiC transistors, the truth is that those are mostly cascodes which switch in such circuits in about 5 ns, the very same results are obtained with Si Coolmos cascodes, because - what is not conveyed - the switching speed in a cascode is solely determined by the lower transistor which is a standard Si mosfet; it is immaterial which kind of transistor is upstairs, also a high fT npn will do. These GaN and SiC cacodes have true advantages in such circuits where also reverse currents flow and they can operate at much higher junction temperatures.

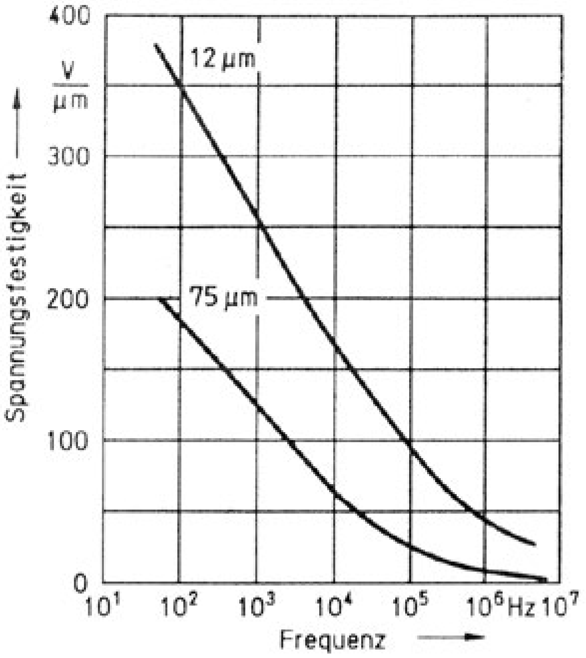

*Figure 5: Dependence of insulation properties on frequency of typical materials, here of polyester foils, shows the drastic decrease. At typical SMPS frequencies around 100 KHz a 75 um foil drops from 200 V/um to 25 V/um, at 1 MHz almost nothing is left! Nevertheless, PE is the most used material for SMPS inductive components.*
*Such graphs are rarely available for thernally conductive insulation materials.*
*50 Hz material specifications have no meaning at these frequencies and will lead to grossly false designs*

The insulating properties of all insulators deteriorate drastically with increasing temperature, also their life is shortened, ceramics excepted. Ceramics like alumina are ideal:  from the electrical standpoint, they take high voltages and have extremely low losses and capacitances, they take high temperatures without ageing, but in practice they are difficult to handle and expensive. The best material is beryllium oxide but it is poisonous. Even if the surfaces of ceramics are lapped they can hardly be mounted without thermally conductive grease on both sides. Only spring clips may be used although most ready-made plates have holes.

Plastic insulation materials age, the more, the higher the operating temperature which is, as a rule, quite high for thermally conductive insulation.

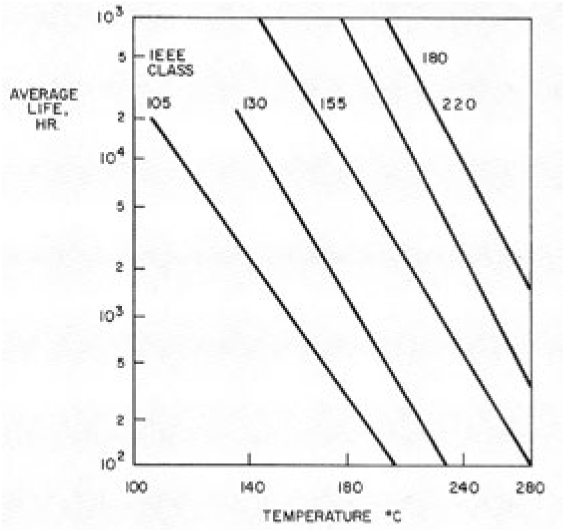

*Figure 6: The 5 IEEE classes for insulation materials. The graph shows the dependence of life on the operating temperature. This is especially important for electronic gear which is continuously on. Take class 130 as an example: at 100 C life is only 2 x 104 which is a little more than 2 years*

In practice 3 kinds of materials are used: 1. silicone rubber, filled with ceramic powder, 2. socalled phase-change materials. 3. Gels.

Earlier mica and silicone grease, filled with silica, alumina or zinc oxide, were customary, but the latter suffers from severe disadvantages: Grease tends to migrate, leaving a film which fouls up connectors, prevents adhesion and soldering. The thermal cycling favours the migration of the grease which then leaves voids under the device, causing increased thermal resistance and higher Tj, even failure. It is also deleterious to eyes and hands and unpopular in production environments.

The first material class fulfills all requirements, but care must be taken not to use too thin materials, the transistor cases will cut into the material, for offline-SMPS purposes 0.4 mm material is a minimum.

Phase-change materials are solid and can be applied like any other solid material; as soon as the transistor heats up to its operating temperature this material starts to soften and flow, filling the gaps and holes like a grease, but it does not migrate. The thermal conductance is the same as that of grease. The gel materials deliver the best performance, they transfer the heat at the lowest necessary pressure and don't migrate either.

Of course each insulator contributes additional thermal resistance. Typically a TO-220 transistor silicone rubber, ceramic filled,  insulator of 0.4 mm shows 4 K/W which is much compared to the transistor's Tjc  of e.g.1.5 degrees/W, not to speak of large dies in professional TO-3 cases which sport 0.1 degree/W. Taking the above example 10 W of dissipation would create a ΔT = + 55 K between junction and cooling surface. At a typical 85 C ambient temperature in a SMPS and at its housing the Tj would reach 140 C which is not acceptable. Either the dissipation must be reduced or an overtemperature sensor on the cooling surface (chassis) switches off when 60 C are exceeded. This example illustrates, by the way, that the currents and power dissipations on data sheets have mostly lttle bearing in practical applications. Fictitious 25 C specs are theoretical, no power device operates at 25 C case.

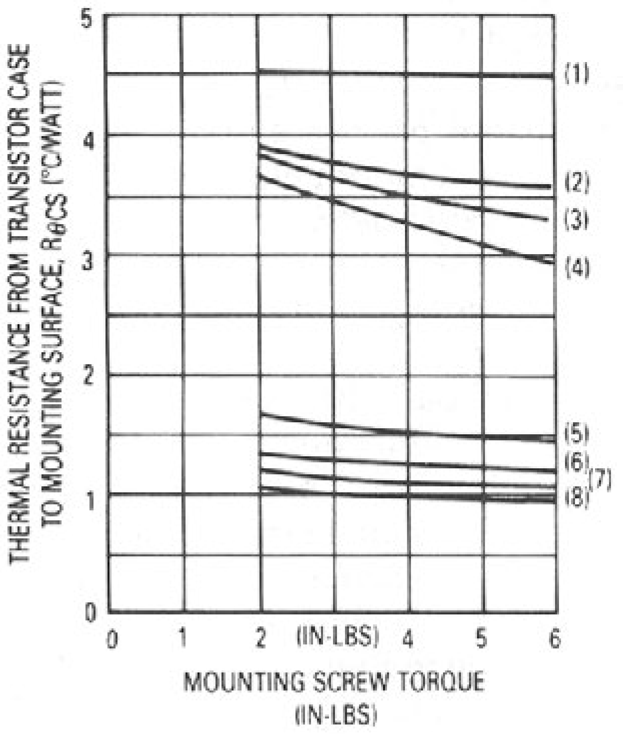

*Figure 7: Interface thermal resistance of TO-220 without grease for several older interface materials.*
*Curve 1 Thermalfilm*
*Curves 2 and 3 mica*
*Curve 4 Hard anodized*
*Curve 5 and 6Thermalsil*
*Curve7 Bare joint*
*Curve 8 Grafoil*

**Thermal runaway**

Thermal runaway is a condition which leads to eventual destruction of a power device. If a transistor heats up, its power dissipation increases, this holds for all types. In mosfets the Rdson increases. The higher dissipation causes a temperature increase. This is a thermal closed loop system, similar to an electrical closed loop. As long as the loop gain stays below unity the system is stable. Each ΔP creates a ΔTj. Two situations must be considered. In the first scenario the cooling surface remains at a fixed temperature. When the power dissipation rises, the temperature difference (equals voltage) between the junction and the cooling surface increases, causing increased heat flow (equals current).In practice, this is rare, consider a popular execution of a SMPS, the U-shaped chassis, also called open frame, which serves as the cooling surface for the power devices; this will heat up, so that the temperature difference between junction and cooling surface will remain constant or shrink. An increased power dissipation will hence not cause an increased heat flow. The consequence is that the junction temperature must rise according to the sum of Rth,jc and Rth, c-to-chassis . Now comes the dependence of the transistor losses on its temperature into play: Rdson rises with temperature and mostly in a nonlinear fashion. Each ΔP causes a higher ΔTj the higher the temperature already is. In other words: the ΔP necessary to generate a given ΔTj becomes ever smaller the hotter the junction, eventually it becomes zero, and this is the point of runaway. The vital fact is that in such a situation the increase in power dissipation comes about automatically, without an increase in the product voltage times current. The loop gain is now unity, the temperature will increase fast to destruction.

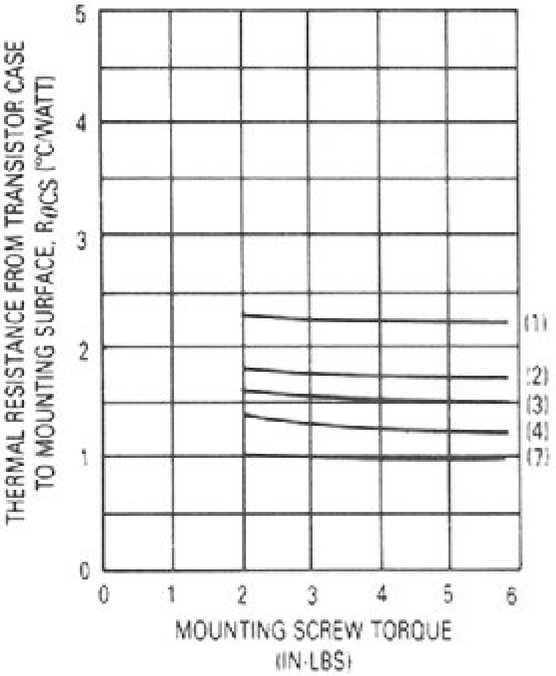

*Figure 8: TO-220 with thermal grease and the same materials as above.*

It is hence necessary, in a professional design, to check whether there is the danger of thermal runaway; with the aid of the curve Rdson vs. junction temperature in the data sheet and the known thermal resistances this can be done. Each SMPS requires an overtemperature sensor which switches off before destruction can set in. The right place is mostly the chassis in the vicinity of the power devices  Quite independently an electrical overload protection must exist, if this is not provided an output overload will cause a sudden increase in junction temperature; before the chassis is heated up so much that the sensor responds, the transistor will be destroyed. There are other temperature sensitive devices, e.g. low forward voltage Schottky diodes; they suffer from the disadvantages of low reverse voltage and very high leakage currents which can cause thermal runaway.

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# Solving the Voltage Drop Problems of Industrial Power Lines

*The LT8710 is a versatile dc-to-dc controller that supports boost, SEPIC, inverting, or flyback configurations, and is widely used in automotive and industrial systems. It includes features that enable use in applications with high impedance power supplies, or where input current must be limited. For example, long power lines in industrial plants and warehouses add significant input source resistance, as well as a significant voltage drop from converter to load.*

*By Victor Khasiev, Analog Devices, Inc.*

This value can change as equipment is relocated, further complicating regulation. Solar panels also have a high impedance input, with a peak power output and a narrow voltage range. This design note demonstrates how the LT8710 can solve the problems of high impedance and current limited input sources, through the example of a lithium-ion battery charger.

### Circuit Description and Functionality

Figure 1 shows a charger solution for a 20 V lithium-ion battery commonly used in portable power tools. The voltage source, VSRC, is 24 V via a high impedance power line, resistor RLN, resulting in the voltage VIN at the charger input terminals. The voltage source could be considered as a popular 12 V solar panel with 22 V to 24 V open-circuit and 18 V to 19 V optimum operating voltage. The charger is based on a synchronous, noncoupled SEPIC topology and controlled by the LT8710. The power train consists of discrete inductors L1, L2, transistors Q1, Q2, decoupling capacitors between the inductors, and input/output filters. Resistor RSC sets 2 A of charge current, ICHRG; resistor RV(FL) sets the float voltage of 21 V. The resistor divider RIN1/RIN2 sets input voltage regulation level, which is 18.6 V in this example.

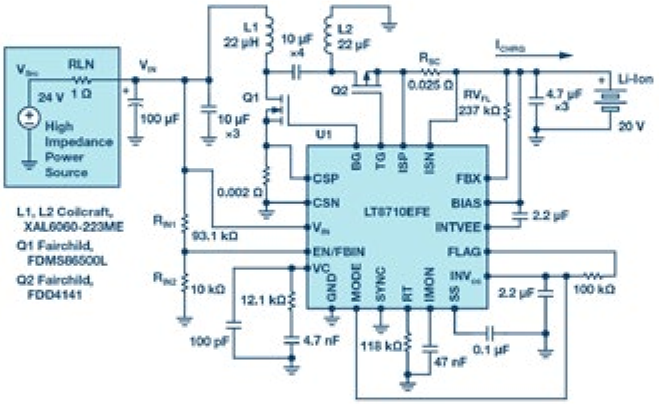

*Figure 1: Electrical schematic of a LT8710 lithium-ion battery charger in high impedance input lines.*

Figure 2 illustrates the functionality of the charging solution over time. When VIN and power source voltage VSRC are above 19 V, the LT8710-based SEPIC charges the lithium-ion battery to the programmed 2 A, ICHRG. As VSRC drops below 20 V, the value of VIN drops correspondingly. When VIN reaches the input voltage regulation level, the LT8710 reduces the charging current, ICHRG, to maintain VIN, even as VSRC continues to decline. The horizontal axis represents normalized time, which can be hours for a solar panel, or minutes, or seconds, for power supplies in complex industrial systems.

Another way to control the load for converters based on the LT8710's input current is to monitor voltage of the capacitor from the IMON pin. Select resistor RSC to provide a voltage close to 50 mV at the maximum current. A corresponding voltage is reflected across the IMON capacitor. If there is no current flow and the voltage across the ISP and ISN pins is zero, then the IMON voltage is approximately 0.616 V. If the ISP–ISN voltage is 50 mV, it reflects the IMON voltage as 1.213 V. This feature, as well as many others, can be evaluated using our demonstration circuit DC2067A and corresponding LTspice® models.

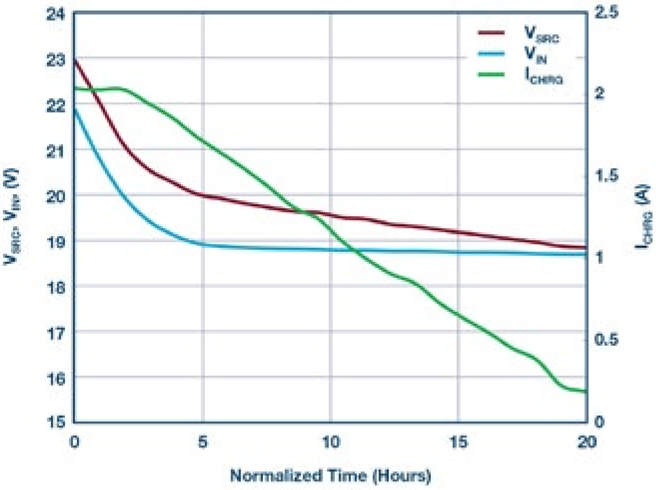

*Figure 2: Charging current (ICHRG) as a function of the voltages power supply (VSRC) and charger input terminals (VIN).*

### Conclusion

The LT8710 is a versatile and flexible controller that supports synchronous SEPIC, boost, and inverting converter topologies. Along with a wide range of input voltages and switching frequencies, it includes advanced features, such as the ability to regulate the input voltage and output current based on input current or voltage. These features make the LT8710 ideal for industrial, solar panel system, and other current limited applications

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# A New Dual-in-Line Surface Mountable IPM for Motor Drive Applications

*This article introduces a new dual-in-line surface-mount device (SMD)-type intelligent power module (IPM) specialized for low-power BLDC motor-drive systems such as fan motors used in home appliances air-conditioners that require highly compact size with reliable and efficient design allowance. The proposed ultra-compact surface mountable IPM has an 18mm x 7.5mm package dimension and is composed of three-phase MOSFET bridge and gate control ICs. The integrated functions include bootstrap circuit, under-voltage lockout (UVLO) protection, temperature monitoring (VOT) and over-temperature protection. It can greatly help to simplify the inverter design in conjunction with smaller footprint PCB and enhance the reliability and cost reduction of the system. The key features associated with design and application consideration are described.*

*By Bum-Seok Suh and Junho Lee, Alpha and Omega Semiconductor, Inc., USA*

**Introduction**

A BLDC-based inverter system is widely used in such consumer applications as refrigerators, washers, dryers, room air-conditioners, and fan motors because it is quicker, quieter, and more energy efficient than the conventional solutions using dc motors or ac induction motors with on/off control. Nowadays, its demand and expansion is becoming mandatory requirement due to energy saving and regulations. The key technology that has enabled this progress is an inverter technology, particularly the transfer mold integrated power module.

Since 1998 transfer-molded package technology has been successfully applied to IPMs for motor-drives utilizing IGBTs, freewheeling FRDs and MOSFETs as power switches, and high voltage integrated circuits (HVICs) as the gate driver [1]-[6]. The voltage and current ranges of the IPM have been successively increased up to 1200V and over 50A. The advantages of transfer mold technology are mainly dual use of the copper lead-frame as electrical conductor that can dramatically reduce the package size as well as the manufacturing cost.

The low-power BLDC-fan motor inverter design used in air-conditioning and purifying systems for home appliances has highly strict cost and size limitation requirements due to its huge quantity and limited product space. There have been several development efforts on one-chip inverter solution for this application by integrating the lateral IGBTs with control circuit on a single silicon chip. They can provide further smaller circuit area, however there are several drawbacks. There is no flexibility of circuit design, and moreover, the power dissipation is concentrated in one location, which can cause a problem of thermal management. The switching performance and ruggedness of LIGBT are less than that of the conventional switching device, which result in very limited application range and controllability.

For these small fan motor-drive applications, Alpha and Omega Semiconductor has developed a new surface mountable IPM. The proposed module consists of advanced MOSFETs and gate driving ICs in a new package, as highly compact, reliable and cost-effective solution. The IPM has extremely small package size thanks to partial super-junction MOSFET technology, HVICs with integrated bootstrap circuit, and optimized design of the package, so that one can significantly enhance the cost-effective development of the system reducing the inverter board size and obtaining easy and reliable PCB assembly.

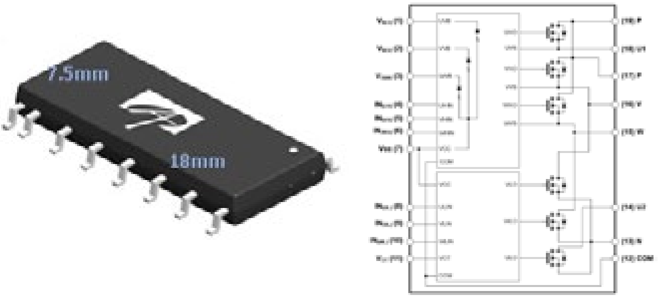


*Figure 1: Proposed IPM. (a) External view, (b) Internal equivalent circuit and pin configuration*

**Compact Package and Electrical Design**

Figure 1(a) shows the outline of the 19-pin counting package of the proposed dual-in-line IPM. A lead-frame construction has been employed and multi chips of MOSFETs and gate-drive ICs have been soldered on it. The total surface required from this package is 18mm x 10.3mm = 185.4mm$^2$ including pin leads. A discrete solution utilizing three pieces of SO-8 packaged HVIC half bridge driver each having a surface demand of 5mm x 6.2mm = 31mm$^2$ and six pieces of DPAK packaged power devices each having a surface demand of 6.5mm x 10mm = 65mm$^2$ requires 483mm$^2$(= 3x 31mm$^2$ + 6 x 65mm$^2$) of the surface. Thus, the conservatively summarized size advantage, ignoring the space for the complicated routing, can be a PCB space requirement of only 38% compared to that of a discrete solution. Figure 1(b) illustrates the internal equivalent circuit and pin configuration which is composed of six MOSFETs as power switching devices, high side gate-driving HVIC including integrated bootstrap components, and low side gate-driving LVIC including temperature sensing (VOT) and fixed over-temperature protection function. Signal COM is located with the power ground N terminal. There are two u-phase output pins U1 and U2 which need to be connected by external PCB wiring.

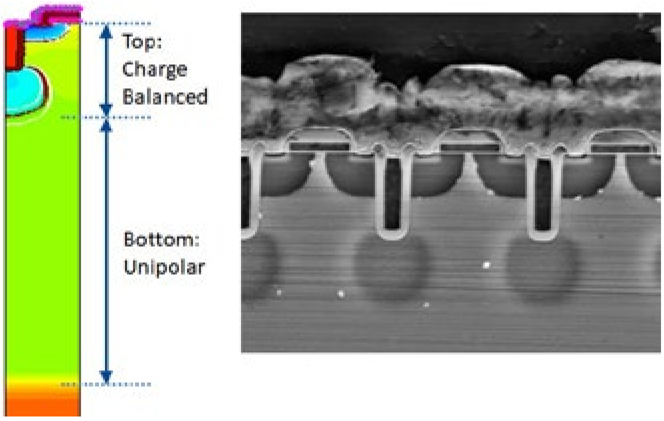


*Figure 2: Vertical structure of a new MOSFET*

Figure 2 indicates the vertical structure of a new MOSFET that is integrated in the IPM. It has been newly developed for motor drive applications which has partial super-junction configuration. The power density Rds·A has been improved by over 30% compared to conventional planar MOSFETs, and it can provide more suitable EMI controllability than super-junction devices.

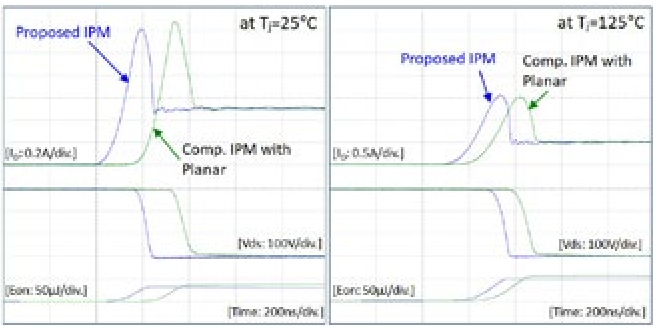


Figure 3: Turn-on switching behavior

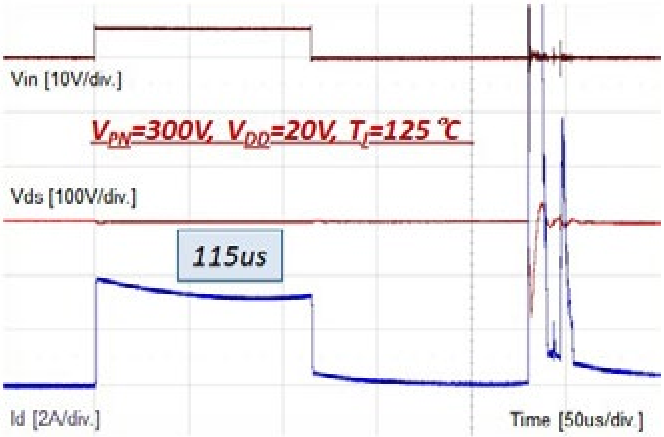


*Figure 4: Short-circuit ruggedness*

An appropriate turn-on switching performance has been achieved by the micro fabrication and wafer process technology for the designed partial super-junction MOSFET. From the experimental waveforms shown in Figure 3, we can clearly state that Irr, Qrr and trr performances are comparable to those of the conventional planar MOSFET technology used in 3-phase motor-drive applications concerning EMI, noise and power dissipation.The optimal selection and design of the gate resistors, Qg, and Vth have been made to prevent the shoot-through issues at turn-on.

Figure 4 shows the evaluation waveforms of short-circuit ruggedness of the MOSFET. It shows over 100us withstanding time that can be good enough for the stable design and control of the inverter.

The switching operating SOA has been evaluated in the light of the practical IPM inverter circuit condition including parasitic circuit inductances. We have increased the applied dc-link voltage up to over 600V although the proposed IPM has 500V of voltage rating limited by the MOSFET breakdown voltage (BV). To guarantee 500V, the typical BV design of the MOSFET is based on 550V. It is noted that there is no any abnormal phenomenon in the switching operation with the condition of 550V of dc-link voltage due to highly rugged MOSFET design as is shown in the waveforms of Figure 5. When we apply over 600V of dc-link voltage, it is observed that abnormal turn-on currents occur because of partial shoot-through current. But there was no destruction failures of the IPM due to strong short-circuit ruggedness.

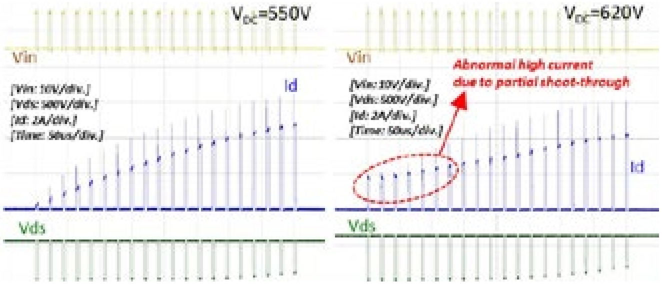


*Figure 5: Switching SOA test*

High precision temperature converting circuit has been integrated into the embedded gate-driving LVIC by the laser-trimming technology. VOT pin generates analog output voltage signal that is corresponding to LVIC temperature. It is possible to use the IPM at a junction temperature much closer to the tolerable maximum rating. Figure 6 illustrates the output characteristics of VOT. Different lot samples have been evaluated to verify the tolerance of VOT performance at the real application condition. It is significant to observe that the LVIC

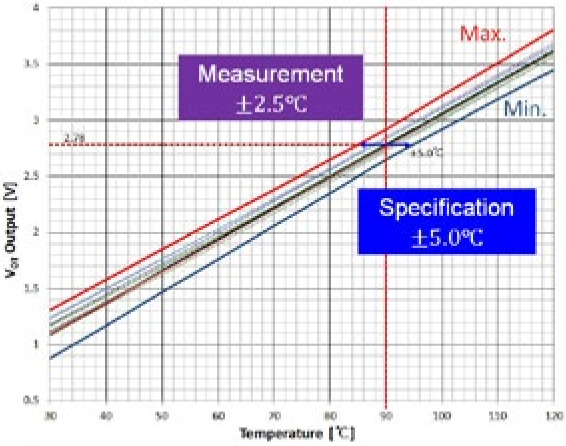


*Figure 6: LVIC temperature output of the proposed IPM*

temperature is accurately measured through the appropriate design of the LVIC and its precise waferprocess technology. Due to the tiny package size of the proposed IPM, the voltage output of VOT will make fast response time according to the junction temperature of the MOSFET. It can provide simple, cheap and accurate solution for the application.

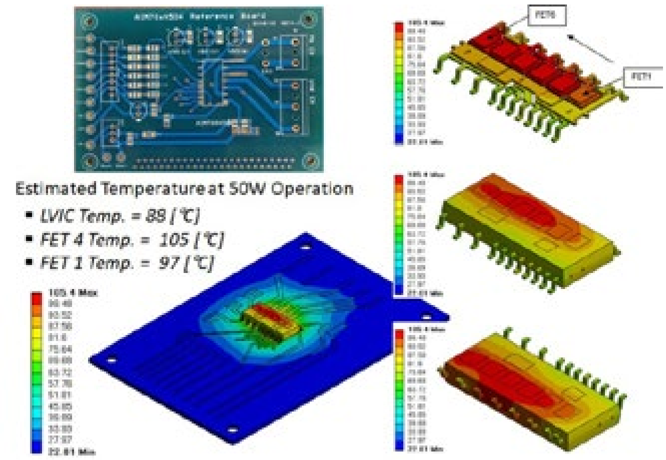


*Figure 7: Operating thermal simulation at fSW=20kHz, PF=0.8, VDC=300V, VCC=15V*

**Application Consideration**

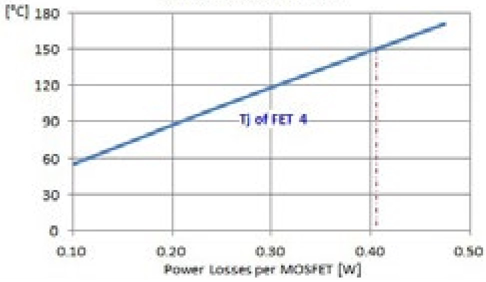
Thermal simulation has been carried out considering 50W-BLDC motor operating condition. The 20kHz of PWM switching frequency has been applied that is considered as normal frequency in the field to avoid audible noise. From the simulation result shown in Figure 7, it is observed that FET 4 has the highest junction temperature and low side FET 1 has the lowest temperature rise. The temperature difference was 8°C between the two MOSFET chips. It can be mentioned that the power rating of the module would be limited by the center chips of FET 3 and FET 4. The LVIC temperature shows 17°C lower than FET 4 one under the applied operating condition.

Figure 8 explains the simulation summary about the application example of the proposed IPM, where the simulation has been carried out based on the continuously operating power condition. In Figure 8(a), the power loss was calculated at 150°C of junction temperature. It was assumed that the maximum operating junction temperature of FET 4 determines the maximum power rating. It should be noted that allowable operating power is decided and controlled by the case temperature Tc as shown in Figure 8(b). The temperature difference between LVIC and FET 4 can reach over 30°C depending on operating power, as depicted in Figure 8(c). In the module design, the fixed OT protection level is typ.130°C of the LVIC temperature. Figure 8(d) indicates FET 4 temperature is slightly higher than FET 3.

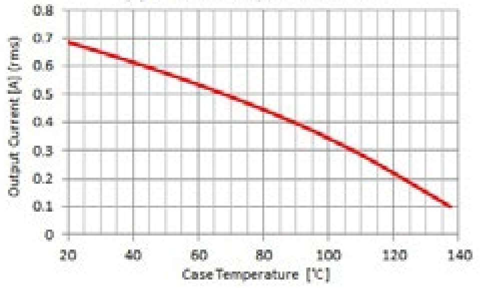
Figure 9 illustrates an application circuit example and experimental set up. The internally fixed over-temperature protection function can be disabled by connecting 10kΩ of pull-down resistor to VOT (pin number 11) or enabled by no connection of the resistor. The analog voltage output VOT to detect the LVIC temperature is always activated no matter what the pull-down resistor connection. It is recommended to use R2-C5 (2kΩ-10nF) filter to avoid noise malfunction for temperature sensing function.

Figure 10 shows the temperature profile taken by an infrared camera. It is shown that the temperature of the center area of MOSFET chips is about 14°C higher than that of the LVIC part at 50W inverter operation.

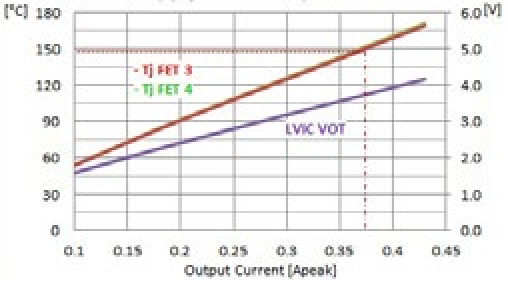
(a) Tj vs. Power Losses



(b) Allowable output current vs. Tc



(c) Tj and LVIC Temp. VOT



(d) Temp. difference between FET and LVIC

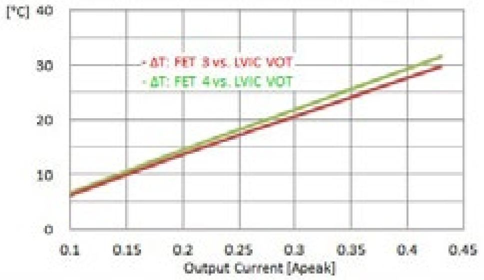


*Figure 8: Simulation result. (a) Power loss, (b) Allowable operating current, (c) Temperature rising, (d) Temperature difference*

Figure 11(a) shows the experimental result for Enabled OT protection function. The OTP is activated when the LVIC temperature reaches its trip level, typ. 130°C. At that point, the measured case temperature Tc was 144°C. The OTP operation is deactivated when the LVIC temperature decreases to its reset level, typ. 100°C. It is obvious that 30°C of the OTP hysteresis level has been accurately designed.

The temperature rise in the case of Disabled OT protection has been also tested by connecting 10kΩ of pull-down resistor to pin 11 as is shown in the measurements of Figure 11(b). It is observed that the LVIC temperature reaches 144°C when the case temperature Tc becomes 160°C. The inverter system has been shut down intentionally for safety.

Another interesting investigation of the IPM application is in the variation of the bootstrap capacitor voltage, as shown in Figure 12. The inverter output frequency was running at 60Hz with 20kHz of switching frequency. The bootstrap voltage is depicted with the output current of the inverter. When the current was positive, the bootstrap voltage VBS increases close to VCC=15V, but it dropped to almost 13V when CBS=1uF. This is caused by different charging mechanism according to the current direction. When the output current is positive, it flows through either a high-side MOSFET or a low-side body diode. In this case, the bootstrap capacitor CBS is charged when the low-side body diode is turned on. The charging peak voltage will be slightly lower than VCC supply in the MOSFET IPM if the body diode voltage VSD is not higher than the forward voltage drop of bootstrap diode during that charging mode. When the output current is negative, the charging voltage will drop as much as the forward drop of MOSFET when the low-side MOSFET serves as the active switching device. However, the bootstrap voltage is the gate driving power supply of the high-side MOSFET and critical only when the current is positive. When the current is positive, the bootstrap voltage does not vary much due to the low VSD of MOSFET, eliminating the need of large bootstrap capacitor. One can have small bootstrap capacitor that is enough to hold the bootstrap voltage against the standby current of HVIC, only when the output current is positive. In the proposed IPM, the high-side UVLO is designed to be typ. 10V.

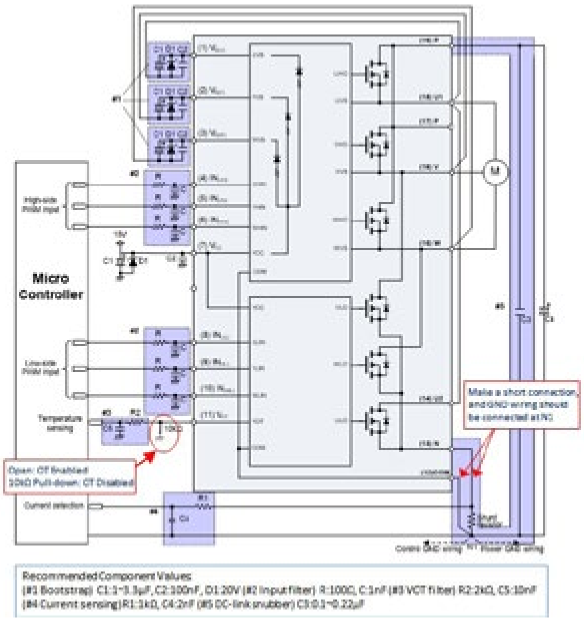


Figure 9: Application circuit example

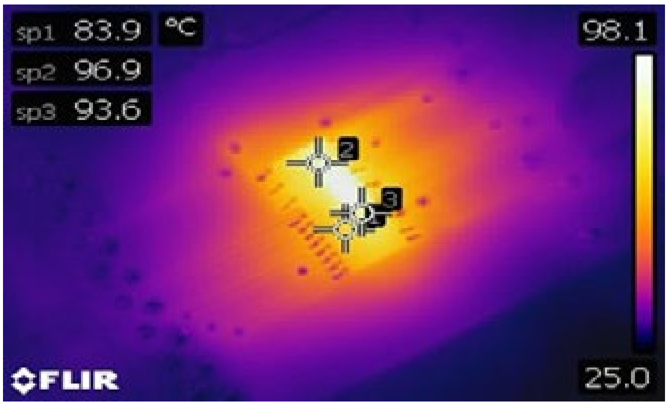


*Figure 10: Temperature profile by an infrared camera*

**Conclusion**

We have presented the new ultra-compact surface mountable IPM for low-power BLDC fan motor-drive system used in home appliances, where ruggedness, temperature protection, power dissipation, electromagnetic interference, noise immunity, and cost reduction are primary concerns. Although the small MOSFET-IPM has reached certain maturity, there are still some issues to address to further increase its performance and reduce its cost. Moreover, advances in enabling IPM technologies and their applications continuously open new development trends and industrial interest. It is expected that the proposed IPM can significantly enhance easy and reliable design of the inverter board, and can allow considerable cost-effective solution of the system.

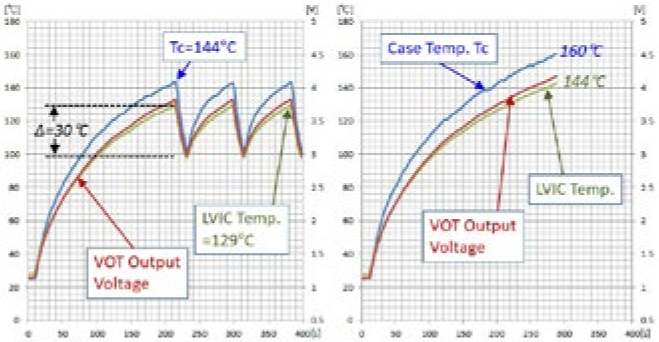


*Figure 11:*
*Over-temperature operation. (a) Enabled OT, (b) Disabled OT*

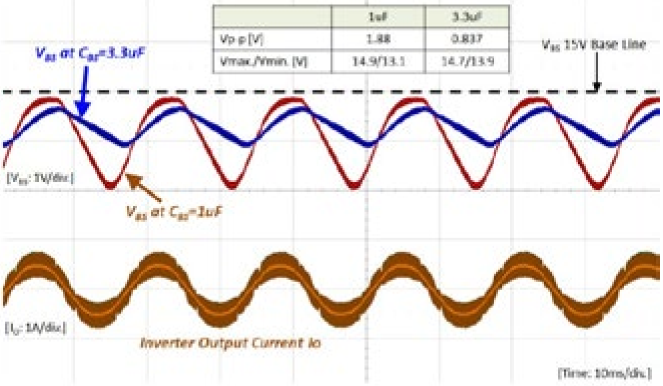


*Figure 12: Variation of the bootstrap capacitor voltage*

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# Digital Power Supply Loop Design Step-by-Step: Part 1

*Designing digital power supply control loops is surprisingly easily. The reason for the mystique may be that even though we study all the necessary techniques at university, unfortunately they are often taught only at great theoretical depth. The theory however, is rarely applied to real life circuits such as a power supply, often making the task intimidating.*

*By Ali Shirsavar*

In this article, and subsequent ones, we will present easy to follow, practical techniques for digital PSU control loop design to help engineers stabilise their digital control loop. These are some of the techniques that are a taught in Biricha's Digital Power Supply Design Workshops [1].

## Introduction

One point that we should stress at the onset is that there is nothing scary about digital control loop design; all we are doing is using a microprocessor to solve a single mathematical equation.

In the analog world, we design our control loops using operational amplifiers. Operational amplifiers also solve mathematical equations. The trick is to create an equation in the digital domain that gives us the same answer that we would get out of our operational amplifier. You will see in the course of this article that the gain output of almost "any" analog op-amp with a known transfer function can be replicated very accurately in the digital/discrete domain with a single equation. There will be some discrepancy in the phase plot of an analog op-amp's transfer function with respect to its digital counterpart, but we will deal with that in a later article.

As suggested in previous Biricha Articles in this magazine, most analog PSU compensators are either a Type II or Type III op-amp circuit [2],[3]. Therefore, all we have to do is to convert the transfer functions of each one of these op-amp circuits into a single discrete time/digital equation.

## Digital Power Supply Building Blocks

In the next figure we have shown a standard digital power supply where the op-amp has been replaced by an ADC and a digital compensator called Hc[z] which, as mentioned earlier, is just a single equation. For now, let us ignore what this equation is and instead concentrate on what happens in a digital power supply in a step-by-step manner.

Please note that we are operating on numbers that are sampled by the ADC and therefore we only know these numbers whenever we have the sample; this is called "Discrete Time". For example, if our switching frequency is 200kHz and we sample the output voltage once per cycle, then every 5µs (i.e. 1/200kHz) we know the output voltage.

So starting from the left hand side of our PSU figure, we have our output voltage Vout in volts plotted with respect to time as shown on Plot A. Therefore, every 5µs. i.e. at a rate of 200kHz, our ADC samples Vout, giving us Plot B. Plot B is a digitized representation of our output voltage.

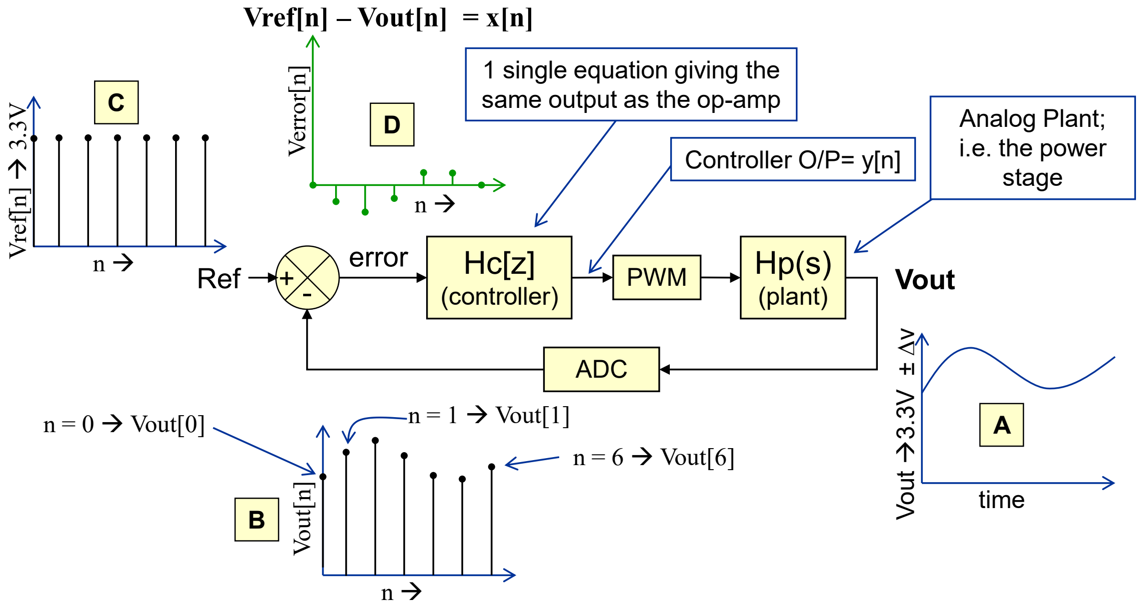


*Figure 1: Digital PSU Building Blocks*

You will see from Plot B that when n = 0, i.e. at time t = 0µs we have a sample from the ADC, then 5 µs later i.e. when n = 1 or at t = 5µs we have a second sample, then 5µs later we will have our 3rd sample and so on. Therefore, Plot B is our Vout plotted with respect to sample number n.

Ignoring all our scalings for now (we will deal with these later) and assuming that we would like an output voltage of 3.3V, then we have Plot C. In this plot, we show the voltage that we would like to have at every sampling interval. In other words, when n = 0, i.e. when t = 0 µs, we would like to have 3.3V on the output. Then, 5µs later i.e. when n = 1 (so t = 5µs), we would like 3.3V on the output, then 5µs later, again we want to have 3.3V on the output and so on. This is our reference or demand voltage Vref[n] plotted with respect to sample number.

Now, if starting at t = 0, at 5µs intervals, we subtract the voltage the ADC says we have on the output, i.e. Vout[n], from the voltage that we actually want on the output Vref[n] then the difference between these two is our error Verror[n]. This signal is the input to the controller which for simplicity from now on we will call x[n]. We have shown this on Plot D.

Now that we have our error signal, we can compensate for it using a digital equivalent of an op-amp compensator. As mentioned earlier, this is just a single equation. The output of this equation y[n] at every sampling interval is a near exact replica of the output of the equivalent op-amp compensator and sets the new value of our duty. Note that for now we are ignoring the scalings and any phase delay due to digitization; we will deal with these later articles.

Finally, the output y[n], i.e. our demand duty is fed into the digital PWM block as shown which will then turn on the switch. You can see that we have closed our loop. Provided that we can derive a discrete time mathematical equation that gives the same output as the op-amp compensator then our digital power supply should, in theory, behave just like the analog one.

**Can an Equation in Discrete Time/Digital Domain Give the Same Output as an Op-Amp?**

Yes it can! It is done by using something called a “Linear Difference Equation” or LDE. In fact almost any continuous time/Analog transfer function can be converted into a near equivalent digital version using LDEs.

Here is an example of a discrete time linear different equation:
y[n] = x[n] + 0.5 y[n-1]

There is nothing scary about LDEs, in fact they are very very easy to calculate. We just need to spend a few minutes discussing what all the “n”s in the square brackets mean.

y[n] means the output of our digital controller at this exact instance. This is the value that updates our duty and should be exactly the same as the output of our equivalent op-amp circuit, ignoring all the scalings and phase losses for now.

x[n] is the input to our digital controller at this exact instance. As discussed earlier, this is simply our error signal, i.e. the difference between the Vout that we want and the Vout that we are actually getting.

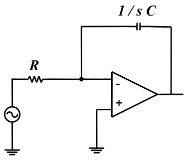
Then we have a coefficient of “0.5” multiplied by y[n-1]. Every time we see a y[n-1], it means our “previous” output, i.e. the output of our controller delayed by 1 sampling interval, or, in other words your output 5 µs ago. So 0.5 y[n-1] means half of our last output from 5µs ago. Of course the microprocessor know this value because we have the value of y[n] from 5µs ago.

If we see a y[n-2], it means our ‘Previous Previous’ output; in other words the output of our controller 10µs ago. y[n-3] would mean our output 15 µs ago and so on. Similarly x[n-1] means our previous input and so on

Therefore, all we need to get the LDE to give the same output as an op-amp is to fill in the correct sample values in the LDE, multiply by the correct coefficient and then sum them up to get the new value of y[n] which sets our duty.

Let us use a real life example to put these in perspective. Consider the simple op-amp integrator shown in the next figure. This has a pole at origin and can be considered to be a Type I compensator.

If we solder a 1.6kΩ resistor for R and a 10nF capacitor for C then our gain plot will cross the zero dB axis at 1/(2π R C) = 10kHz. From previous articles [2] and Biricha workshops [3], we know that the Gain Plot of this circuit will look like the red trace figure shown below. You can see from this figure that the red trace crosses the zero dB axis at 10kHz.



$$y[n] = \left(\frac{-T_s}{2RC}\right)x[n] + \left(\frac{-T_s}{2RC}\right)x[n-1] + y[n-1]$$

Figure 2: Simple Op-Amp Integrator

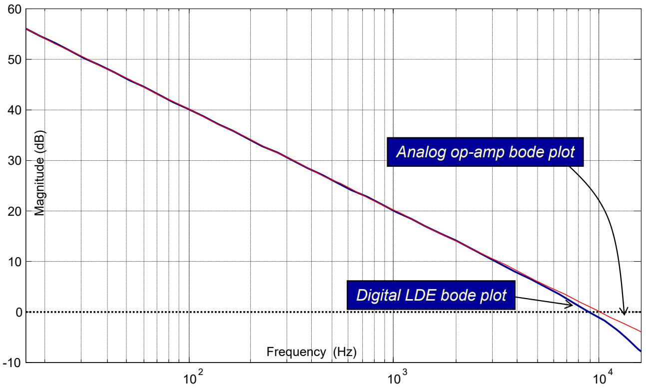


Figure 3: Gain plots of our op-amp integrator and its equivalent digital LDE

But what about the equivalent digital Linear Difference Equation? Well, the equation below is our digital equivalent LDE. We will talk about how we derived this later but for now let us see if there are values within this equation that we do not know.

We can calculate y[n]; i.e. the controller output at this exact sampling interval. This is the output of our LDE which sets our duty and should be numerically equivalent the output of our op-amp circuit. We calculate this every sampling interval.

We know x[n]; our current input at this exact sampling interval. This was the input to our controller, which in our case was the error signal.

Of course, we also know both x[n-1] i.e. our previous input from 5ms ago and y[n-1] i.e. our previous output from 5ms ago.

Finally, we can see that our current input x[n] and our previous input x[n-1] are multiplied by the same coefficient $\left(\frac{-Ts}{2\,R\,C}\right)$.
We know that R = 1.6kΩ and C = 10nF and let us assume that our sampling frequency is 50kHz and hence Ts = 20µs.
[illegible] oefficients of both x[n] and x[n-1] → $\frac{-20\mu s}{2\times 1.6k\Omega\times 10nF} = -0.625$.

By substituting -0.625 into our linear difference equation becomes:

$$y[n] = -0.625\,x[n] - 0.625\,x[n-1] + y[n-1]$$

Looking back at the gain plot of our op-amp, you will see that we have superimposed the output of this equation in frequency domain on top in blue. As you can see, we have a near-perfect match and we have successfully created a digital compensator/LDE with a gain frequency response that is almost exactly the same as that of an analog op-amp.

We should point out that for teaching purposes we reduced our sampling frequency down to 50kHz to show some discrepancy! If we were sampling at 200kHz we would barely be able to tell the difference until we approached the Nyquist frequency. Provided that we keep our compensator's crossover frequency less than 1/20 of our sampling frequency, we can have a near perfect match in digital world compared to analog.

**How Do We Derive LDEs?**

The equation in this article was derived using the Bilinear Transform. Although there are other methods, the Bilinear Transform is a very common technique used to convert analog transfer functions into digital format. There is nothing complicated about it; it just requires a little bit of algebra to go from a transfer function in Laplace domain to a discrete time LDE. The good news is that because the vast majority of power supplies in the Analog world are stabilised with either a Type II or a Type III, you may not need to learn the Bilinear Transforms at all. All you need is the LDEs for the Type and Type III and we will provide you with both of these simple equations in forthcoming articles.

These two equations (one for Type II and one for Type III) should cover many applications; however, for those who need to create their own high performance algorithms then we do cover the Bilinear Transforms in Biricha's Digital Power Workshops for completeness.

**Concluding Remarks**

You can see from the previous discussions that that it is possible to emulate the output op-amp compensator with a single linear difference equation. In this article we demonstrated this fact using a simple op-amp integrator. However, nothing stops us from applying the same principle to Type II and Type III compensators.

In the forthcoming articles we will address all of the remaining issues and explain how to overcome them. We will present the LDEs that you need to create a digital version of a Type II compensator as used in most current mode power supplies as well as Type III, as applied to voltage mode.

We will discuss all scaling factors in detail with worked examples to show how to account for them. We will also discuss how to calculate and overcome the phase loss in a digital power supply. Finally we will carry out a detailed step-by-step design example for a real power supply and present real experimental results to verify the theory.

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[1] Biricha Digital's "Digital PSU Design Workshop" Handbook
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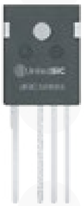


# Safe, High-Accuracy High-Voltage Measurement

*One of the first principals learned as an engineering student is the "observer effect" which states that simply observing a situation or phenomenon necessarily changes that phenomenon. Accurate high-voltage measurement is a clear example of the validity of this theory.*

*By Chad Clark, Vitrek, LLC*

The accuracy of the resulting measurements is affected by three important elements:
- environmental factors,
- errors that are introduced by the measurement probe, and
- the intrinsic accuracy and performance of the measuring instrument.

This article will address each of these areas with the objective of providing guidance in safely achieving optimum accuracy in making high-voltage measurements.

### High-Voltage Applications

For the purposes of this article, "high-voltage" is defined as 1 KV to 150 KV, either AC or DC.  Accurate high-voltage measurement is essential in design and manufacturing of a remarkably wide range of applications:
- Analytical instruments (Mass Spectrometry, Photomultiplier tubes, others)
- Defense and Aerospace (Radar, CRT, Simulators)
- Homeland Security (Explosive Detection Systems (EDS), Explosive Trace Detection (ETD), Baggage Inspection, X-Ray Inspection)
- Inspection & Non-Destructive Testing Systems
- Manufacturing Processes (Electron Beam Welding, Electrostatic Coatings, Induction Heating, Crystal Pulling, Capacitor Charging, Photoreceptor Corona Charging, others)
- Medical & Biotechnology (X-Ray, Radiography, Electrophoresis, others); Pulsed (Laser, Capacitor Charging, Sonar, others)
- Research Laboratories (Detectors, Accelerators, Nuclear Instrumentation, Electrophotography, others)
- Semiconductor Equipment (Ion Implantation, Sputtering, Epitaxy, Deposition, Electrostatic Deflection, Plasma Diffusion, Plasma Chemical Vapor Deposition, others);
- High Voltage Power Supplies
- RF Generators and Matching Networks
- High Voltage Amplifiers
- Electrical Distribution (Corona Detection, Cable Insulation Testing)

Accurate high-voltage measurement is needed in all of these applications and in the calibration labs used to maintain these instruments.

### Environmental Factors

High voltage measurements are susceptible to errors and to environmental factors. At elevated voltages, electromagnetic effects must be taken into account. Just walking past the measurement setup can cause errors.  The Operator's Manual for the Vitrek 4700 Precision High Voltage Meter provides insights into the importance of a controlled environment:
- The instrument should not be used in an environment where conductive pollution can occur, e.g., in an outdoor environment.
- If fluids or other conductive materials are allowed to enter the unit enclosure, even if not powered, the unit should be taken out of operation and services as safety may have been compromised.
- If the unit is transported between differing environments and condensation is suspected, the unit should remain unpowered for the condensation to be dissipated.
- When AC voltages are present, even if there is sufficient insulation in the connections, there may be significant capacitive coupling which can cause an unsafe current to flow into nearby objects. Corona may occur even outside the insulation.  These effects are made worse by sharp corners. In severe cases, corona can cause interference with the measurements and will reduce the capabilities of the wiring insulation over time, eventually resulting in insulation failure.

Rules regarding the location of the probe must also be carefully followed:  As an example, for Vitrek's 35 KV SmartProbe, the manual makes this prescription:
Full accuracy specifications are valid assuming that there are no objects within a cylinder of radius 18" centered on the probe body extending from the handle (or base) to a point 6" beyond the probe tip. The connection to the probe tip is assumed to extend from the probe tip in line with the probe for at least 6".
Typically, the effect of a hand-sized grounded object is <0.01% at 60Hz when placed 4" from the probe and <0.1% at 400Hz when placed 18" from the probe. As long as objects do not move relative to the probe, there is negligible effect on DC measurements caused by nearby objects. Objects generating fields may need to be placed further away from the probe. At higher voltages, the radius increases. For the 150 KV probe the radius of the cylinder increases to 48".

### Measurement Probe Effects

Most high-voltage meters are capable of making direct measurements (with a handheld probe) for up to 1KV, while others can handle direct measurement up to 10 KV.  In consideration of the hazard potential, use of a hand-held probe comes with a serious warning like this:
WARNING – The instrument measures high voltages on the direct terminal. These voltages can cause severe injury or death. The user must ensure that connections have sufficient insulation. Even when sufficient insulation is present, the user should not put any part of their body in proximity to the connections while high voltages are present (at least 1 in per KV is recommended). The user should not insert or remove any connections when high voltages are present.
WARNING – Do not apply high voltages to a probe without it being properly plugged into the meter.

### Measuring High Voltages with External Probes

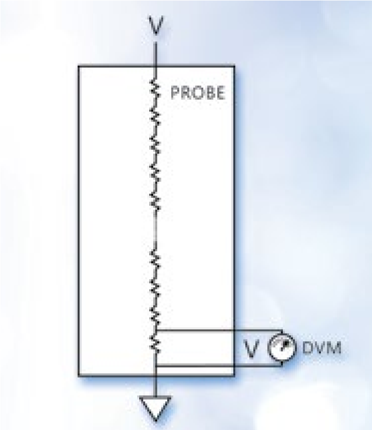


*Figure 1: A voltage divider is typically used to measure voltages above the instrument’s direct input range.*

When measuring higher voltages, an external probe is used. The most common type of probe utilizes the method prescribed in a NIST document with details on utilizing a voltage divider network to reduce the voltage applied to the meter to within its basic input range (Figure 1). The voltage divider is comprised of a series of identical precision resistors. For example, a 100:1 voltage divider would allow an instrument with a 1 KV max input to measure an applied voltage of up to 100 KV.

The voltage divider is comprised of a large number of precision resistors in order to limit the error and uncertainty. The series of carefully matched resistors would (theoretically) eliminate errors from self-heating or other factors that would affect the resistor string in a uniform fashion. Even so, there remain a number of contributing factors to error and uncertainty:

- Resistance variation from one resistor to another
- Variations (although minor) in temperature coefficient
- Electromagnetic effects
- Capacitance effects

In order to mitigate these effects, a series resistor voltage divider would typically take on a configuration like the one shown in Figure 2. The resistors in the array would be arranged in a helical fashion to reduce errors from electromagnetic and thermal factors.

*Figure 2: 100:1 voltage divider network built in compliance with the NIST standard.*

The voltage divider network is susceptible to a number of error-producing effects, among them, self-heating, capacitance effects on AC measurements and electromagnetic effects. Voltage divider probes must be calibrated with the meter. Calibration should also identify sources of uncertainty.

**As stated in one manufacturer’s materials:**

“For highest accuracy in high impedance, low input capacitance types, consideration must be given to induced voltage pick-up in leads, contact potential, corona, effective capacitance, and voltage gradient and capacitance shift related to proximity to high voltage sources, ground planes, walls, enclosures, and loads.

Preferably the divider should be calibrated with the specific instrument being used and specific proximities if extreme accuracy is required, Greatest accuracy, particularly AC accuracy, is attained with proper ground plane and if maximum clearance to conductive materials, which can cause capacitance variation and corona. If available, user’s proximity dimensions will be simulated when calibrating.”

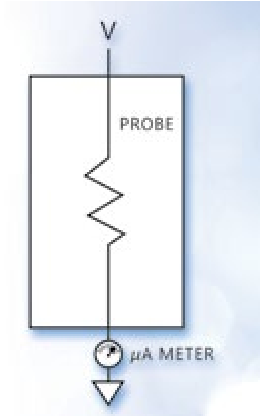


*Figure 3: Vitrek’s 4700 Meter measures microamperes using high voltage SmartProbes*

An alternative, and perhaps more elegant solution is to connect the source to a single high resistance and measure the microampere current. This, of course, requires the precision “voltmeter” to also operate as a, low-impedance, precision ammeter. For example, this alternative is utilized with Vitrek’s high-voltage Smart Probes (Figure 3). Unlike voltage dividers that must be calibrated with the meter, these smart Probes include calibration data that is automatically updated when the probe is connected to any Vitrek 4700 meter. Comparison of the performance of these alternative approaches is difficult because it involves so many factors including the environment, the test setup (including impedance matching) and the basic accuracy of the instruments. But it can be said that the integrated system approach is vastly better at dealing with the range of errors that have been discussed in this article.

### Meter Performance & Accuracy

Most precision high-voltage meters are capable of direct measurement; i.e., without requiring an attenuating probe, for voltages of up to 1000V. An example of this type of meter is the Fluke 8846A 6.5-digit precision multimeter. Meters like this typically have a measurement range of 100mV to 1000V with excellent accuracy specs. However, for voltages between 1000V and 10 KV, meters in this class must utilize an external probe.

A great many high voltage measurements (both AC and DC) are found in the “lower” high-voltage range of greater than 1000V and less than 10KV. Examples of devices that can accommodate direct input within this voltage range are the Kikisui 149-10A and the Vitrek 4700.

### Conclusion

Precision high-voltage measurements require careful attention to the environmental conditions, the proper application of high-voltage probes and the basic functions and features of the meter. Careful selection of a highly functional meter can provide both flexibility in application and reduce the need for multiple meters.

**www.vitrek.com**

# Acoustic Investigation

*TO-247 packages, along with TO-220s, are designed for use in high-power, through-hole situations. The package may contain transistors (“TO” stands for “transistor outline”), silicon-controlled rectifiers, or integrated circuits.*

*By Tom Adams, consultant, Nordson SONOSCAN, and*
*Enes Ugur, Power Electronics and Drives Lab, The University of Texas at Dallas*

A package may have three or more leads. There is a metal tab with a hole for attaching the package to a heat sink to achieve high heat dissipation. The two packages have similar designs, but the TO-247 can dissipate greater amounts of heat. To determine whether a lot of TO-247s contains any internal structural defects that could result in field failures, or to see nondestructively the cause of a failure that has already occurred in an individual TO-247, an acoustic micro imaging tool can be used to image internal structural features without damaging the part.

An ultrasonic transducer scans over the surface of the part at high speed while inserting several thousand pulses per second into the part. As the pulse travels into the part, portions of the pulse are reflected from any interface between two different materials, but not from the bulk of homogeneous materials. The greater the difference between the acoustic properties of two materials, the higher the amplitude of the echo. The highest amplitude comes from the interface between a solid and air - in other words, where the pulse traveling through a solid encounters an air-filled defect such as a void or crack. None of the pulse enters the void or crack (it can’t travel through air), but virtually all of the pulse is returned to the transducer, where, because of its high amplitude its pixel is assigned the highest color on the color map being used. The interface between two materials produces an echo containing information about the materials as well as the depth of the interface. An interface between two solids will reflect from a few percent to 50 percent of the pulse, but not the 100 percent reflected by a solid-to-air interface. The echo from each location becomes one pixel in the acoustic image. X-y locations without echoes are typically black, or the lowest color on the map.

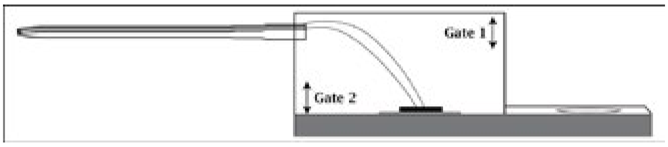


*Figure 1: Each gated depth will produce its own acoustic image.*

Figure 1 is a side-view diagram of a TO-247 package. The heat sink is at the bottom. The black item is the chip, whose wires run to the leads at upper left. Mold compound fills the rest of the package interior. The transducer travels a few mm above the top of the package, to which the ultrasound is coupled by an accompanying water jet. Each ultrasonic pulse travels from the transducer, through the water, and into the package.

The water-to-mold compound interface involves two materials, and a pulse striking this interface reflects an echo to the transducer. For most imaging of internal features, the collection of echoes begins below this interface. The “gate” - the vertical extent from which echoes are collected for imaging a single depth of interest - may be thick or thin. Its vertical extent is designed to ensure that all features are in focus. There may be multiple gates. Figure 1 shows two gates, each of which will become a separate acoustic image. An echo’s assignment to a particular gate is determined by its arrival time at the receiver. The acoustic images shown here were made with a C-SAM® acoustic micro imaging tool in Nordson SONOSCAN’s headquarters laboratory.

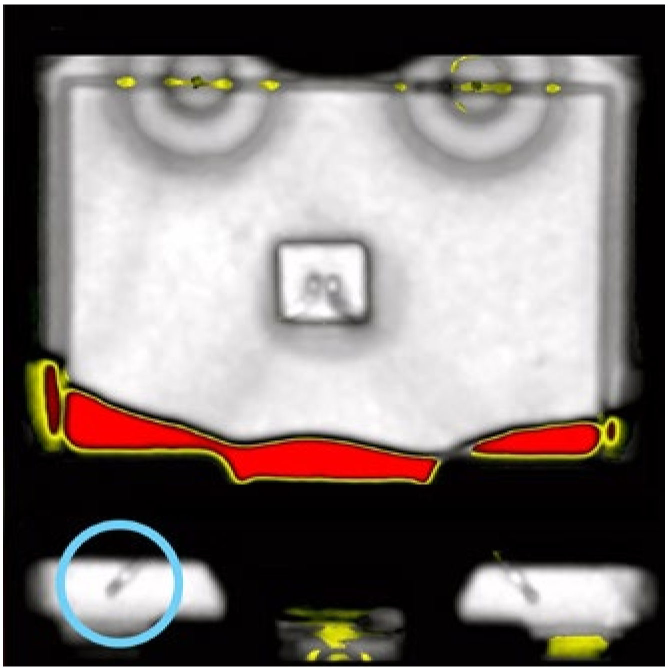


*Figure 2: The red regions represent delamination of the mold compound from the heat sink.*

Figure 2 is the 2-dimensional 15 MHz C-mode™ image of a TO-247 with defects. C-mode pulses ultrasound into a part and collects the return echoes from material interfaces. It is the most frequently used imaging mode. Figure 2 actually consists of two images. The larger top section of the figure was gated from the heat sink upwards to above the die. This depth is Gate 2, as shown in Figure 1. The bottom portion of the figure was gated above and below the tops of the leads to which the wires run (Gate 1).

In the Gate 2 image of Figure 2, the large red features are delaminations of the mold compound from the heat sink. The top of this gate lies below the top surface of the part, so the pulse traveled through homogeneous mold compound before encountering the mold compound-to-air interface and being reflected at high amplitude. The danger of delaminations is that in service they may expand until they reach the die or a wire and cause an electrical failure.

The two large circular features at the very top are mold marks on the surface of the part. They are largely gray because they are acoustic shadows - that is, they lie above the top of Gate 2 and block ultrasound returning from below, thereby creating shadows. It appears, though, that a small bit of the mold marks and/or the accompanying straight groove are within the gate, because they are yellow and not the gray color of an acoustic shadow.

In Gate 1 - the lower section of Figure 2 - the two wires are shown on their respective leads. The small white portion of the wire on each lead (circled at left) indicates that the wire is well bonded to the lead.

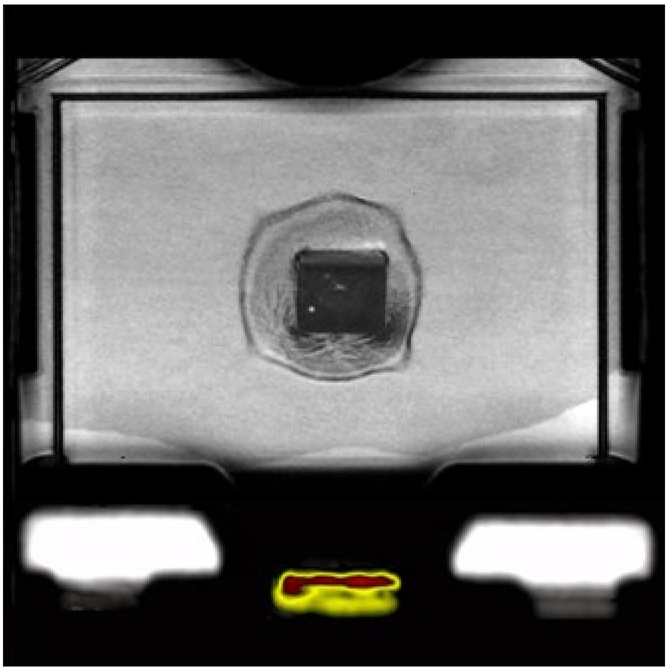


*Figure 3: The delaminations are visible - but white - when viewed through the back side of the heat sink.*

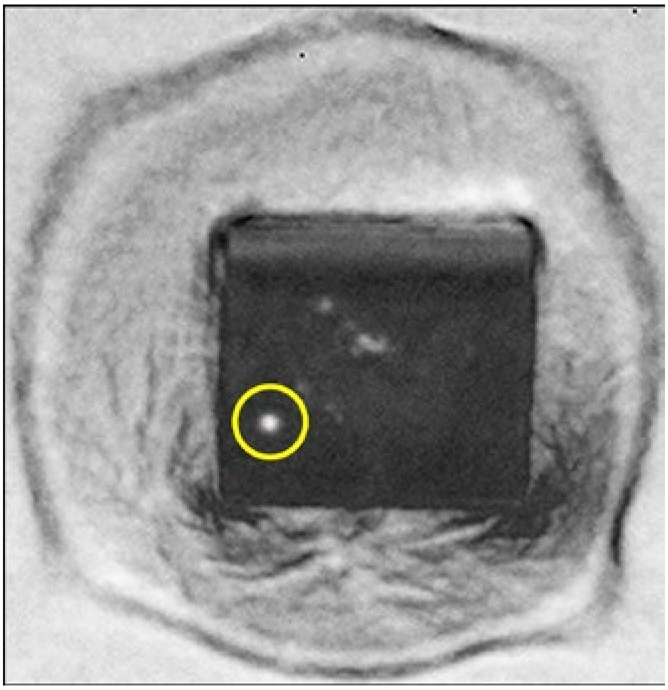


*Figure 4: A magnified view of voids in the die attach material*

The same component was then flipped over and imaged from the back side (Figure 3). Imaging was done in two steps, with two different frequencies, because of the significant difference in attenuation between a) a pulse inserted into the back side and traveling through only the heat sink to reach the die and die attach; and b) a pulse inserted into the back side and traveling through the mold compound to reach the leads near the top of the package.

The top portion of the image in Figure 3 was imaged with a 100 MHz ultrasonic transducer. Transducers for acoustic micro imaging range from 10 MHz (low resolution but deeper penetration) to 400 MHz (high resolution but limited penetration). A 100 MHz transducer provides very good resolution and penetration in parts like this.

The same large delamination that was visible from the front side of the device is visible here as a long feature along the bottom edge. Here the delamination has the same shape, but is reversed.

A more highly penetrating 15 MHz transducer was used to image the lower section. The bottom sides of the two leads at either side are bonded to the mold compound in which they are embedded, but the red color of the middle lead indicates that it is disbonded from the mold compound.

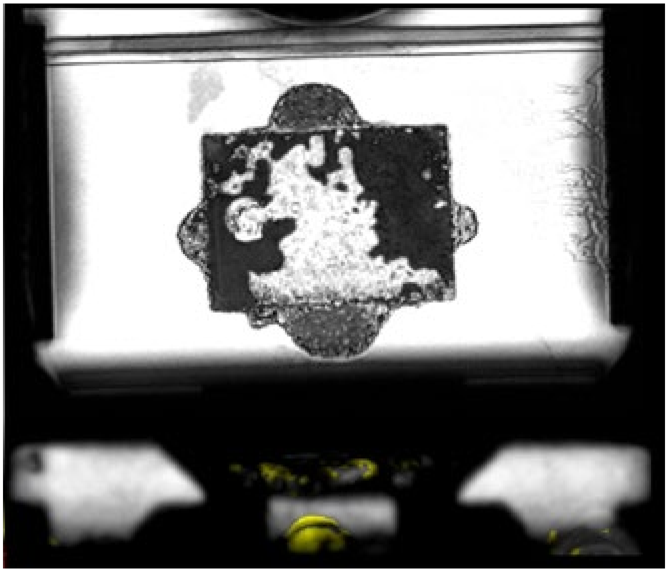


*Figure 5: Imaging through the back side of a different TO-247 revealed extensive delamination of the die.*

The TO-247 in Figure 5 was imaged only from the back side, and has defects that can only be described as catastrophic. The bottom section was imaged at 15 MHz to achieve penetration through the mold compound. In the bottom section, the only visible anomaly is a void on the middle lead.

In the top section, imaged at 100 MHz, white areas around the die show that the topside mold compound is largely delaminated from the heat sink. In addition, much of the area of the die attach is white, meaning that it consists of heat-blocking voids. This TO-247 would be a good candidate for immediate catastrophic failure if used in a high-voltage application. Acoustic imaging of TO-220s is essentially the same as the imaging of TO-247s, with one exception. A small heat-blocking defect that might be acceptable in a TO-220 may be unacceptable in a TO-247 because of the higher heat.

*C-SAM™ is a registered Nordson SONOSCAN trademark.*

**www.nordsonsonoscan.com**

# High CV MLCC DC BIAS Capacitance Loss Explained

*MLCC capacitors are dominating today's capacitor market enabling high grade of electronics miniaturization. The continuous downsizing and use of higher and higher dielectric constant materials for MLCC class II capacitors has however resulted in worsening of some electrical parameters such as capacitance drop at operating conditions.*

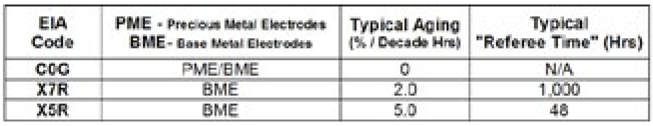
*By Tomas Zednicek Ph.D., President of EPCI European Passive Components Institute*

Thus, in consequence, what can be considered as an enabling technology for consumer and wearable applications may pose some risk if used in critical applications such as automotive, safety, medical or industrial sector, that are also in need for continuous miniaturization. In many cases, capacitance loss data available from MLCC manufacturers are given as "typical" performance leaving responsibility for "guaranteed" operation to the electronic system designer.

**MLCC Capacitance Ageing with Time**

The MLCC class II capacitors are using BaTiO3 ferroelectric materials as a high dielectric constant material to achieve its very high capacitance values in small dimensions. Downside of this material is its strong dependency on operating conditions – namely loss of capacitance – with DC Voltage (DC BIAS), AC Voltage, temperature and ageing with time. In addition, piezo noise may degrade smoothing capabilities of these capacitors at certain condition.

BaTiO3 has a cubic crystal structure above the Curie temperature (approx. 125°C or more), but below the Curie temperature it turn into a different crystal structure (tetragonal) that creates a dipole, respectively domains of dipoles with different dipole orientations that reduces its original polarization and reduces its capacitance values. The dielectric grain size/shape/distribution may impact number of dipoles and domains and the capacitance loss. As this structure changes with time, dielectric constant is reduced and over time, the capacitance continues to decline.



| EIA Code | PME - Precious Metal Electrodes<br>BME - Base Metal Electrodes | Typical Aging (% / Decade Hrs) | Typical "Referee Time" (Hrs) |
|---|---|---|---|
| C0G | PME/BME | 0 | N/A |
| X7R | BME | 2.0 | 1,000 |
| X5R | BME | 5.0 | 48 |

*Table 1: MLCC typical aging and referee time. source: Kemet*

Capacitance Ageing effect depends to MLCC dielectric type and it is constant per time decade (so the process slow down exponentially). Typical values see Table 1 above.

Various manufacturers use different time, but the most common reference points are 48 or 1kHz as also shown in table 3. with note that manufacturers are measuring capacitance with one day or twenty-four hours after "last heat" that is also in accordance to MIL specification conditions. (Re)heating to Curie temperature "reset" the structure and returns capacitance value to its initial value.

**MLCC Class II Capacitance with DC BIAS**

Some of the BaTiO3 dipoles are also blocked by DC voltage and it cannot move further with small AC voltage changes resulting in loss of capacitance.

The level of Capacitance loss (number of blocked dipoles) is proportional to the DC field (V/mm), thus capacitor with thinner dielectric and higher volts per dielectric thickness exposure will exhibit higher capacitance loss with DC BIAS. Type and structure of the dielectric (grain size, shape, distribution, impurities) may have also a significant impact to the capacitance loss level.

In consequence, the capacitance loss level may increase with higher CV density (high capacitance in small dimensions) and it may be part number and manufacturer specific. See figure 1. below as an example. The loss at rated voltage can vary from -35% to -65% at rated voltage that may result in significant different performance among manufacturers.

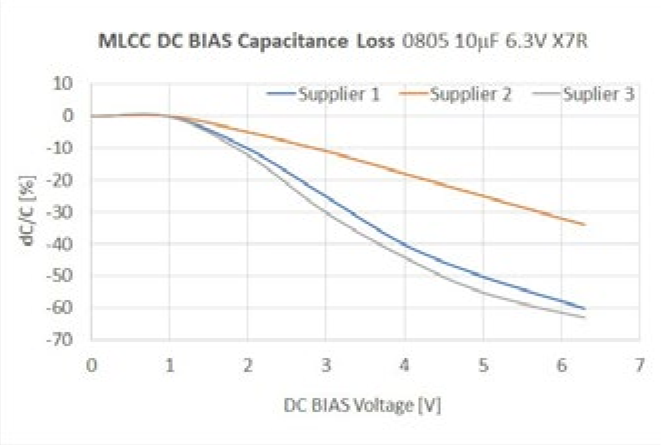


*Figure 1: Capacitance loss with DC BIAS on 10µF 6.3V MLCC X7R 0805 case by three different vendors; source: EPCI using manufacturers' datasheets*

It may be of critical importance to evaluate such characteristics when qualifying alternative MLCC manufacturer.

The drop of capacitance due to DC BIAS is not happening immediately, but some time is needed for slower dipoles to be completely blocked. Thus, we can see some fast-immediate drop of capacitance at time close to zero after DC Voltage plug in, and some additional drop within tenth of minutes to hour(s) to get to final capacitance drop level. See Figure 2.

Once all dipoles are blocked there is no further significant impact of DC voltage in longer timeframe. MLCC manufacturers use to talk about behaviour of the capacitor in decades … so what happens in first decade, second decade etc. as this is directly link to physical mechanisms and its impact to overall performance.

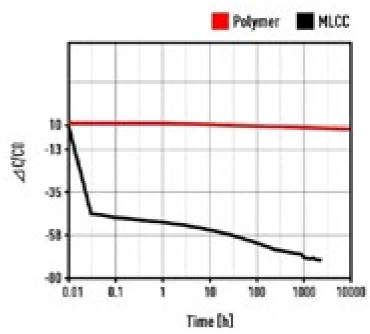


Figure 2: Capacitance drop with time under DC Voltage BIAS; source: Panasonic

The Capacitance loss with DC BIAS effect can be reduced by using a physically larger case that reduces V/mm electrical field exposed to the dielectric. See Figure 3 as an example of 0805 vs 0603 case sizes. Another choice, if applicable, is to use a higher-grade dielectric type material such as moving from X5R to X7R or tighter tolerance field e.g. moving from X7R to X7P. See Figure 4 as an example of X5R vs X7R capacitance loss with DC BIAS on 1uF 6.3V 0402 types.

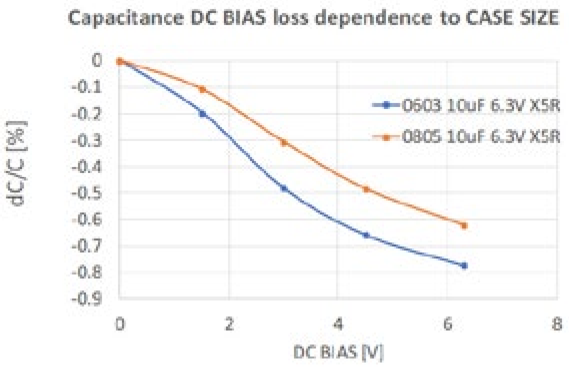


*Figure 3: Example of 0805 vs 0603 10μF 6.3V X5R capacitance loss with DC BIAS voltage*

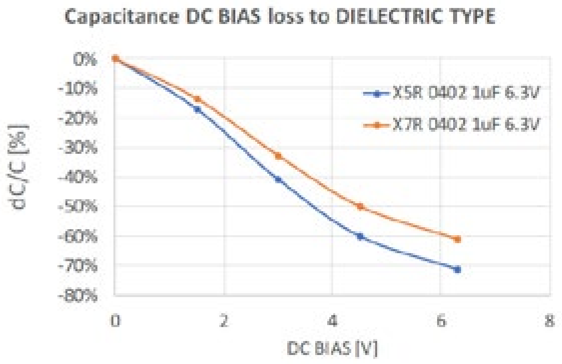


*Figure 4: Example of X5R vs X7R capacitance loss with DC BIAS voltage on 1uF 6.3V 0402*

**MLCC Class II Capacitance with AC Voltage**

Ferroelectric materials (BaTiO3) exhibit some hysteresis in polarization as a function of electric field that is causing MLCC capacitance dependency also to AC voltage. The level depends mainly to the dielectric type as shown in Figure 5.

The reference standard capacitor AC volt measure conditions are set to 1Vrms at 1kHz and room temperature. Nevertheless, there are number of MLCC capacitor applications that are operating at significantly lower AC voltage such as 10mV. In this case we can expect capacitance drop of capacitance due to the small AC voltage in range of additional -5 to -15%.

The “AC voltage hysteresis” is also “re-settable” by heating of the capacitor to Curie temperature.

**How to Specify MLCC class II DC BIAS Capacitance loss**

This chapter propose definition of MLCC class II capacitance loss for future specification:

***Capacitance loss guaranteed not to exceed XX% (for example -70%)[1] at 100%[2] of rated voltage, measured at reference conditions: after 12hrs[3] post last de-ageing and DC BIAS voltage applied at least for 10hrs[4] at RT, 1kHz and 1VAC.***

Procurement specification proposal to be agreed between customer and supplier on each PN under qualification:

The supplier shall also provide typical Capacitance loss with DC BIAS charts or link to an on-line simulation tool. Such specification would help designers to see some fixed capacitance loss guaranteed working point and evaluate the worst case at the edge operating conditions.

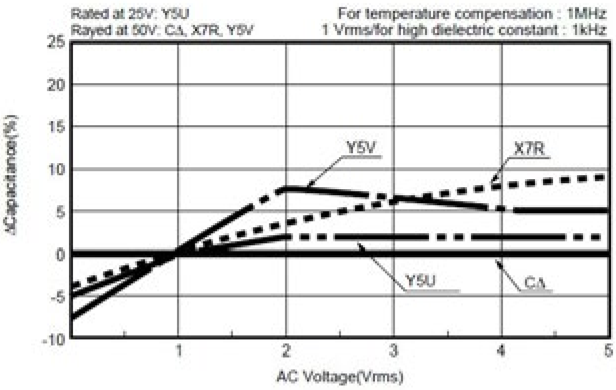


*Figure 5: Capacitance change with AC voltage by different dielectric types; source: Murata*

**Customer Designer Guidelines:**

- If you discover that this capacitor is unsuitable due to the capacitance loss as defined in the specification above, you have the following options:
- You can check if lower Capacitance DC loss / piezo suppression series is available by a manufacturer (need check with purchasing team as this can be more expensive part or single source)
- Use a larger capacitance value so that when the capacitance loss is considered, you still have enough capacitance for the required functionality. Note: higher values may have even worse DC bias characteristics due to even higher CV factor. This also may be an issue of distortion in large-signal AC, and likely will just make the problem worse and may not lead to the problem solving.

- Use a physically larger package size. This would reduce V/mm electrical stress and thus reduces also DC BIAS capacitance loss dependency. So, if you have enough room in your design, moving one step up in case size, for example from 0402 to 0603, 0603 to 0805 or a 1210 will significantly reduce the issue.
- If applicable, you can consider using more stable dielectric type such as moving from X5R to X7R, from X7R to X8R dielectric type or tighter tolerance field such as from X7R to X7P types. (multi-sourcing and price increase options to be checked)
- Use a different capacitor type. Sometimes, you won't be able to escape the DC bias issue or piezo issues at all. In this case, consider looking at a different capacitor type, such as an aluminum hybrid if you have enough board space or a tantalum polymer capacitor that may provide low profile, high CV and stable option.

**Notes:**

1. The level of defined maximum capacitance loss may be a part number specific, the actual value or some more detail guideline, if possible, to introduce some general rules to be discussed with manufacturers.

2. The cap loss reference DC BIAS is suggested to 100% of rated voltage, but it can be changed upon discussion with manufacturers. If suppliers are pushed to "legally" guarantee the worst capacitance drop, they will have to 100% measure and screen their production. The standard way of mass production 100% electrical capacitance measurement today is by CLR measure bridge with small BIAS 1-2V. There are two ways to measure capacitance at higher BIAS voltage:
    - use of external BIAS source with CLR measurement bridge or
    - indirect capacitance measurement – from I=C*dV/dt, for example to use IR measurement with 100%Vr charging for capacitance calculation and correlate it to the CAP loss characteristics.

3. the best fit method with low introduction cost, consistent correlation and quick implementation to be discussion with capacitor manufacturers, as one of the targets for panel discussion.

4. 12 or 24hrs measurement after last heat/deaging is a standard time used also in MIL standards to define state of the dielectric after the last "reset".

5. 10hours of DC applied as reference selected in respect to decades behaviour references that is used by MLCC manufacturers … what is happening in first, second, third decade …etc. 1hour may not be sufficient in some cases to see all slow polarization to happen and need to add some safety, thus 10hours (or more) is set as the reference point.

The next PCNS 2019 Passive Components Networking Symposium September 10-13th, 2019 in Bucharest, Romania will introduce MLCC Class II DC BIAS & Ageing Capacitance Loss as the Hot Panel Discussion Topic to initiate discussion between manufacturers and users on this topic.

**www.passive-components.eu/pcns**

# High Temperature Automotive IC's

CISSOID announces Automotive Integrated Circuits (IC's). These products are part of CISSOID CXT series of automotive grade components rated and qualified for operation from -55°C up to 175°C, in excess of AEC-Q100 Grade 0 qualification standard.

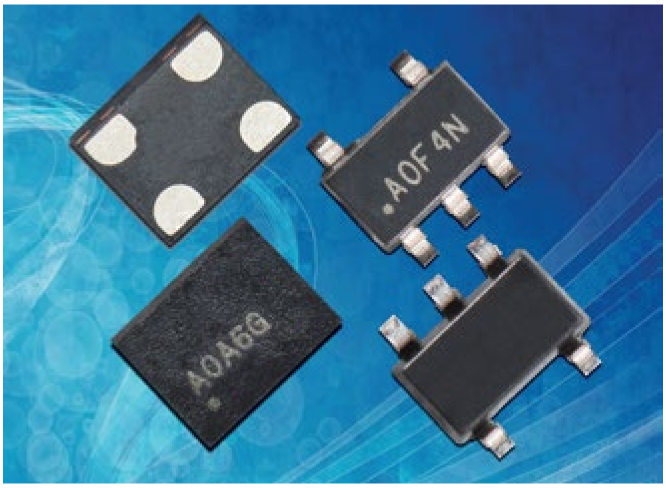
CXT-STA4919 is a high-temperature, high-reliability, 50mA adjustable linear voltage regulator generating any regulated voltage in the range +3.3V to +28V from an input between +4.5V to +35V. The component is operating reliably at junction temperatures from -55°C to +175°C. It is self-protected with a built-in current limiter and a thermal protection. The regulator is available in a PSOIC8 package with exposed pad for small PCB footprint and low thermal resistance.

"This product offers a low cost, small footprint and reliable solution for compact voltage regulators in ECU's, motor drives modules and sensor interfaces located in harsh automotive thermal environments where thermal requirements are difficult to meet" says Pierre Delatte, CISSOID CTO. "We see also demand in high power density converters and SiC gate drivers in EV and HEV" he added. The company is also introducing automotive configurable logic gates, referenced as CXT-741GXX, rated from -55°C to +175°C and available in a small SOT-23-6 package.

**www.cissoid.com**

# High-Integration MEMS Oscillators

AEL Crystals has added SiTime MEMS oscillators to its range. SiTime's silicon-based MEMS oscillators join AEL's existing range of products designed for the IoT. The Internet of Things (IoT) brings a new dimension to frequency control, as it uses multiple protocols (Bluetooth®, ZigBee, Z-Wave, 6LoWPAN, CSR Mesh / Bluetooth Low Energy (LE), Sigfox and Thread). Frequency control product manufacturers have to meet the demand for reliable, wireless frequency generation while, at the same time, increasing miniaturisation, reducing power consumption and providing consistent performance over a broad operating specification. The SiT15xx 32.768 kHz MEMS timing solutions are designed for mobile, IoT and wearable applications where space and power are critical.



SiTime MEMS oscillators offer high levels of integration, new packaging options and space savings, with surface mount and ultra-small chip-scale package (CSP) choices. A particular benefit for IoT applications is the clocking for monitoring circuitry. The real-time clock (32.768 kHz) is always-on, contributing to extending the life of the battery. The MEMS oscillators are available in a 2.0 x 1.2 mm (2012) SMD package for designs that require crystal resonator compatibility. The CSP MEMS oscillator reduces footprint by up to 80%, compared to existing 2012 SMD crystal packages and is 60% smaller than the 1610 crystal package (1.6 x 1.0 mm).

**www.aelcrystals.co.uk**

# Temperature Indicators Provide Prevention of Overheating Damage

Littelfuse, Inc. announced an expanded PolySwitch® setP™ series of digital temperature indicators, designed to protect USB TypeC and USB power delivery charging cables from dangerous overheating. The newest addition to the product family, the SETP0805-100-CC, is optimized for use in cables equipped with USB Type-C connectors at both ends. Typical applications for SETP0805-100-CC temperature indicators include consumer electronics, primarily for mobile and wearable devices equipped with:

- USB Type-C cables (with a Type-C plug on each end)
- USB Type-C chargers (such as cables fixed or captive to a charger "brick" for laptops)

When dust, dirt, or other debris becomes trapped in a USB Type-C cable connector or the connector has deformed pins, it creates a resistive fault from the power line to ground, which can cause a dangerous temperature rise without increasing the current. When the temperature reaches the setP's indicating temperature (100°C), the setP switches from low resistance to very high resistance, shutting down the flow of power. Once the user disconnects the cable and removes the debris, the cable can resume normal operation. The compact 0805 (mils) footprint of setP temperature indicators makes them at least 50 percent smaller than other solutions that require placing a device on the power line. The setP devices can be used to protect cables designed for 100 W of power or more.

**www.Littelfuse.com**

# Isolated CAN-Transceiver Reference Board

Now available from Dengrove Electronic Components, the RECOM R-REF03-CAN1 reference board streamlines the design of an isolated CAN interface with all the necessary circuitry to reduce noise and protect the system against excessive voltages. To ensure signal integrity and reliability, isolated CAN transceivers need isolated power as well as properly designed bus protection. The R-REF03-CAN1 satisfies these requirements as a ready-to-use reference board that solves the critical component-layout, signal-termination and routing challenges when bringing up a robust and reliable transceiver design. The board contains a TI ISO1042 isolated CAN transceiver, which supports data rates up to 5Mbps in CAN-FD mode and 1Mbps in CAN Classic. All the necessary protection components including TVS diodes and common-mode choke are provided, and the board gives users the flexibility to bypass these if desired. A 120Ω line-termination resistor can also be added for optimum CAN-bus performance with 120Ω-impedance twisted-pair cable. A RECOM R1SX-3.305/H isolated surface-mount DC/DC converter provides the single 3.3V rail needed to power the ISO1042. Energy efficient and compact, measuring only 10.8mm x 12.75mm x 5.5mm, the converter is pre-configured with a “split” termination network. Common-mode capacitance and additional capacitors on the CAN bus are included for optimum protection.

**www.dengrove.com**

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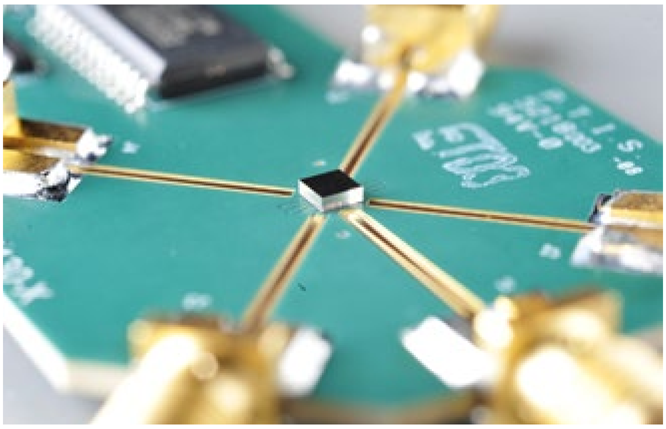
# Switches that Perform Beyond 20GHz

Menlo Micro introduces their latest series of RF/microwave switches. These products, which operate at high power with ultra-low RF losses, and in a miniaturized surface-mount package, bring unprecedented performance improvements as compared to electromechanical and solid-state RF switches. The MM5130 SP4T switch is designed to handle power levels up to 25W and demonstrates less than 0.6dB of loss at 12GHz, with 3dB performance beyond 20GHz. The MM5120 incorporates an integrated driver to facilitate switch control. This type of RF performance is usually reserved for large RF mechanical relays, which are 50x larger, 1000x slower and 1000x less reliable than products manufactured with Menlo Micro’s Ideal Switch technology. In addition, the MM51xx series features extreme linearity and harmonic performance, in many cases +30dB to +40dB better than solid-state, all with high power handling capability and stable performance over much broader bandwidths, down to DC. These attributes make the MM51xx series very attractive solutions for low-loss switched filter banks, tunable filters, step attenuators, and even beam steering antennas for a variety of radio architectures in both commercial and military communications networks. The high-channel density and low losses make them ideal for ultra-compact switch matrices for test and measurement applications.



**www.menlomicro.com**

# Eight-Port Switch in Power over Ethernet Standard

Microchip Technology Inc., via its Microsemi subsidiary, announces a cost-effective eight-port Power over Ethernet (PoE) switch which provides guaranteed power of 60 Watts (W) per port for all eight ports simultaneously. Ideal for digital ceiling installations, the IEEE 802.3bt-compliant PDS-408G PoE switch runs noise-free with a fanless design. Designed for enterprise connected lighting applications, the PDS-408G connects separate systems such as lighting, sensors, HVAC and Wi-Fi® access points over a single switch. The switch has eight PoE ports, which is the optimal number for connected lighting, and offers end applications additional cost-savings from energy savings and lower operating expenses. In compliance with IEEE 802.3bt, the PDS-408G provides a total of 480 W, including up to 90 W for any individual port or 60 W for eight ports simultaneously.

The PDS-408G is plenum rated and can be installed in any air handling space, making it ideal for digital ceiling installations. Its fanless design provides the features needed for buildings that require noise-free and reliable operation, such as offices, hospitals and hotels. The PDS-408G also provides other proven advantages of PoE, including safe power, simple installation, flexible deployment and remote power management.

The PDS-408G joins Microchip's portfolio of end-to-end PoE solutions. Developers can use the PDS-408G switch together with the company's extensive portfolio of 8- and 32-bit PIC® and AVR® microcontrollers (MCUs) at the end node.

**www.microchip.com/eoe**

# 6-16A Non-Isolated POL DC/DC Converter Series

MORNSUN released a non-isolated POL DC/DC converters K12T series. The K12T series features compact SMD package and provides an output current of 6A, 10A, 16A, and their output voltage can be accurately adjustable from 0.75V to 5.0V. The 6-16A non-isolated POL DC/DC converters can supply a large high speed transient response current for high speed chips such as FPGA, DSP, ASIC to simply its system design, which are suitable for a wide range of industrial applications including communication, computer network industry and dynamic distributed architecture, workstations, servers, LANs/WANs.

**www.mornsun.com**

# Single-Phase Filter for AC and DC Applications

SCHURTER extends its successful family of chassis mounted filters for 1-phase systems, FMAB NEO with the new series FMAB HV. It is suitable for applications up to 277 VAC as well as 400 VDC. In North America, there are various 1-phase applications in the 3-phase 480/277 VAC network. 400 VDC is often used in modern data centers with DC power supply. The single-stage filter series combines a compact design with a high level of performance. With 277 VAC and 400 VDC approval, the FMAB HV filter family offers the greatest possible flexibility for various applications. Today, more and more mixed AC and DC power supplies are used for better energy efficiency and/or improved reliability. In these applications, the filter can be used on both the AC and DC sides. The filter series has a shiny steel housing with a closed filter base. This effectively shields the filter, no matter how it is mounted. The series is particularly suitable for devices with high symmetrical interferences, such as devices with semiconductors, which regulate high outputs (e.g. commercial coffee machines, hot water dispensing machines, and all types of industrial electronics).

**www.schurter.com**

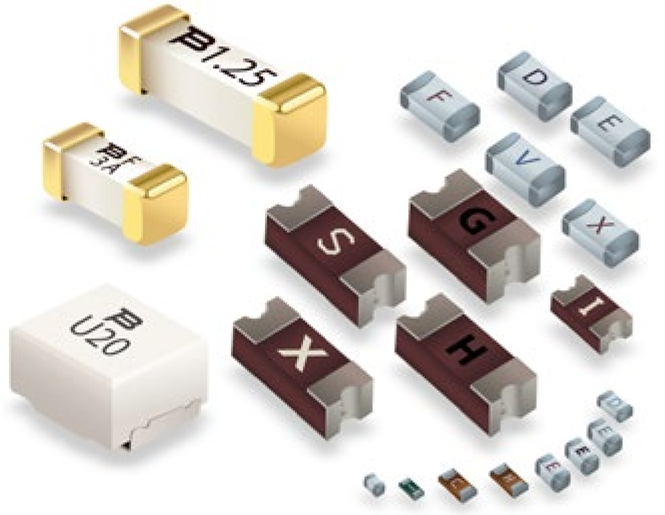
# Touch-Safe Linear Mini Power Supplies

Acopian announced the availability of touch-safe linear regulated mini encapsulated power supplies with output voltages from 3.3Vdc to 48Vdc and up to 15 watts of output power with an operating ambient temperature to 71°C. Small in size, these mini-modules offer extremely low ripple (1mV RMS), precise load and line regulation, temperature stability and can be mounted in an area only 3.5” x 2.5”. Terminal block input/output connections eliminate all need for sockets or soldering and are touch-safe. Standard features include short circuit protection, encapsulated construction, and conservative design to assure long term reliability. All models are UL60950, UL508 and CE recognized/listed components. Units are designed for use in all applications where reliable and clean power is required. Available options include 24 Vac, 100 Vac, and 230 Vac inputs; DC ON LED indicator, output voltage adjustment of +/- 2% and DIN Rail and Wall mount adaptors.

**www.acopian.com**

# Overcurrent Protection Line

Bourns, Inc. announced the completion of a significant expansion of its SinglFuse™ overcurrent protection product line, adding 33 model series to the portfolio over the last 18 months. A rising focus on safety across many industries has led to increasing requirements for effective circuit protection. Designed to safety standards and to provide reliable overcurrent protection in sensitive circuitry, the expanded SinglFuse™ portfolio supports a wide range of current and voltage requirements with ratings up to 100 A and 600 V AC. These features meet a broad spectrum of overcurrent protection requirements in applications such as handheld consumer devices, telecom infrastructure and industrial automation equipment, battery management and energy storage systems. The latest SinglFuse™ products feature a broad variety of fusing speeds and capabilities including fast acting and slow blow, fast acting precision, time lag, high inrush, high current, and high voltage. Offered in standard EIA package footprints from 0402 to 3812, Bourns® new SinglFuse™ devices are drop-in replacements for similar fuse products and can easily fit PCB layouts. The additional breadth in Bourns® enhanced standard SinglFuse™ product offering enables customers to select an ideal overcurrent protection solution for their design while still meeting aggressive time-to-market schedules. Another advantage from the expanded portfolio is Bourns› ability to rapidly design, develop, and produce custom solutions to meet unique performance specifications.

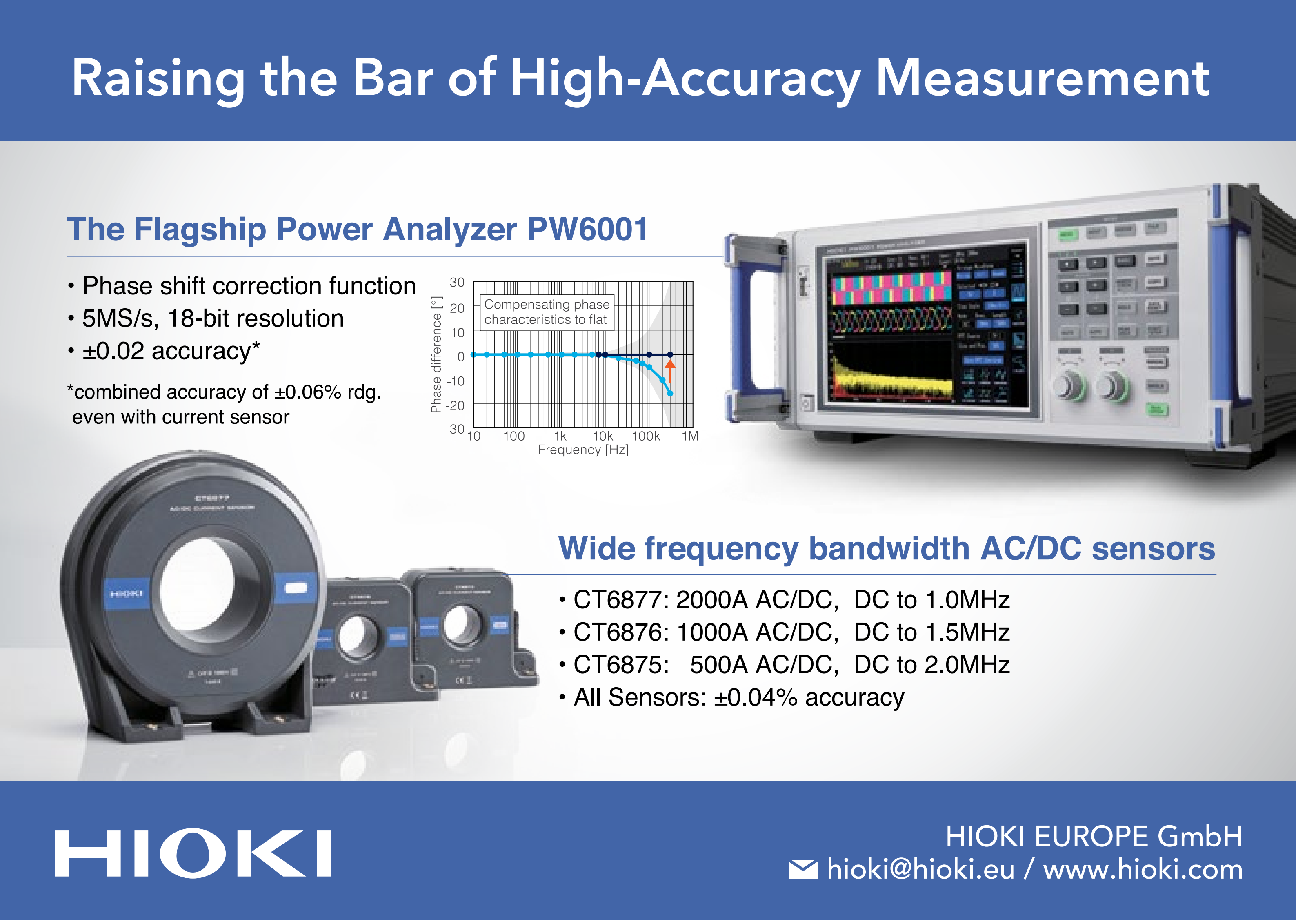


**www.bourns.com**

# Technology of Magnetic Components Officially ESA Qualified

Exxelia is pleased to announce the ESA qualification of its CCM technology, according to specification number ESCC 3201/011. Exxelia’s highly customizable Chameleon Concept Magnetics product line, a molded SMD Magnetic Component using Linear Winding Technology, allows to design both SMD inductors and transformers. While standard packages such as RM and EQ offer a limited number of outputs, the five sizes (CCM4, CCM5, CCM6, CCM20, CCM25) offer up to 2x10 output pins while still being easy to mount on PCB without additional leads ensuring time saving and increased reliability! Thanks to its optimized thermal design, CCM products reduce the temperature rise by 50% compared to standard technologies, hence allowing an additional 30% power density into the same package. In addition, its unique design with epoxy molded winding ensures extreme high robustness and mechanical performance up to 100g shocks and 30g vibrations. Perfect for use in switch mode power supplies, CCM platform is now available for customization.

**www.exxelia.com**



# Laminates for Higher Microwave & Industrial Heating Applications

Rogers Corporation is pleased to introduce TC350 Plus laminates. TC350™ Plus laminates are ceramic filled PTFE-based woven glass reinforced composite materials providing a cost effective, high performance, thermally enhanced material for the circuit designer. With a thermal conductivity of 1.24W/mK, this next generation PTFE-based laminate is ideally suited for higher power microwave and industrial heating applications requiring higher maximum operating temperatures, low circuit losses, and excellent thermal dissipation within the circuit board. Additionally, the advanced filler system used enables the composite to have much improved mechanical drilling performance when compared with other competitive laminates. This will result in lower manufacturing costs during circuit board fabrication. The standard TC350 Plus laminates are offered with a smooth (Rq= 1.0μm) electrodeposited copper foil cladding to reduce insertion loss and RF heating of conductors within the circuit. Resistive foil and metal plate options are available upon request. TC350 Plus laminates are available in thicknesses from 0.010” to 0.060” to address higher power design needs. The woven glass reinforcement combined with the high filler content of the laminate affords excellent dimensional stability.

ROGERS CORPORATION

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## Advertising Index

| | |
|---|---|
| ABB Semi | 33 |
| Dr.-Ing. Artur Seibt | 41 |
| Broadcom | 13 |
| Cornell Dubilier | 35 |
| CWIEME Americas | 58 |
| Danfoss | 23 |
| DAPE | 27 |
| EA Elektro-Automatik | 9 |
| Electronic Concepts | 1 |
| EPE ECCE | C3 |
| Fuji Electric Europe | 21 |
| GvA | C2 |
| Hioki | 64 |
| Hitachi | 11 |
| ineltron | 61 |
| Infineon | C4 |
| LEM | 5 |
| Microchip | 15 |
| Mitsubishi Electric | 37 |
| Mue Cap | 19 |
| Plexim | 17 |
| ROHM | 7 |
| Semikron | 43 |
| ST Microelectronics | 29 |
| United SiC | 51 |
| Vincotech | 25 |
| Würth Elektronik eiSos | 3 |
| ZH Wielain | 49 |

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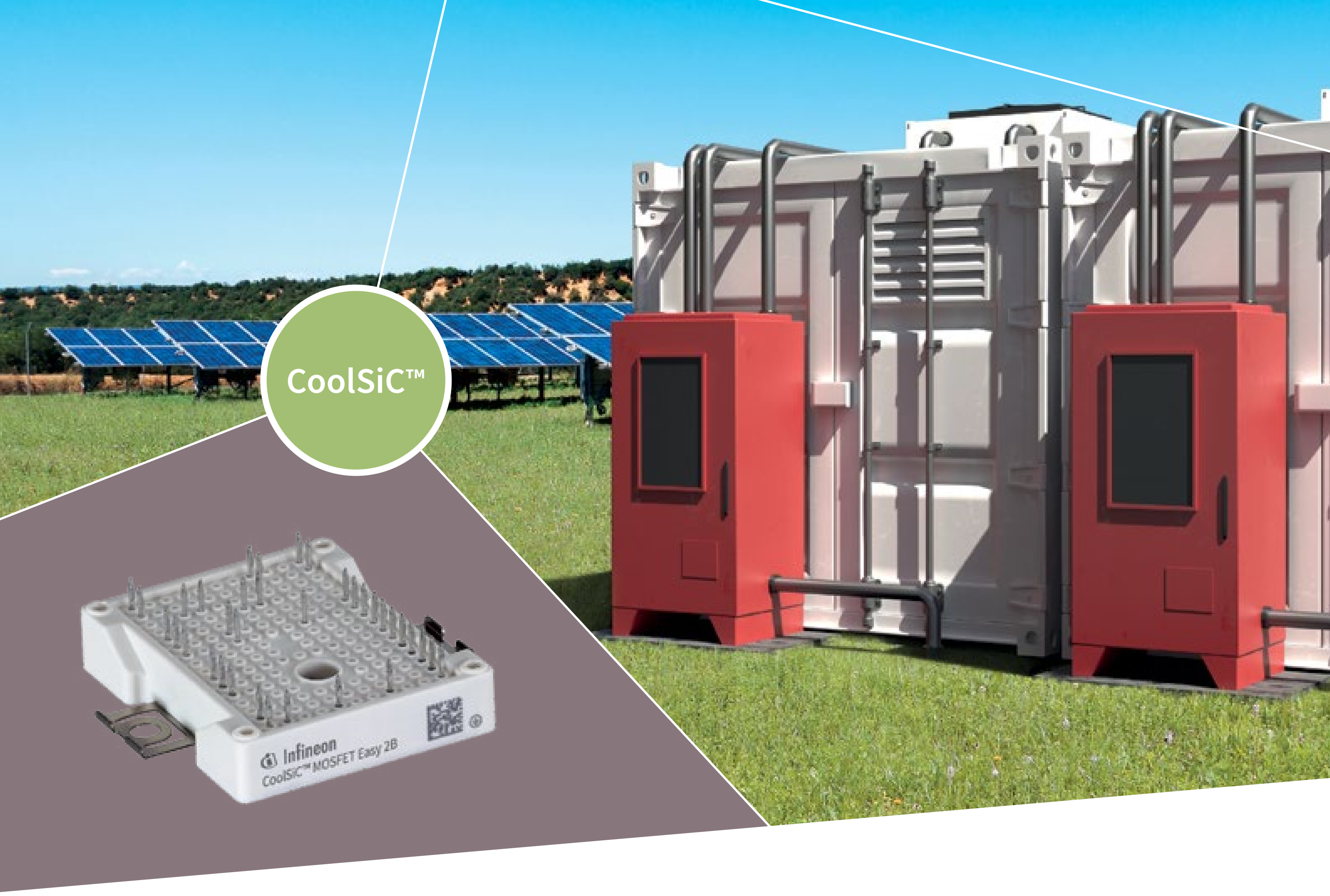

# CoolSiC™ MOSFET for 1500 V solar and energy storage applications

### 3-level active-neutral-point-clamped module in Easy 2B housing

The special adaptation of the active-neutral-point-clamped (ANPC) topology allows taking full advantage of the benefits of CoolSiC™ MOSFETs in combination with cost-effective and highly efficient Si-based IGBT solutions.

**CoolSiC™ MOSFET in Easy 2B has unique advantages**

- Full 1500 $V_{dc}$ capability (with 1200 V switches)
- Hybrid module with 45 mΩ CoolSiC™ MOSFET and 100 A Si IGBT
- Best-in-class switching and conduction losses
- Low inductive design
- PressFIT contact technology
- No external SiC free-wheeling diodes as the body diode can be fully utilized

**CoolSiC™ characteristics bring unbeatable performance**

- Power density can be more than doubled
- System efficiency can reach more than 99%
- Higher frequency operation up to 48 kHz
- Reduced system costs

www.infineon.com/coolsic-mosfet