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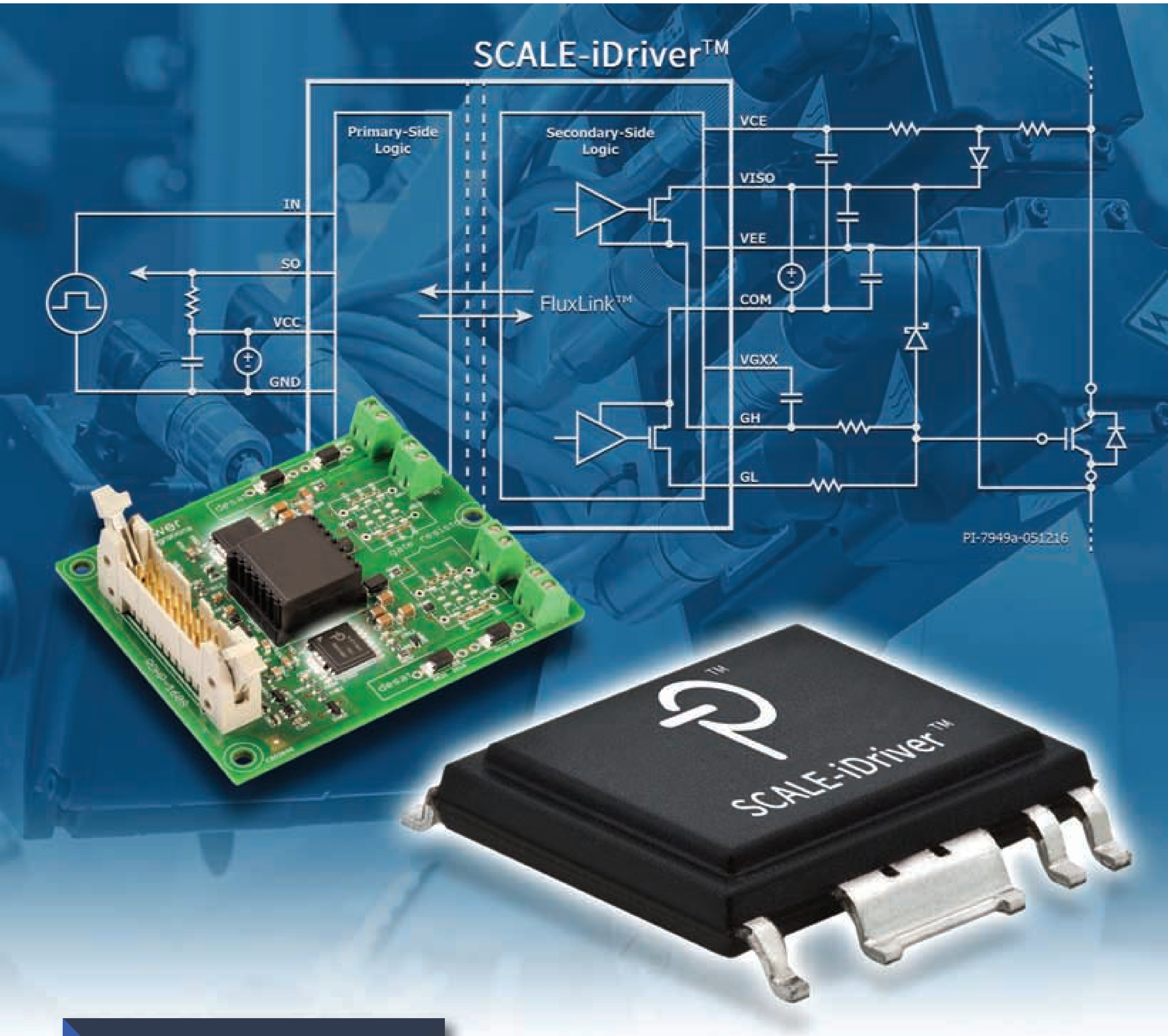
IGBT DRIVERS

1200 V Gate Driver ICs Featuring FluxLink



THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

Also inside this issue

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with our solder bond family providing highest power density

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- Profit from over 20 years of expertise in IGBT soldering and bonding
- Fast and extensive technical support

Main Features

- Blocking voltage $V_{DRM} = V_{RRM} = 1{,}600\,V$
- Average current 60…320 A
- Surge current 1,500…9,500 A
- Available with thermal interface material TIM

www.infineon.com/solderbond-family

Infineon Technologies Bipolar

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DfA media

COVER STORY

1200 V Gate Driver ICs Featuring FluxLink

Power Integrations has introduced a new family of IGBT and Power MOSFET drivers which incorporates its unique FluxLink™ isolation barrier communications technology. First used on the InnoSwitch™ AC/DC controller products and now in volume production, FluxLink provides the reinforced isolation required for switching applications up to 1200 V. The FluxLink technology is a high speed bi-directional communications link that sits across the isolation gap. Using a robust signalling protocol, it provides very high EMI and magnetic field immunity and exceeds the standards IEC61800-4-8 and IEC61800-4-9 in all three axes. It features a very low propagation delay and a very low jitter of only +/-5ns. This link not only isolates the low voltage input control side of the device but also communicates back any fault conditions measured on the high voltage side of the device back across the barrier to a microcontroller responsible for control and monitoring the device operation. More details on page 20.

Cover image provided by Power Integrations, USA/Germany

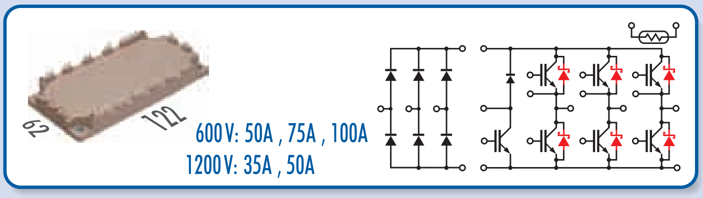
Fuji Electric

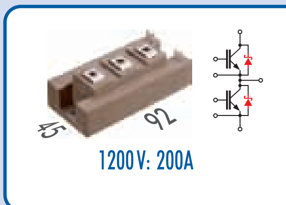
Innovating Energy Technology

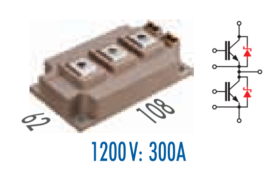
Hybrid IGBT Modules

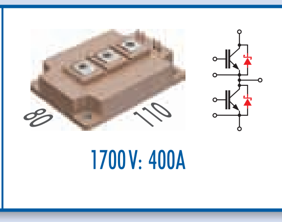
Si-IGBT with SiC-Schottky diode

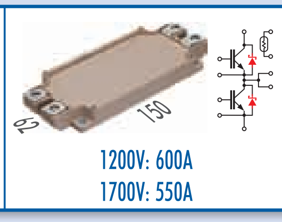
- Higher efficiency
- Higher output current
- Suitable for high switching frequencies
- Significant lower reverse recovery and turn-on losses

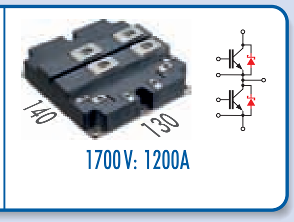






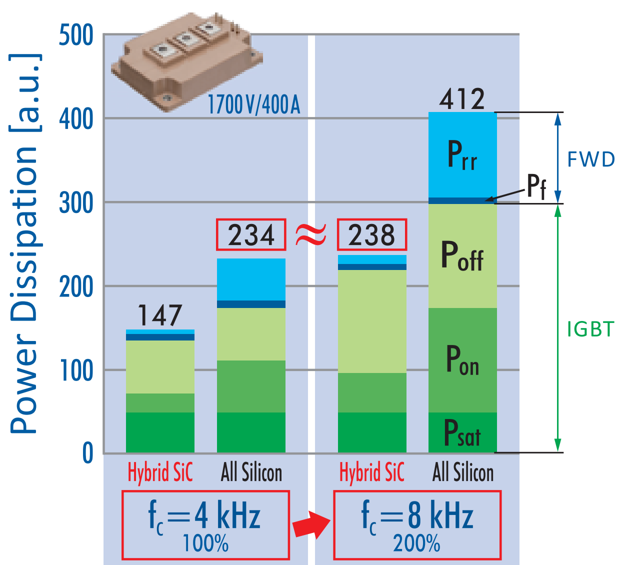






Comparison between All Silicon and Hybrid-SiC Module

Increase of switching frequency



100% higher carrier frequency at same power dissipation

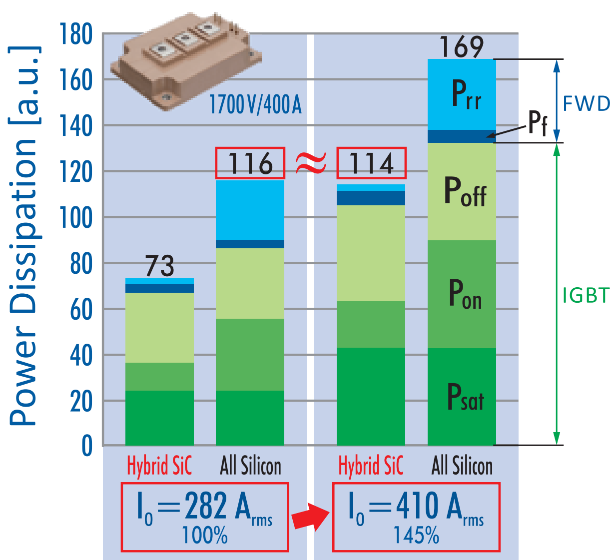
Conditions

V_{CC} = 900 V • f_0 = 50 Hz • cosφ = 0.9 • λ = 1.0

I_0 = 282 A_{rms}

f_c = 4 ~ 8 kHz

Increase of output current



45% higher output current at same power dissipation

Conditions

V_{CC} = 900 V • f_0 = 50 Hz • cosφ = 0.9 • λ = 1.0

I_0 = 282 ~ 410 A_{rms}

f_c = 4 kHz

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More SiC-MOSFET Vendors Give Market Push

Will Silicon as the major power semiconductor material survive in the future or will it be replaced by Gallium Nitride (GaN) in the lower and Silicon Carbide (SiC) in the higher power level? This question might arise by listening to the keynotes and speeches given at PCIM Europe in May – and by interviewing the involved companies.

In the early 1980's the Silicon bipolar transistor has been replaced by MOSFETs, the 1990's saw the adoption of IGBTs, and the 2000's brought superjunction MOSFET into volume. Now an even more fundamental transition is underway as Silicon is overtaken by the introduction of SiC and GaN power products. The breakthrough performance of qualified products, with the subsequent application benefits of size and cost, is now fully appreciated by power system designers. As the 'eco-system' continues to mature, with new enabling topologies, control ICs and magnetic solutions, the transition will accelerate and transform the power industry. It's time for a change from Silicon to Gallium Nitride, Superjunction (SJ) Silicon will become GaN and IGBTs will become Silicon Carbide, so the summary of Dan Kinzer's PCIM keynote, CTO/COO of Navitas Semiconductor. In his vision off-line AC/DC converters and inverters are about to undergo massive transformation, as new GaN power ICs are introduced to the market. Switching frequencies >5 MHz in bridge topology and >25 MHz in single ended resonant topologies are already demonstrated (see PEE 2/2016, pages 26-28). As the SiC and GaN 'eco-system' continues to develop and mature, with enabling topologies, packages, new control ICs and new magnetic solutions (materials and implementations), the transition to wide band-gap materials will continue to accelerate and transform the power industry. Perhaps he might be right – researchers such as German Fraunhofer Institute IISB are developing new power electronic designs exclusively with SiC or GaN devices. In terms of GaN PCIM did not offer real news – everything had been said already at APEC 2016 in Long Beach/USA.

SJ MOSFET components were commercially released for the first time in 1998 by Infineon Technologies. This year, the company has announced the seventh (gold) generation. Though new players are entering the market, historical players are willing to maintain their lead by decreasing production cost as much as possible or by introducing different technologies. On the other side, GaN on Si offer new capabilities, such as the possibility of working at higher frequencies and increasingly competitive manufacturing costs. GaN on Silicon may enter the 600/650 V power device sector - but at the same time, improvements in Silicon SJ MOSFET components will keep them on the market and drive them to become more standardized and popular. According to market researcher Yole, GaN HEMT clearly offers better technical performance, and GaN on-resistance per square costs less than Si SJ MOSFET. However, to deal with the competition, MOSFET devices are continually improving in performance and keeping costs competitive. At PCM Infineon's Neil Massey, Senior Product Marketing Manager for CoolMOS, said that the latest CoolMOS devices nearly equal the on-resistances of GaN, but not the in- and output capacities. Yole underscores the attractiveness of low-voltage applications, a $8.3 billion market in 2014, and the fierce competition between SJ MOSFET and GaN technologies. At the opposite end, for higher voltages, applications are less cost-driven and the competing technology, SiC, is more appealing.

This situation has been realized also by Infineon Technologies by introducing its first 1200 V SiC-Trench-MOSFET at PCIM and thus enlarging the offering of the traditional vendors such as Wolfspeed/Cree, ROHM, Mitsubishi, Toshiba, or ST Microelectronics. Infineon's market entry was highly appreciated by Wolfspeed's product marketing director Guy Moxey who expects an increased SiC-MOSFET acceptance by Infineon's potential in general.

This Trench-MOSFET design limits the electric field in the gate oxide in on-state as well as in off-state. A specific on-resistance of 3.5 mΩcm^2 for 1200 V is provided, achievable even in mass production in a stable and reproducible way. The on-resistance is already achieved at gate-source voltage of 15 V. The gate-source-threshold voltage is close to 4 V. These boundary conditions are the baseline for transferring quality assurance methodologies established in the Silicon power semiconductor world in order to guarantee FIT rates expected in industrial and even automotive applications. The optimized design against too high gate oxide field stress provides IGBT-like gate oxide reliability. Analysis confirms a full controllability of the voltage slopes of turn-on and turn-off transients. The current slopes for turn-on can be controlled by the gate resistor. In turn-off, the slope is determined by parasitic capacitive effects. Compared with the SiC-JFET, the SiC-Trench-MOSFET shows a further improvement at half the total switching losses, Infineon's speaker stated at the SiC Session of the PCIM conference. And also compared to IGBTs a SiC-MOSFET converter reference design show remarkable benefits – the efficiency increase particularly at higher switching frequencies led to much lower size and weight of the total solution – reducing effectively costs involved in passive components and also packaging perhaps to equal or less system cost. Sooner or later also Fairchild Semiconductor will launch a 1200-V-SiC-MOSFET – after its unsuccessful debut with SiC Bipolar Transistors some years ago. Other future SiC-MOSFET candidates could be Panasonic and Littelfuse.

More on the following pages - enjoy reading.

Achim Scharf
PEE Editor

Largest Planned Battery Project in UK

The 20 MW battery system that RES will provide to the U.K.'s National Grid represents the largest planned battery project to provide frequency regulation in the country – a trend that IHS **(www.ihs.com)** predicts will continue in the coming years.

After several years of rapid price reduction, large-scale batteries are increasingly being considered an attractive alternative to conventional thermal generators that provide electricity grid balancing services — in particular, frequency regulation. Average lithium ion (Li-ion) battery prices have fallen by over 60 percent in the last four years, largely because of growing competition in the stationary and automotive battery sector.

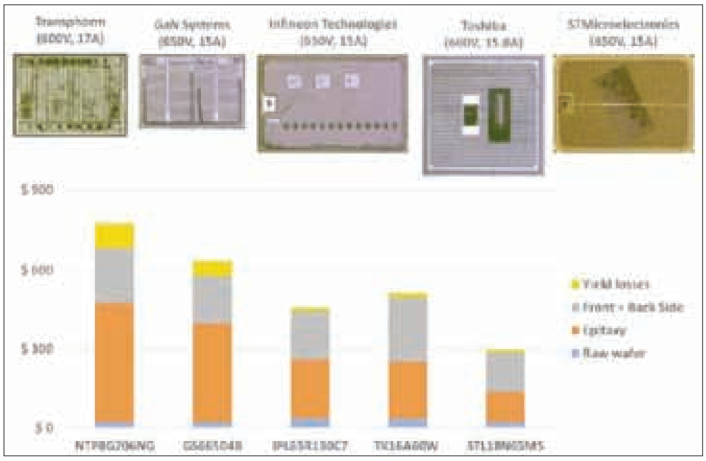
Because of their extremely fast response, high efficiency and long-life, Li-ion batteries have quickly established themselves as the leading battery technology for these types of applications. To date the majority of such systems have been developed in the United States, Germany, South Korea and Japan. Aided by the National Grid's upcoming tender for 200 MW of "enhanced frequency response," and with quickly rising demand for batteries to store surplus solar power in homes, IHS expects nearly 1 gigawatt (GW) of batteries will be installed in the United Kingdom's grid by 2020.

Silicon Superjunction versus Gallium Nitride

SJ MOSFET components, a Si technology, were commercially released for the first time in 1998 by Infineon Technologies. This year, the company has announced the seventh (gold) generation. Though new players are entering the market, historical players are willing to maintain their lead by decreasing production cost as much as possible or by introducing different technologies. On the other side, GaN on Si HEMTs offer new capabilities, such as the possibility of working at higher frequencies and increasingly competitive manufacturing costs.

GaN on Si HEMTs are good candidates to enter the 600/650V power device sector. But at the same time, improvements in silicon SJ MOSFET components will keep them on the market and drive them to become more standardized and popular. "GaN HEMT clearly offers better technical performance, and GaN RdsonA costs 40% less than Si SJ MOSFET on average. However, to deal with the competition, MOSFET devices are continually improving performance and keeping costs competitive. Will Si SJ MOSFETs maintain their lead and stay attractive compared to GaN technologies? The battle is raging on", underlined Yole's **(www.yole.fr)** analyst Elena Barbarini.

Yole analysts underscore the attractiveness of low-voltage applications, a $8.3 billion market in 2014, and the fierce competition between SJ MOSFET and GaN technologies. At the opposite end, for higher voltages, applications are less cost-driven and the competing technology, SiC, is more appealing. "The manufacturing processes selected by each company are key, especially at the packaging level", comments Véronique Le Troadec, Laboratory Engineer, at Yole's partner System Plus. Here more than 30 power devices were disassembled to identify and understand the latest innovations. "And these technical choices strongly impact the price of the device. Indeed, in this fast-moving, competitive environment, industrial companies are focusing their strategy on developing new manufacturing technologies and coming up with attractive power devices for end users. With these new technologies, power electronics companies are seeking to decrease device cost and improve performance", Le Troadec commented. In example Infineon and STMicroelectronics have adopted similar approaches using multiple epitaxy and implantation processes, whereas Toshiba fostered a new solution using deep trench and epi filling processes. Transphorm and GaN Systems also developed their own technologies, as well as special packaging. GaN Systems chose embedded-die packaging technology for its power device components, collaborating with Austrian AT&S to do so. Packaging has clearly and gradually become an inescapable way to decrease manufacturing costs and attain competitive prices. However, despite of this huge push in innovation, we are not likely to see a significant decrease in power device prices in less than 5 years, Le Troadec stated in its comparative analysis of GaN vs. Si power devices.



Die structure and cost comparison of various Si SJ and GaN devices

Source: Yole/System Plus

PMBus Zone Control Operations Released

The PMBus specification working group has released Application Note AN001 which provides in-depth discussion of the PMBus Revision 1.3 Zone commands and detailed examples to provide guidance to designers and architects implementing zone operations in their systems.

PMBus Revision 1.3 includes new enhancements called Zone Write and Zone Read. The Zone operations bring an important, and powerful, new functionality to PMBus systems. With a single transaction Zone commands provide the ability to read from or to write to all of (or a subset thereof) a system's devices, including any pages within those devices. Implemented on top of the latest SMBus 3.0 [R03] transport specification operating at up to 1MHz clock, Zone commands provide for faster transactions while maintaining backward compatibility with the older PMBus 1.2 protocol.

The Zone Read command enables a fast, prioritized response to a query of any data. For example, a Zone Read operation can be used to discover all of the devices attached to a PMBus in one transaction – something that previously could require up to 255 bus operations. Further, Zone Read operations offer improved methods of retrieving system information and provide a means to receive the information of highest priority to the master first. The application note includes 6 detailed examples of the use of Zone Read commands. These include Discovering Zone Active Devices in a System, Priority-Based Fault Reporting and Fault Handling, Highest Data Value Request, Fast Telemetry, Priority-Based Telemetry and Reconfigurable Sequencing Based on the Power Good Signal. Conversely, the Zone Write command provides a solution for synchronized data execution by offering a way to send commands to some or all of the devices on a PMBus in a simple, short transaction. The application note provides 3 examples of Zone Write commands comprised of Synchronizing Device Turn On and Turn Off, Simultaneous Output Voltage Margin and Simultaneous Configuration Storage. The Application Note, "AN001: Using the ZONE_READ and ZONE_WRITE Protocols", is free and can be downloaded from the technical section of **www.pmbus.org**.

Future of Energy Supply

Dramatically falling costs are driving the global solar boom. In many regions, the levelized cost of energy (LCOE) produced from solar power is now the same as, or even lower than, that of energy from fossil fuels. In fact, large-scale PV power plants can generate solar power for as little as 0.08 US dollars/kWh. This is the situation facing Intersolar Europe from June 21 – 24 in Munich, celebrating its 25th anniversary.

All continents are showing trends towards large-scale PV power plants with high, double-digit – or even three-digit – megawatt capacities in both new and established markets. "Solar Star" (579 MW), completed in California in June 2015, is currently the world's largest photovoltaic power plant connected to the grid. Additionally, the construction of a photovoltaic project with a total capacity of 350 MW was put up for tender in the United Arab Emirates, and Chile has the "El Romero Solar" PV power plant in the pipeline which has a projected nominal power output of 196 MW.

The major challenges facing the sustainable energy industry are the digitalization and networking of technologies. The modern energy supply is both smart and renewable. Photovoltaics (PV) is booming worldwide: According to SolarPower Europe, over 50 gigawatts (GW) of new PV capacity were added worldwide in 2015, including 8 GW installed in Europe. The total global capacity has reached approximately 228 GW, around 100 GW of which are in Europe.

Millions of decentralized renewable energy plants, storage systems and consumers who draw power not just from the grid, but also use environmentally friendly methods to generate power – this is the energy world of the future. To achieve this, intelligent infrastructure and storage options to make it possible to connect the many different renewable energy installations and also to offset the temporal fluctuations in supply from renewable energy sources are needed.

Consumption and generation are automatically analyzed and optimized, creating smart energy. Large-scale storage systems and intelligent networks are already being combined with decentralized photovoltaic installations and battery storage systems for domestic power supply to provide the public grid with balancing power.

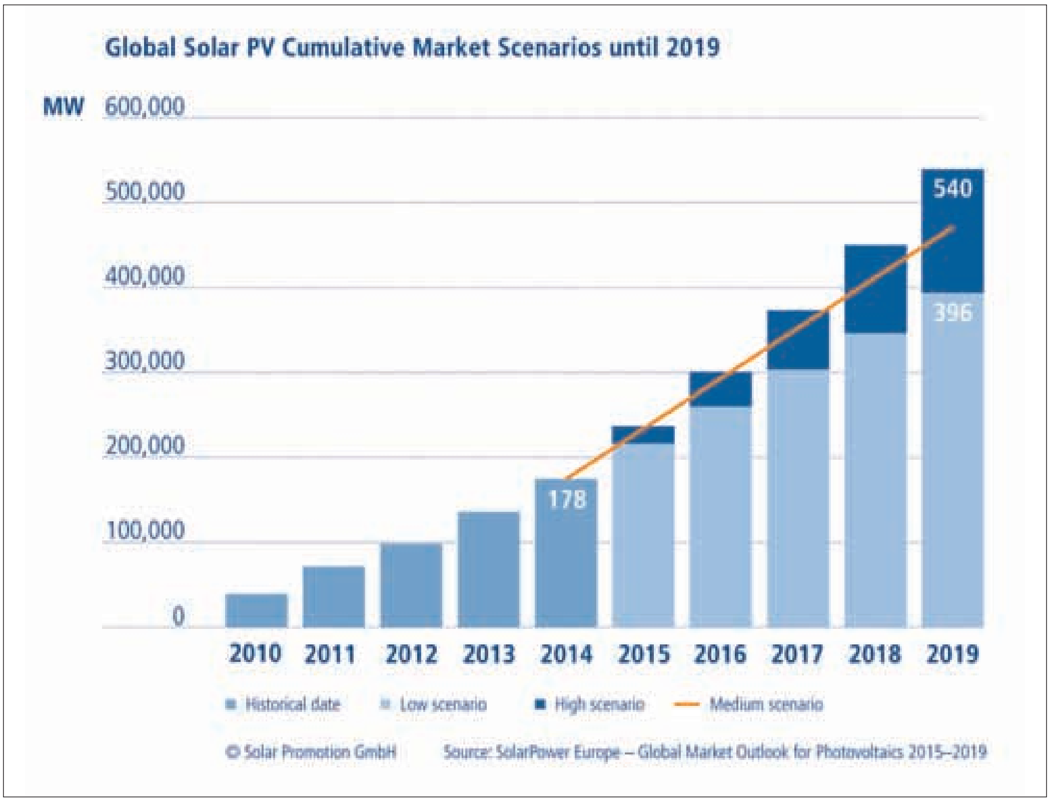
Intersolar and ees Europe 2016 will present systems and communication technologies, and new services and business models – including small and large electrical storage systems, intelligent transformers and virtual power plants.

The technological home – and future – of this new energy world is Germany and Europe. More renewable energy is integrated into the grids here than anywhere else in the world, and nowhere else is there more expertise and experience in this area.

Energy storage devices and wind energy into the grid

The global expansion of photovoltaics and wind energy in new and established markets alike requires the grid integration of both private solar installations and multi-megawatt power plants. In Europe, for instance, photovoltaic systems are already feeding a total output of almost 100 GW of solar power into the grid. In Germany alone, PV installations producing around 41 GW and wind power plants with 42 GW are connected to the grid. To interconnect the numerous renewable energy installations and to balance out the temporal fluctuations in energy production, an intelligent infrastructure with storage options is required.

PV plants, inverters and battery storage systems can and must provide system services, for example through helping to maintain voltage stability in the power grid or regulating voltage in the event of a failure in the grid. In addition to small storage systems and battery storage systems for domestic power supply, virtual power plants and interconnected large-scale storage system are already being used to provide the public grid with balancing power.



Global Solar PV Cumulative Market Scenarios until 2019
Source: SolarPower Europe - Global Market Outlook for Photovoltaics 2015-2019

More Power for PCIM Europe

PCIM Europe 2016 closed on May 12 with positive results after three days. On an area of 21,500 sqm, a total of 436 exhibitors, as well as 93 represented companies presented the latest innovations in power electronics to more than 10,000 visitors. With 308 oral and poster presentations, the conference attracted 771 delegates. At PCIM 2015 around 700 delegates, 417 exhibitors plus 88 represented companies and nearly 9000 visitors were counted – thus an overall slight increase was observed.

The conference started traditionally with the award ceremony for the young engineers and the best paper. As well as being able to present the paper at the PCIM Europe Conference and see it published in the conference proceedings, the winner received 1,000 Euros and a paid trip to PCIM Asia 2017 in Shanghai, sponsored by PEE and Semikron. This year Nicolas Quentin from Sagem/Ampere Labs, France, was awarded (see our feature '1 MHz Converter with 95 % Peak Efficiency for Aircraft Applications'). The Yound Engineer Award received Christian Felgemacher (University of Kassel), Stefan Hain (University of Bayreuth), and Christoph Marxgut (Helbling Technik) – all of Germany.

A Post-Silicon world?

In the early 1980's, industry pioneers transformed the silicon bipolar transistor into the mass production MOSFET. The 1990's saw the adoption of IGBT, and the 2000's brought superjunction MOSFET into volume. "Now, an even more fundamental transition is underway as Silicon is overtaken by the introduction of SiC and GaN high performance, wide band-gap power products. The breakthrough performance of qualified products, with the subsequent application benefits of size and cost, is now fully appreciated by power system designers. As the 'eco-system' continues to mature, with new enabling topologies, control ICs and magnetic solutions, the transition will accelerate and transform the power industry", stated Dan Kinzer, CTO/COO of Navitas Semiconductor (**www.navitassemi.com**) in the first PCIM keynote. "Navitas is the latin name for energy, and that is our mission as a start-up company. It's time for a change from Silicon to Gallium Nitride, Superjunction Silicon will become GaN and IGBTs will become Silicon Carbide", he said.

"In high power (multi-kW) applications like electric vehicle drive and solar string inverters, IGBTs are being surpassed by 1,200V SiC-FETs which utilize a cost-effective vertical structure to enable high efficiency, simplified architectures. In lower power (~300 W) solar micro-inverters, high frequency 650 V GaN systems are under evaluation. As manufacturing volumes increase and costs fall, low voltage (100 V) Si used in solar optimizers may also be replaced by GaN devices". Additionally, material properties of WBG devices such as high critical E-field and high carrier mobility, enable SiC and GaN to achieve huge improvements over Silicon in current-handling and high-frequency operation. Advances in low-inductance packaging and a transition from discrete power and drive implementation to co-packaging and monolithic integration simplify and optimize end applications, enabling new form-factors and lower system costs".

In his vision off-line AC/DC converters and inverters are about to undergo massive transformation, as new GaN power ICs are introduced to the market. Switching frequencies >5 MHz in bridge topology and >25 MHz in single ended resonant topologies are already demonstrated (see PEE 2/2016, pages 26-28). As the SiC and GaN 'eco-system' continues to develop and mature, with enabling topologies, packages, new control ICs and new magnetic solutions (materials and implementations), the transition to wide band-gap materials will continue to accelerate and transform the power industry.

More Silicon Carbide Vendors

Japanese ROHM Semiconductor (**www.rohm.com**) pioneered besides US-based Cree the SiC-MOSFET. SiC devices have been a focus of the power semiconductor market due to the realization of improved material characteristics over Silicon. "For these reasons, we have continuously

PEE Editor Achim Scharf (left) and Semikron's Scheuermann (right) handed over the Best Paper Award to Nicolas Quentin from Sagem/Ampere Labs, France

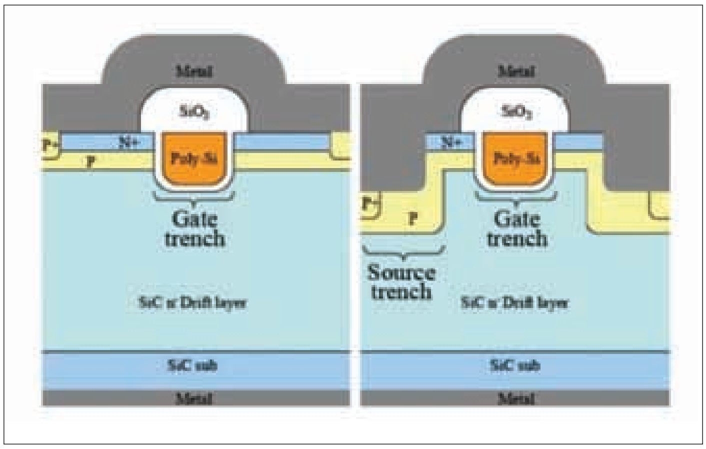
"It's time for a change from Silicon to Gallium Nitride, Superjunction Silicon will become GaN and IGBTs will become Silicon Carbide", stated Navitas' Dan Kinzer in his keynote **Photo:AS**

developed SiC-SBD and MOSFET devices over the past 10 years. Furthermore, many recent applications required us to propose suitable products for realistic scenarios by expanding on the current selection of SiC devices in use today. As SiC market commercialization accelerates, we are well situated to introduce the combination of controller IC and 1700 V SiC-MOSFET for industrial power supplies and contribute to improved efficiency in these applications. Additionally, expanding on our line-up of robust devices for high temperature and high humidity environments has led to the evolution of a new generation of devices which is realized in the lower on-resistance trench-gate SiC-

This final Navitas statement on SiC and GaN left PCIM Conference Director Leo Lorenz with some questions **Photo: AS**

MOSFET", said Product Planning Engineer Naoyuki Kizu.

"The most noteworthy product release in our SiC product line-up in 2015 was the world-first commercialization of the SiC "Trench" MOSFET, which is our 3rd gen SiC-MOSFET. We developed a double-trench, SiC MOSFET structure, which has both gate and source trench. A conventional trench device structure suffers from poor gate oxide reliability due to high electric field concentration at the bottom corners of the trench structure. Our solution to this technical challenge was to form the source trench with the gate trench, thus named double trench structure", explained Kizu. The most prominent feature of the



Schematic cross section of conventional single-trench SiC-MOSFET structure (left) and double-trench structure with source trench and gate trench

new 3rd gen SiC "trench" MOSFET is a 50 % reduction in on-resistance per chip area compared to the existing planar SiC-MOSFETs (2nd gen SiC-MOSFET) in all temperature ranges. On-resistance per chip area of the 1200 V class 3rd gen SiC "trench" MOSFET is 4.1mΩcm^2, and of 650 V 3rd gen SiC "trench" MOSFET is 3.1mΩcm^2. The initial product line-up covers 22 mΩ to 40 mΩ for 1200V class and 30 mΩ for 650 V class devices.

Although SiC-MOSFETs have superior characteristics, they need optimized gate drive control. Gate-source voltage is the most significant differences between SiC-MOSFETs and Si- MOSFETs. "Our SiC-MOSFETs are optimized with driving voltage of 18 V to turn-on while Si-MOSFETs generally require 10 V. Our newly released Quasi-resonant flyback control IC is optimized to drive our SiC-MOSFET with adjustable gate-source voltage and under-voltage lockout protection, and consequently can draw out the performance benefits of SiC-MOSFETs. Using a reference circuit, the SiC-MOSFET improved conversion efficiency by 6 % at full load compared to the Si-MOSFET, which suggests potential for downsizing the power block", Kizu pointed out.

Infineon presented its first SiC-MOSFET rated 1200 V (**www.infineon.com/coolSiC**) with an on-resistance of 45 mΩ and rated current of 25 A. In general, this SiC-Trench-MOSFET shows superior performance in terms of switching behavior and overall losses. "Compared with our SiC-JFET, the new SiC-MOSFET allows a significant reduction of the switching losses. The device concept shows considerably suppressed parasitic turn-on under typical operating conditions. This results in drastically reduced recovery losses leading to very low total switching losses", underlined Peter Friedrichs, Senior Director SiC. "First products will be available in 3-pin and 4-pin TO-247 packages targeted at photovoltaic inverters, UPS, battery charging and energy storage applications. Both devices are ready for use in synchronous rectification schemes thanks to the robust body diode operating with nearly zero reverse recovery losses. The 4-pin package incorporates an additional (Kelvin) connection to the source, which is used as a reference potential for the gate driving voltage. By eliminating the effect of voltage drops due to source inductance, this further reduces switching losses, especially at higher switching frequencies". So far Infineon will focus on 1200 V devices and single-trench technology.

A challenge in the development of SiC-Power-MOSFETs is to balance gate-oxide reliability and low on-resistance. Due to the MOS-interface defect structure the MOS-channel resistance contributes largely to the total on-

"Our SiC-Trench-MOSFET concept shows considerably suppressed parasitic turn-on under typical operating conditions. This results in drastically reduced recovery losses leading to very low total switching losses", underlined Infineon's Senior Director SiC Peter Friedrichs **Photo: AS**

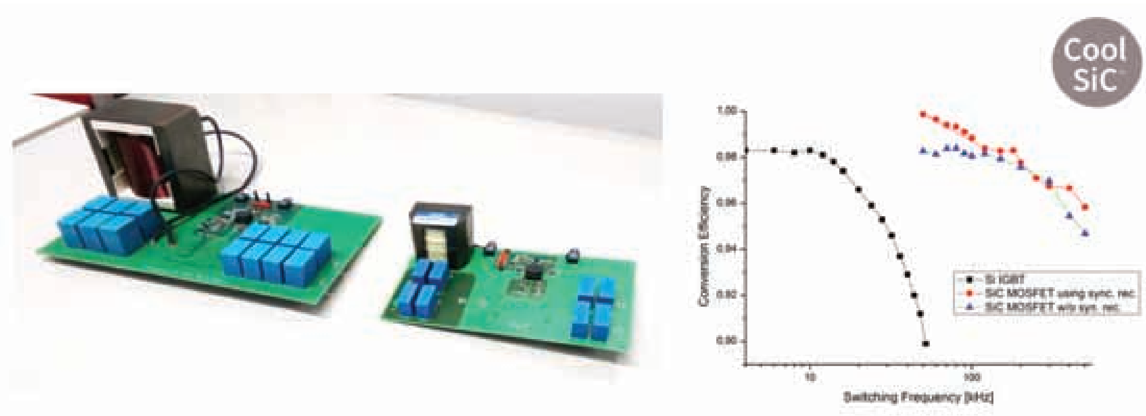
resistance. For achieving an acceptable on-resistance, the inversion in the channel region is forced by a design using high electric fields, even in the gate oxide. Hence there is the risk of too high gate oxide stress which can lead to poor long term reliability. "Our SiC-Trench-MOSFET-concept combines both, an attractive on-resistance and an optimization against too high gate oxide field stress", said Infineon's Daniel Heer in his conference presentation of the company's new SiC MOSFET.

Heer continued: Switching losses of SiC-MOSFETs are usually quite low and especially almost temperature independent. Today R&D activities focus on the area specific on-resistance as the major benchmark parameter for a given technology. For 4H-SiC based planar MOSFETs being manufactured on the so-called Silicon face of the SiC-wafer, one has still to deal with an extraordinary high interface trap density close to the conduction band. This ends up at very low channel mobilities and therefore high contributions of the channel to the total on-resistance. Even the progress made many years ago by the introduction of nitride oxides was not able to eliminate this drawback in an acceptable manner. The high defect density is reflected in various peculiarities of SiC-MOSFET based devices. One example are weak transconductance characteristics in comparison to Silicon based power MOSFETs, often in combination with a low threshold voltage of around only 2 V instead of 4 V and above as usually this is the case in Silicon based power devices. Another implication is an abnormal temperature behavior of the on-resistance.

Planar SiC-MOSFETs have actually two sensitive areas with respect to oxide field stress, first the usually discussed stress in reverse mode in the area of highest electric field close to the interface between drift region and gate oxide and second the overlap between gate and source which is stressed in on-state. Heer expects that the stress in blocking mode is the less critical one since it can be mitigated by a proper device design, e.g. shielding by p-layers. In addition, in the practical operation of a device nearly never the full field will be applied. Even in the most critical target application regarding DC reverse bias stress over a longer period of time like solar booster circuits maximum 1000 V will occur with 800 V being the normal average bias level. However, a high electric field in on-state is seen as more dangerous since no device design measures are in place which could reduce the field stress during on-state. Thus, the overall goal is to combine the low on-resistance with an operation mode where the part remains in the well investigated safe oxide field conditions. In the on-state, this can be realized today by moving away from the planar surface with its high defect density towards other more favorable surface orientations. MOS-channels on the so-called a-face of SiC which lies 90° inclined towards the planar surface offer a factor of minimum 10 lower defect densities. Thus, one widely investigated approach is to use a trench based structure, similar to nearly all modern Silicon power devices. This approach does not only open up the door towards a low channel resistance, also the options for cell shrink are extended compared to a planar device design. Attractive on-resistance values can be achieved without the need to apply critical oxide fields in on-state.

"Thus we have developed a Trench-MOSFET design which limits the electric field in the gate oxide in on-state as well as in off-state. A specific on-resistance of 3.5 mΩcm^2 for 1200 V is provided, achievable even in mass production in a stable and reproducible way. The on-resistance is already achieved at gate-source voltage of 15 V. The gate-source-threshold voltage is close to 4 V. These boundary conditions are the baseline for transferring

Comparison Infineon's SiC-MOSFET vs. Si IGBT regarding switching frequency on system level



		SI IGBT Reference	SiC MOSFET Demonstrator
L	Size (H x W x L) [mm³]	125 x 95 x 70	70 x 55 x 40
	Weight	3.20 kg	0.50 kg
Total	Size (H x W x L) [mm³]	139 x 300 x 185	84 x 206 x 134
	Weight	3.77 kg	0.93 kg

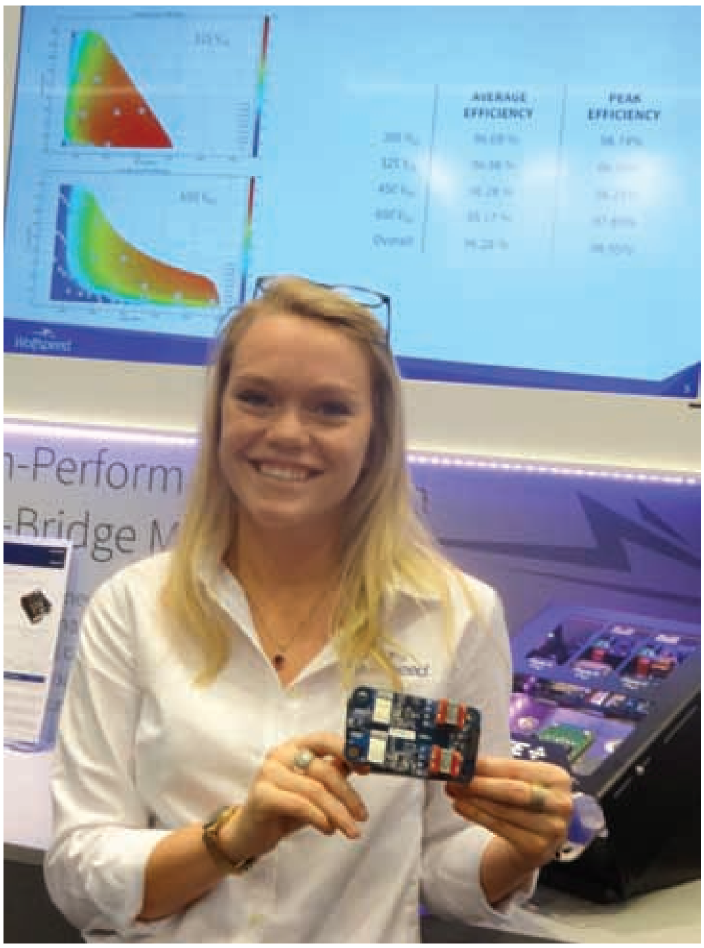
quality assurance methodologies established in the Silicon power semiconductor world in order to guarantee FIT rates expected in industrial and even automotive applications. Our optimized design against too high gate oxide field stress provides

IGBT like gate oxide reliability. Our analysis confirms a full controllability of the voltage slopes of turn-on and turn-off transients. The current slopes for turn-on can be controlled by the gate resistor. In turn-off, the diD/dt is determined by parasitic capacitive effects. Compared with the SiC-JFET, the SiC-Trench-MOSFET shows a further improvement at half the total switching losses", Heer stated.

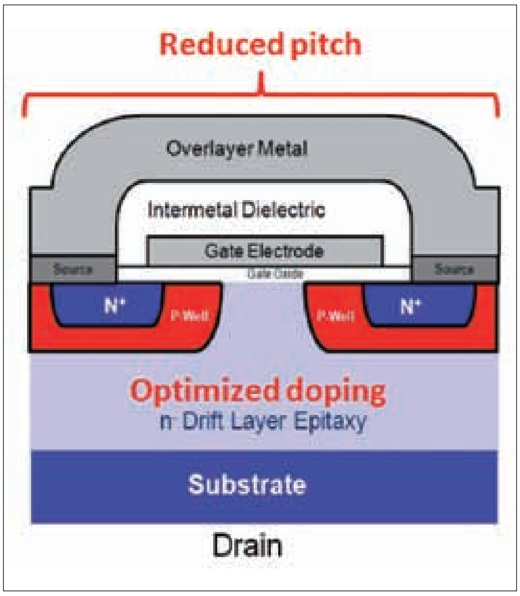
Wolfspeed (**www.wolfspeed.com**), a Cree company, introduced a new 900 V/10 mΩ SiC-MOSFET assembled in a >400 A, half-bridge power module with only 1.25-2.5 mΩ on-resistance at 25°C, depending on the number of chips per switch position (eight or four, respectively). The SiC MOSFET chip has a measured breakdown >1 kV, and a specific on-resistance of 2.3mΩcm^2. The chips were then assembled in 16 power modules, and characterized up to 175°C. Only a 40-50 % increase in on-resistance was measured with a temperature increase from 25°C to 150°C.

With no knee voltage, conduction losses relative to comparably rated Si IGBT power modules can be reduced up to 70 %. The SiC MOSFET chip used here is a planar DMOS design with a total chip area of 4.38 mm x 7.28 mm, with top-level over-layer Al metal, 4µm thick, for standard Al wire-bonding on top-side gate and source. "The measured on-resistance over temperature is positive, but much reduced relative to Si MOSFETs. As a comparison, a 650 V, 19 mΩ Si Superjunction MOSFET's rise in on-resistance is 1.5x higher than the 900 V SiC MOSFET. Over this same temperature range, the Si MOSFET increases by 2.4x, an approximately 60 % steeper slope than the SiC MOSFET", said Wolfspeed's Jeffrey Casady in his conference presentation.

Using a 62 mm module footprint, with 4 nH total inductance, two half-bridge versions of a 900 V SiC power module were demonstrated at the



Wolfspeed's Susan Knowles showing internal structure of the 900 V/4 nH SiC-MOSFET power module manufactured by APEI **Photo: AS**



Device cross-section of Wolfspeed's 900 V/10 mΩ planar SiC MOSFET. Top overlayer metal is 4?m thick Al, backside metal is Ni:Ag (0.6?m:0.8?m thick)

exhibition floor, with 1.25 and 2.5 mΩ charateristics. First prototypes have been shown at APEC 2016 (see PEE 2/2016, pages 20-23). "For bus voltages of 400-700V, a 900 V rated SiC-MOSFET based module could prove to be ideally rated for EV drivetrain applications. At 800A, 175°C, the 1.25 mΩ power modules increased in on-resistance to a maximum of 2.10-2.25 mΩ, and a significant portion of that resistance was from the lead frame of the module", Casady concluded.

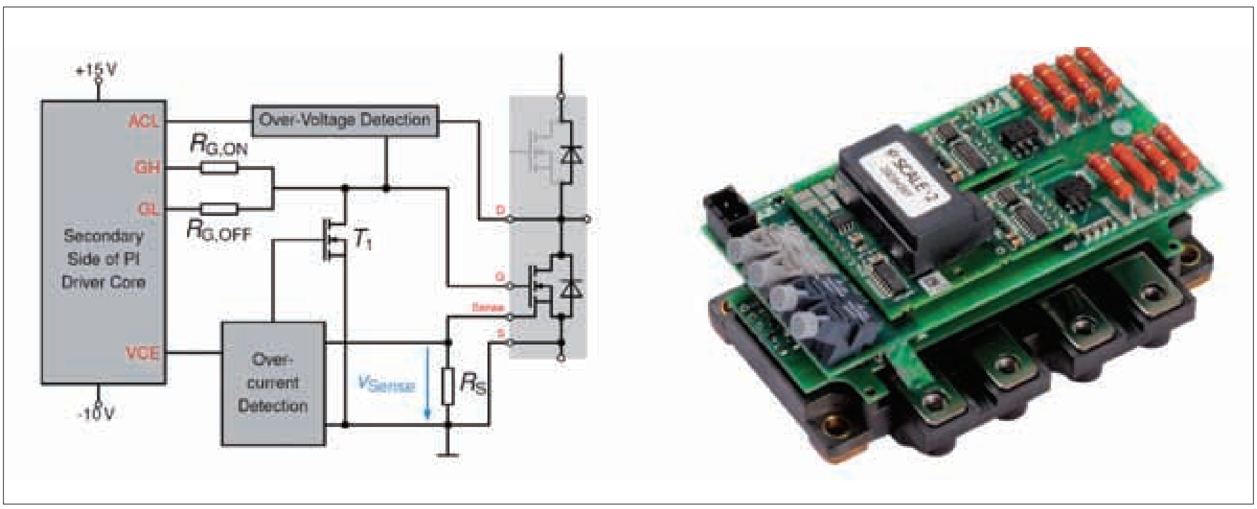
Efficient Drivers for SiC and Silicon

Mitsubishi's (**www.mitsubishichips.eu**) new 800 A/1200 V full SiC module - FMF800DX-24A was developed for high power applications allowing either high switching frequencies (in the range of 30 to 100 kHz) or high efficiency or high power densities. Employing SiC technology facilitates a drastic reduction in the switching losses compared to the Si IGBT. On the other hand, the static losses should be carefully adjusted without sacrificing the ability to handle short circuit conditions. The low on-resistance of the SiC MOSFET is inversely proportional to the chip short circuit (SC) capability. Taking into account the limited SC-endurance capability of today's SiC MOSFET-chips (in the range of a few microseconds) the availability of a separate current sense terminal is a promising option for reducing the response time and accordingly the energy dissipated during SC-turn-off in the MOSFET chip. Furthermore the MOSFET on-resistance can be tuned for lower values. By using this option, over-current conditions (adjustable to any level) can be detected easily and appropriate countermeasures for SC-turn-off can be initiated in the gate driver. As a result the SC-current level and the SC-energy dissipated in the MOSFET can be remarkably reduced.

The 100 A/1200 V SiC MOSFET chips used in the FMF800DX-24A have an isolated source area on top of the source metallization. This small source area is connected to the sense terminal. Thus an earmarked portion of the total source is provided at the sense terminal. The monitored source sense voltage across the sense and source terminals can be used for detecting overcurrents. The current through the sense resistance is proportional to the main source current. The ratio between the sense current and main source current is in the range of 1:61500. The sense voltage across the shunt resistance depends on the junction temperature - by considering these facts an appropriate shunt resistor value can be selected setting the needed over-current trip level. "The efficiency of the advanced protection method was practically realized by implementing it in a core gate driver 2SC0435T from Power Integrations, providing over-voltage protection and over-current detection", Mitsubishi's Eugen Wiesner said within the PCIM SiC session.

Besides this special design for Mitsubishi's SiC modules Power Integrations (**www.power.com**) announced a new family of galvanically isolated single-channel gate driver ICs ranging in output current from 2.5 A to 8 A – without an external booster. SCALE-iDriver™ ICs, optimized for driving both IGBTs and MOSFETs, are the first products to bring FluxLink™ magneto-inductive bi-directional communications technology to 1200 V driver applications, which has already been discussed at APEC 2016 (see PEE 2/2016, pages 7-8). FluxLink technology eliminates the need for opto-electronics and the associated compensation circuitry, thereby enhancing operational stability while reducing system complexity. In addition to combining industry-leading isolation technology, the new gate drivers incorporate advanced system safety and protection features commonly found in medium- and high-voltage applications, further enhancing product reliability. The eSOP package features 9.5 mm of creepage and a CTI of 600, ensuring substantial operating voltage margin and high system reliability (see also our cover story). "By pairing our SCALE technology – which already incorporates all key gate-driver functions into an ASIC – with FluxLink communication, performance and reliability has been increased by an order of magnitude compared to other couplers. Bi-directional communication results in fast, efficient, accurate switching and minimizes signal jitter. The wide FluxLink isolation gap delivers exceptional robustness, and the use of low-profile packaging technology enables two-layer PCBs", underlined PI's VP High-Power Products Wolfgang Ademmer.

Stefan Hain from University of Bayreuth (**www.mechatronik.uni-bayreuth.de**), one of the Young Engineer Awardees, presented at the conference under the title "New Ultra Fast Short Circuit Detection Method Without Using the Desaturation Process of the Power Semiconductor" a new short circuit detection method which is based on monitoring the trajectory of the IGBT in a phase space which is defined by the di/dt value and the gate voltage. The simultaneous exceeding of both corresponding reference values is a solid indication for a fault situation, such as a hard switching fault or a fault under load. A comparison of this method with well known state-of-the-art detection methods illustrates that this method is able to detect a short circuit situation close to the earliest possible point in time, a failure could be detected at all. Furthermore, by evaluating the chronological order of the digital signals of the di/dt comparator and the gate comparator, a hard switching fault could be

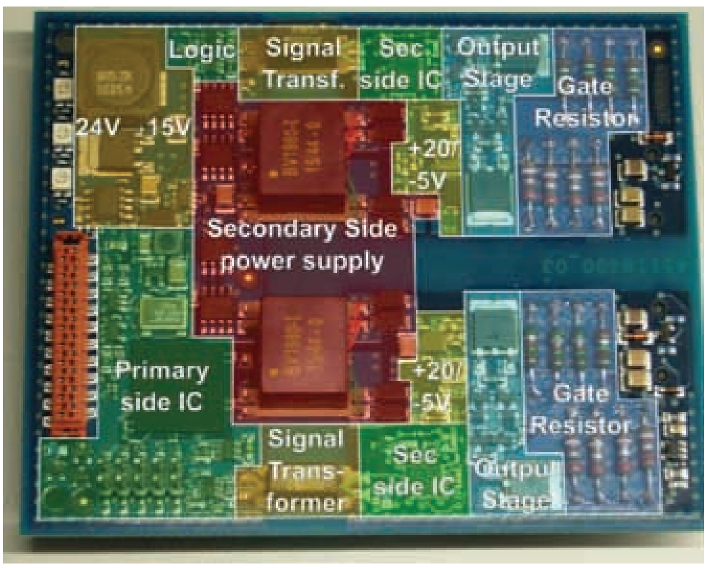


Gate driver for Mitsubishi's SiC-MOSFET protection (right) and its corresponding equivalent circuit diagram (left)

PI's CEO Balu Balakrishnan (right) and VP High-Power Wolfgang Ademmer presented the new 1200 V SCALE Driver incorporating so-called Flux-Link isolation barrier **Photo: AS**

distinguished from a fault under load by using this method. This information could be used to initiate different turn-off strategies, which corresponds to the short circuit fault types respectively. Therefore, this method provides a fast, adaptable and easy to implement short circuit detection method for modern power semiconductors without the need of a desaturation process.

A high power, high frequency gate driver with high integration density using ASICs allowing to drive very low inductive 1200 V, 400 A SiC-MOSFET half bridge modules in both-side sinter technology (SKiN) was presented by Semikron's (**www.semikron.com**) Gunter Königsmann. Because of its low propagation delay, low dead times and very strong output stages of +40/-78 A, the driver for normally-off SiC-MOSFET is suited to switch the 400 A devices up to 200 kHz with extremely low switching losses and low over-voltages. It provides a nominal gate-source voltage of 20 V in the on-state which reduces the on-resistance. In the off-state negative voltages of -3 V...-5 V are needed to prevent parasitic turn-on due to high dv/dt at the parasitic capacitance between gate and drain and in order to reduce the switching losses. The driver uses transformers for bidirectional signal transmission between primary and secondary side (modem), can handle chips with breakdown voltages up to 1700 V and positive and negative offset voltages, respectively. A temperature and short circuit monitoring of the MOSFET switch, as well as differential primary side inputs are used. A galvanic isolated power supply for the secondary sides and a monitoring of all operating voltages of the driver are implemented. The whole driver functionality is integrated in primary and secondary side ASICs. Power supply, output stages and only very few discrete components had to be placed on the PCB, the backside could be completely reserved for shielding and cooling.



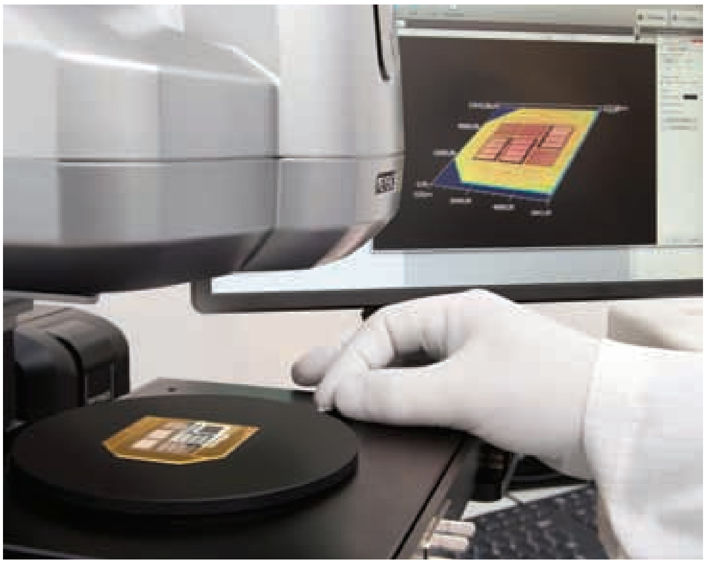
Front side of Semikron's new SiC-MOSFET gate driver board with primary side IC, 2 x secondary side ICs; secondary side power supply and gate driver output stages

Workhorse IGBTs

Though the hype at PCIM was more on the SiC rather than on the GaN side, here everything has been reported in our APEC 2016 review (see PEE 2/2016). IGBTs are still the workhorse in industrial applications.

Fuji's (**www.fujielectric-europe.com**) 7G-IGBTs e. g. have achieved remarkable reduction in switching energy loss as well as lower on-state voltage drop. "As a result, high conversion efficiency is expected even with an extra die shrink in IGBTs and FWDs. In addition, the 7G chipset and package integration were done with the concept of upgrading the continuous operation temperature of 175°C, the critical device capabilities, such as SCSOA, RBSOA for IGBTs, reverse recovery ruggedness for FWD and so on, are carefully considered so that the devices have consistent withstand capabilities when they are compared to the conventional 150°C devices", Thomas Heinzel pointed out at the conference. New thin-AlN substrate, which has thinner but mechanical stronger feature compared to the conventional AlN material, also provides much lower thermal impedance while it keeps or even has better thermal cycling capability. The integration of the chip and new package technologies, the X-series 1700V IGBT family will be soon available. Each package will have extended power rating compared to V-series, such as 1700 V/1800 A rating in PP3 or 1700 V/650 A in DualXT.

StarPower Europe AG (**www.starpowereurope.com**), the European subsidiary of the Chinese power semiconductor manufacturer StarPower Semiconductor Ltd., has developed sintered IGBT half-bridge modules in its Nuremberg-based R&D Center. The IGBT modules are housed in the ECONO Dual Package. By sintering the chips to the substrate, the rating can be increased from 600 A to 700 A. "Thus, one 1400 A Primepack can be replaced by two 700 A Econo Dual modules connected in parallel. This system solution offers the user a significantly more cost-effective alternative", stated



A sintered power semiconductor substrate is being checked for cracks and contamination in Starpower's R&D Center Europe

Managing Director Peter Frey. "Sintering improves the reliability significantly for the 1400 A/1200 V Primepack, compared with soldered modules. The lifetime of an high-performance inverter is increased due to the increased contact strength between chip and substrate. Power cycling tests showed an up to 10 times higher lifetime", explained Christian Kroneder, Head of the R&D Center.

With materials like SiC, modules are further developed to improve switching speed, switching losses and temperature stability. SiC components allow the switching frequency to be increased up to 100 kHz. In combination with the sinter technology, StarPower is developing an extremely low-inductance package, with the aim of being able to offer a high-temperature module of up to 200°C temperature capability. **AS**

1 MHz Converter with 95 % Peak Efficiency for Aircraft Applications

This design methodology of a 50 W isolated DC/DC converter serving as a power supply for aircraft equipment like a FADEC (Full Authority Digital Electronics Control) has been awarded as Best Paper of PCIM Europe 2016, sponsored by PEE. The particularity of this work is the design of a full converter regarding two antagonistic requirements which are a wide input voltage and high efficiency. **Nicolas Quentin, University of Lyon/Ampere/Safran Group, France.**

All the equipments located inside an aircraft network have to respect several requirements imposed by international standards such as the DO160 or manufacturer customs like the derating/stress on a component. One of the most constraining standard is within the Electromagnetic

Interference (EMI) where the converter does not disturb or is disturbed by other equipment on the electrical network.

To reduce the converter size, the general trend is the switching frequency increase but this implies losses increase. Besides, power supplies are installed in an confined environment. They cannot be cooled down by forced convection in the case of the most extreme applications (operating temperature from ?55°C to +110°C). In this condition, power supply losses impact the converter volume and weight to prevent it from overheating. Therefore, a significant gain in efficiency is the main purposes, since it results in a reduction of weight and volume.

When fed by a DC bus in the 18 to 80 V input voltage range, the power cell provides two 15 V isolated outputs to power all standard electronic devices. As shown in Figure 1, the work is not limited to the power cell and filters which represent only 44.5 % of the components size area, but with the design and implementation of the full converter including all auxiliary functions required for the safety and autonomous operation.

The goal is to use a topology which creates the capacity to increase the switching frequency in order to reduce the value and size of passive elements. Soft-switching is a reasonable technique to increase the switching frequency and limit the power losses at the same time. Figure 2 shows the simplified schematics (power cell only) of the Flyback Active-Clamp circuit. This topology is suitable for wide input voltage applications with a step-down and step-up transfer function depending only on the duty cycle.

This topology has two additional benefits for a low-power application: a low number of components and a simple control (duty cycle at fixed frequency). Regarding the efficiency this topology can achieve Zero Voltage Switching (ZVS) at the primary side allowing the converter to increase the switching frequency in contrast to a conventional hard-switching converter such as the classical Flyback converter.

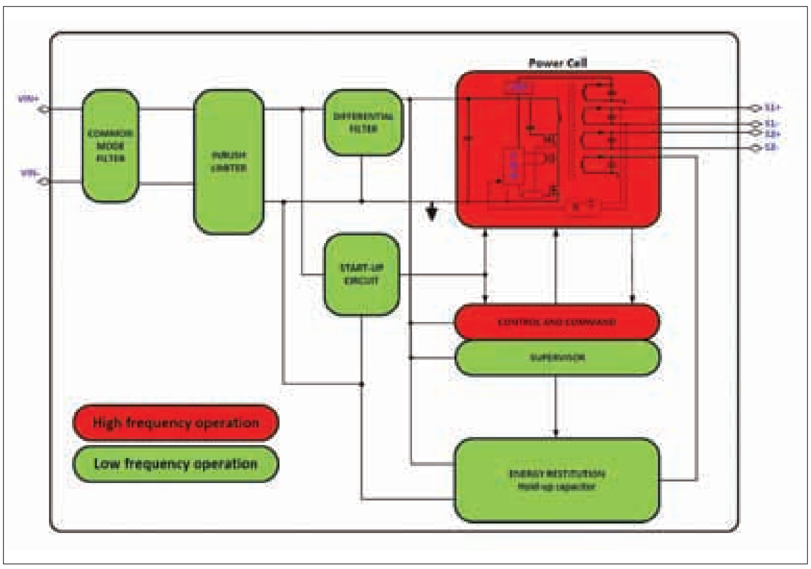


Figure 1. Synoptic of the overall converter including autonomous and safety functions

High frequency operation prerequisites

This converter includes advanced technologies dedicated to high frequency and high ef ficiency operation with the use of GaN transistors from EPC (EPC2010C; 200 V - 22 A) and planar transformer.

In high frequency applications, it seems clear that using GaN transistor creates a real improvement of the efficiency due to its low output charge (Q_{oss}). In a soft-switching topology the device output charge has an important impact on the energy required to achieve ZVS condition providing a larger power storage and transfer period means naturally a higher efficiency. The other GaN transistor benefits are its low total gate charge (Q_g), and its low drain to source on-state resistance (R_{DSOn}), reducing the drive power (losses) and conduction losses respectively. All these features are implemented in a smaller packaging with less parasitic inductances compared to a Si MOSFET with similar power characteristics.

In an isolated converter, the transformer is the key component which has to be designed properly because of its important impact on the efficiency and on

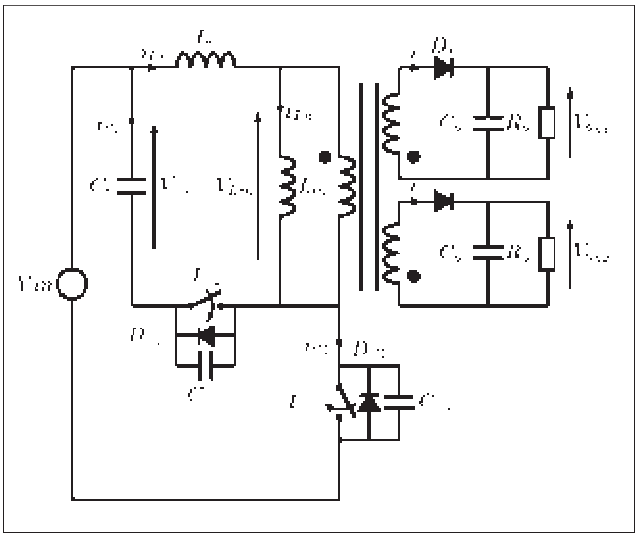


Figure 2. Double output flyback active clamp topology

the global volume of the power cell. For a soft-switching converter, the planar transformer allows to increase the efficiency and the reliability of the converter due to its very low profile, excellent thermal management and the good reproducibility. This last criterion is very important since both magnetizing (L_m) and leakage (L_r) inductances are used to achieve the power transfer and the ZVS conditions.

In a full converter, the transformer has several outputs: two 15 V - 25 W power outputs, one 15 V - 0.75 W to supply the control and command part and one 45 V - 3 W to charge the hold-up capacitor.

Eight layers 70 µm copper PCB have been used to design windings and specific care has been taken on DC resistance in order to limit self-heating. To reduce the leakage inductance, the primary turns are interleaved with the two secondaries. Interleaving windings (primary and secondaries) requires to increase the dielectric layers (so the PCB thickness) to still insure the 1.5 kV insulation requirement. To keep as low as possible parasitic capacitance outside transformer (due to layout considerations), the primary and auxiliary outputs are on one side of the PCB and the two power outputs on the other. Regarding the magnetic part, a 3Ferroxcube F45 ferrite EQ20/PLT-core has been optimized for the application (Figure 3).

PCB size is not directly dependent on the number of components. For example, the supervisor has a lot of small components whereas the filter has less components but larger like the common and differential mode chokes. However in general, the height of the converter is imposed by the highest component (most of the time the hold-up capacitor or the common mode choke). In order to decrease the surface of the converter, the idea is to realize a 3D module on two stages (2 PCB).

The goal is to use the free space around the highest component to implement a part of the converter on a second PCB above the first one. As shown in Figure 4, the separation of the functions on the 2 PCB is done regarding the operating frequency; the low frequency functions (power interruption management system, supervisor, current limiter and soft-start) will be on the motherboard whereas the upper stage is dedicated to the high frequency functions (power cell, driver, control/command) with custom PCB.

This modular strategy allows to adapt the PCB requirements for each part with less connection issues. For instance, the power stage needs thick copper layers (35 – 70 µm) in order to decrease parasitics resistances, whereas the load (digital components) needs high density implementation that imply very thin track (about 5 mils). PCB choice is a trade-off between layer thickness and track width. This approach helps the designer to create a suitable PCB for each function (especially

LEFT: Nicolas Quentin, University of Lyon/Ampere/Safran Group, France.

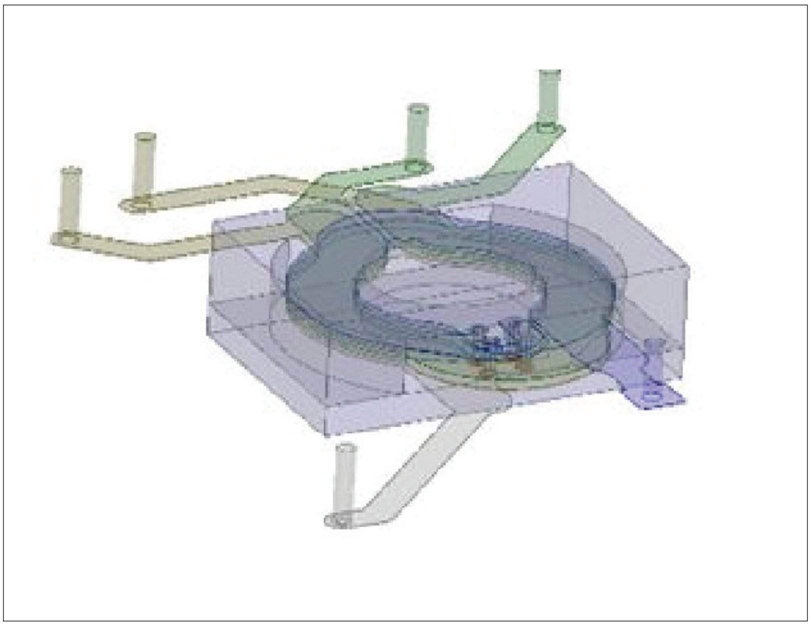


Figure 3. **Planar transformer layout design**

for the planar transformer).

Another benefit is the layout simplification of the full converter. To summarize, the goal of this modular architecture is to increase the power density. For a 50 W DC/DC converter the frequency limit is imposed by the magnetic components and 1 M Hz seems to be the upper value for ferrite material (at 50 W). Therefore, the easiest way to continue to increase the power density is a better use of the space, especially the height available.

Experimental results

The 1 MHz - 50 W prototype of the proposed full converter is shown in Figure 5 (right), left depicts also the operating waveforms with the primary voltages and currents at 28 V - 30 W.

The efficiency approaches 92 % at the nominal input voltage (28 V) and the peak efficiency is 95.5 % for an input voltage of 18 V.

A thermal analysis has been carried out at the nominal operating point 28 V - 30 W power after half an hour of operation. The thermal behavior is good with a small temperature increase of about 30 K. The hottest component is the main GaN transistor and the temperature increase is due to its important thermal resistance.

Conclusions

The use of the soft-switching topology coupled with suitable technologies such as GaN power FET allows the converter to increase the efficiency and frequency at the same time. At the end, the converter is efficient and compact due to the components and modular architecture. This solution creates a reduction of 60 % of the surface with a better use of the space and an easier layout compared to a single stage converter with the same schematic.

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nicolas.quentin@sagem.com

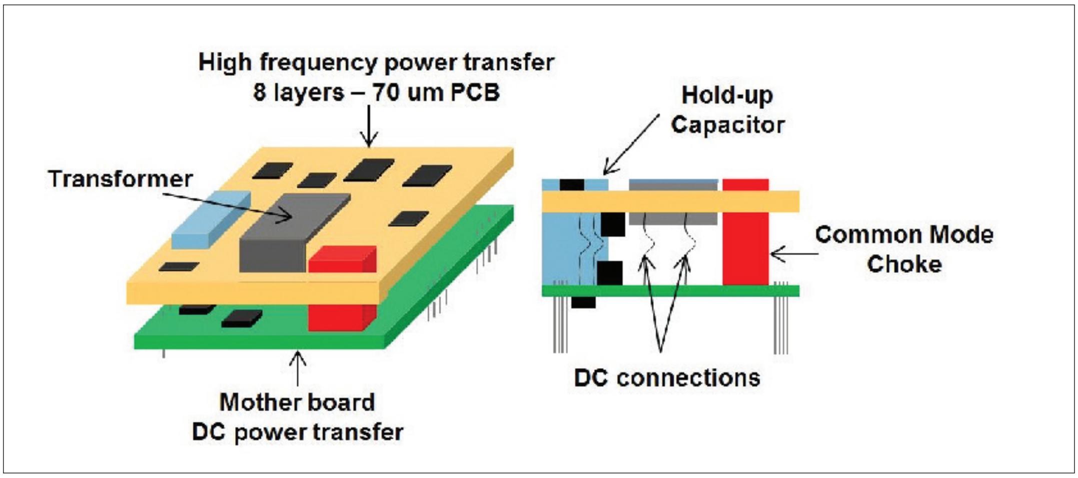

Figure 4. **Schematic representation of the modular PCB strategy**

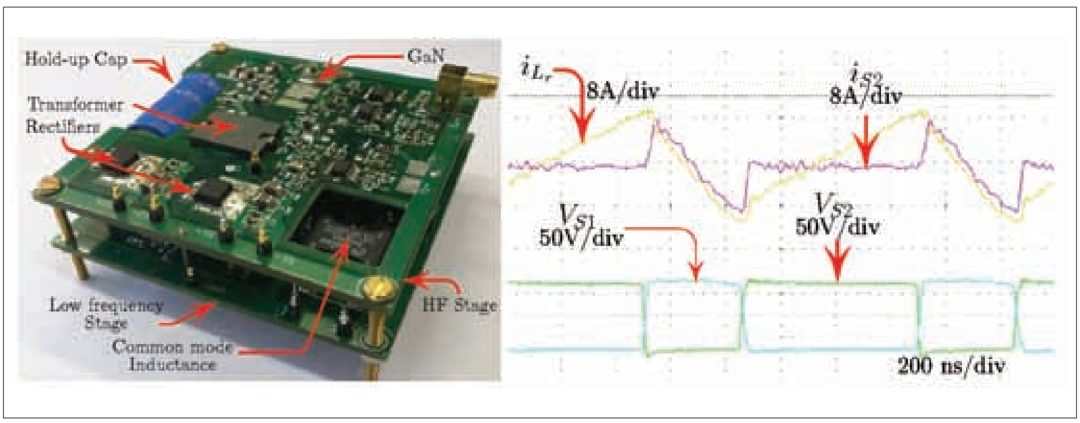

Figure 5. **Prototype with GaN transistor EPC2010C and transformer EQ20/PLT 3F45 (right), experimental waveforms V_{S1} and V_{S2} (20 V/div and 200 ns/div)**


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1200 V Gate Driver ICs Featuring FluxLink

Power Integrations has introduced a new family of IGBT and Power MOSFET drivers which incorporates its unique FluxLink™ isolation barrier communications technology. First used on the InnoSwitch™ AC/DC controller products and now in volume production, FluxLink provides the reinforced isolation required for switching applications up to 1200 V. **Michael Hornkamp; Senior Director Marketing High Power, Power Integrations, Ense, Germany**

Power Integrations has married high-voltage CMOS and packaging technologies with gate driver expertise and ASIC chip design to develop a new family of isolated gate drivers with class-leading peak output current and safety features. These new SCALE-iDriver™ products benefit from the company's extensive expertise in delivering SCALE™-2 gate drivers. By incorporating the galvanic isolation within the IC package, temperature-limited optocouplers traditionally used in conjunction with an IGBT gate driver can be eliminated, improving reliability and performance and reducing board area. The IC package mould compound has a Comparative Tracking Index (CTI) value of 600, which, combined with the eSOP package with creepage and clearance distances of 9.5 mm, provides a robust reinforced galvanic isolation barrier well suited to industrial and automotive applications which require highest levels of reliability (Figure 1).

FluxLink technology

The FluxLink technology is a high speed bi-directional communications link that sits across the isolation gap. Using a robust signalling protocol, it provides very high EMI and magnetic field immunity and exceeds the standards IEC61800-4-8 and IEC61800-4-9 in all three axes. It features a very low propagation delay and a very low jitter of only +/-5ns. This link not only isolates the low voltage input control side of the device but also communicates back any fault conditions measured on the high voltage side of the device back across the barrier to a microcontroller responsible for control and monitoring the device operation. The input pins (IN) and output pins (SO) use 5 V CMOS logic levels. The secondary side only needs a single, unregulated, unipolar 25 V supply which the SCALE-iDriver regulates internally to generate the drive voltages, simplifying the power supply design. Gate driver commands are transferred to gate driver pins GH and GL, allowing the user to turn on and turn off the IGBT with separate independent gate resistors, optimizing the maximum turn on and turn off currents. If both resistors have the same value, then the GH and GL pins can be connected together. Return status feedback is provided via the SO output pin as an open collector output.

Because of the low propagation delay and accurate switching performance, a switching frequency of up to 250 kHz can be used, enabling SCALE-iDriver ICs to address high frequency power switching applications.

All SCALE-iDriver parts are suitable for use with 600 V, 650 V and 1200 V IGBTs and MOSFETs. Devices are available with different peak output gate drive current ratings of 2.5 A, 5.0 A and 8.0 A. If a peak output drive current in excess of 8 A is required, the SCALE-iDriver SID11x2K IC can be used with an external amplifier (current booster) to achieve 15 A or more.

The SCALE-iDriver IC family meets IEC60664-1 and devices are UL and CSA recognised according to UL1577 – file number E358471. Certification is in progress for the latest VDE0884-10 standard and the parts have been designed to meet future standards like VDE0884-17 and IEC60747-17. All the parts in the family operate up to 125 °C and are 100 % tested during production, both Hi-Pot and Partial Discharge, before being functionally tested to ensure zero failures. FluxLink technology delivers a real isolation barrier separate and away from the ICs. IC destruction tests prove that reliable isolation is maintained.

SCALE-iDriver application

Figure 2 illustrates a design using two SID1182K devices and a single isolated power supply (the large rectangular block between the SCALE-iDrivers). The small package and high temperature operation make the SCALE-iDriver parts ideal for use where a compact high power density solution is required such as automotive, motor drive, renewable energy and other industrial applications.

To ensure reliable operation, the gate driver must protect the high voltage switching elements against voltage transients and faults. SCALE-iDriver ICs work with an external booster and

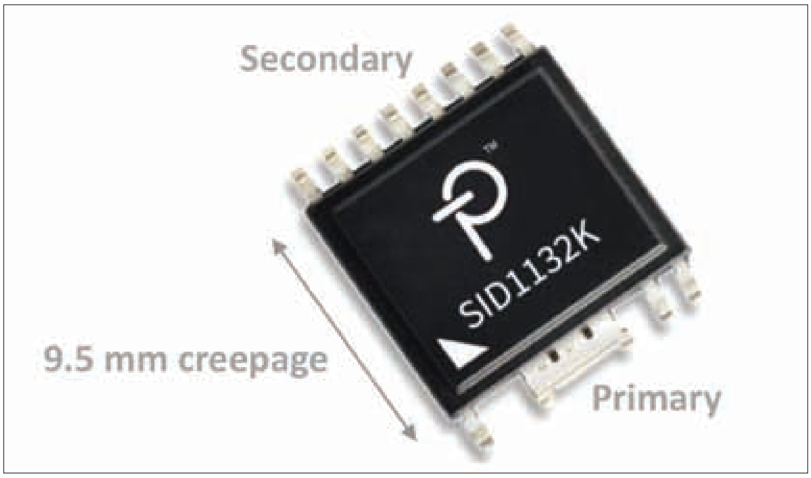


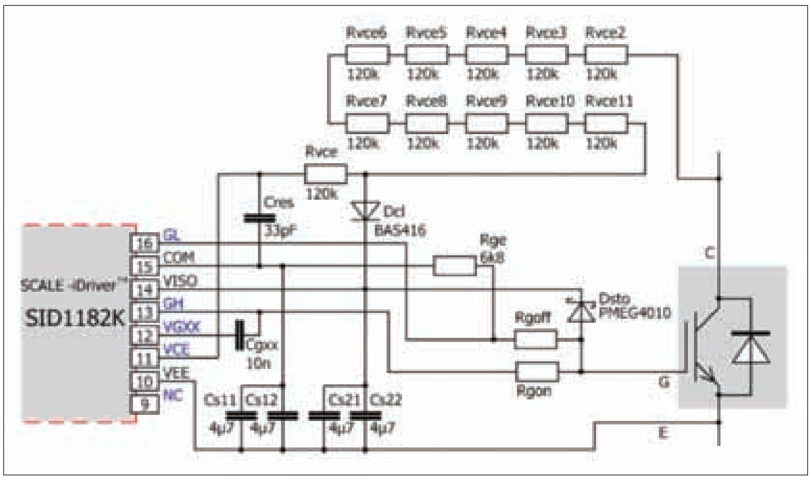
Figure 1. SCALE-iDriver using IC design methodologies incorporating FluxLink isolation barrier

Figure 2. A design using two SID1182K devices and a single isolated power supply

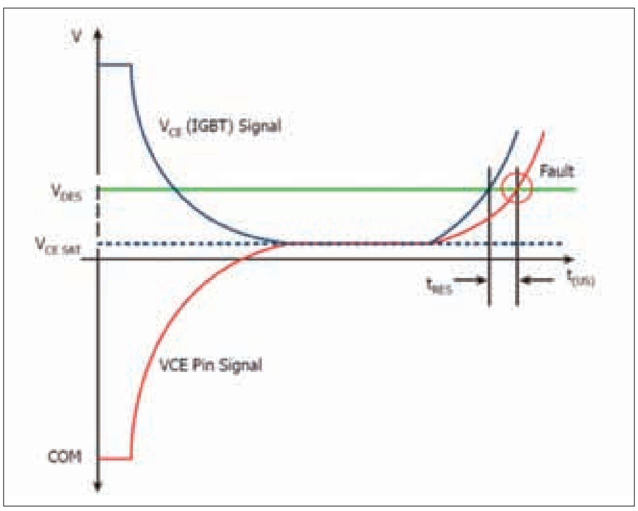
Advanced Soft Shut Down (ASSD) functionality. An external booster enables full soft shut down to be employed, while ASSD is a mechanism automatically triggered by monitoring desaturation levels that protects the power semiconductor switch in the event of a short circuit without requiring any extra components.

Many gate drivers address the problem of short circuits via a desaturation technique and blank time measurement implemented using high voltage diodes. Unfortunately, this technique can be over-sensitive, causing unnecessary shut downs due to noise rather than short circuits. Taking a different approach that is implemented using a simple resistor chain, SCALE-iDriver ICs rely on response time measurement, ensuring that shut down is implemented only if there really is an actual short circuit. During the off-state, the VCE pin is internally connected to the COM pin and resistor chain Rvcex, highlighted in Figure 3, is discharged (red curve in Figure 4 represents the potential of the VCE pin). When the power switch receives a turn-on command, the collector-emitter voltage (V_{CE}) decreases from the off-state level to a normally much lower on-state level (see blue curve in Figure 4) and C_{RES} begins to be charged up to the V_{CE} saturation level (VCE SAT). C_{RES} charging time depends on the resistance of R_{VCEX}, DC-link voltage and C_{RES} value.

The V_{CE} voltage during on-state is continuously observed and compared with an internal reference voltage, V_{DES}. The V_{DES} level is optimized for IGBT applications. As soon as $V_{CE}>V_{DES}$ (red circle in Figure 4), the gate driver turns off the power semiconductor switch with a controlled collector current slope (ASSD), limiting the V_{CE} overvoltage excursions to below the maximum collector-emitter voltage (V_{CES}). Turn-on commands during this time and during tsu are ignored, and the SO pin is connected to GND. The response time t_{RES} is the C_{RES} charging time and describes the delay between VCE asserting and the voltage on the VCE pin rising (see Figure 4). Response time should be long enough to avoid false-tripping during semiconductor turn-on and is adjustable via or R_{VCE} and C_{RES} (Figure 3) values. ASSD is activated after a short circuit is detected. It protects the switching element by ending the turn on state and limiting the current slope in order to keep momentary V_{CE} over-voltages below V_{CES}.



ABOVE Figure 3. Using a simple resistor chain, SCALE-iDriver ICs rely on response time measurement ensuring reliable shut-down



LEFT Figure 4. Turn-off of the power semiconductor switch with a controlled collector current slope (ASSD)

Conclusions

The SCALE-iDriver family includes many technical innovations which provide a wealth of benefits for designers of high power systems that prioritize safety and reliability. The FluxLink isolation combined with the eSOP package provides rugged, reinforced isolation. Optocouplers are eliminated. In combination with a simple unregulated DC/DC converter, SCALE-iDriver ICs enable component count to be minimized and simplified, such that only a basic two layer PCB is required. The design is fast and predictable. With their high output peak drive current the SCALE-Driver ICs can be used with power semiconductors rated up to 450 A, or even higher with an external current amplifier. Built-in protection features like short circuit detection, primary and secondary under-voltage lockout and Advanced Soft Shutdown provide the increased reliability required in modern industrial and automotive applications such as motor drives, solar inverters, medical power supplies, welding and plasma cutting equipment and commercial vehicles.

Literature

'Efficiency Revolution in Auxiliary and Standby Power Supplies', PEE 6/2015, pages 22-24

'Clever Ideas Succeed in the Market', PEE 2/2016, pages 7-8

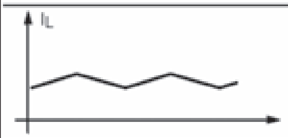
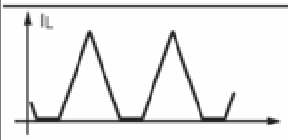
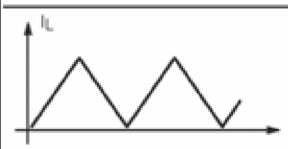
Improving Efficiency and Power Factor at Light Load

Universal input AC/DC power supplies in the range of 80-800W can be found in a variety of applications. Within this power range, the single-stage boost PFC + half-bridge LLC is considered to be a very popular topology, mostly due to the relatively simple structure, mature IC solutions, general good performance, and cost. Multiple global regulatory agencies have proposed standards on efficiency and power factor (PF) for such power supplies. Agencies like DoE, CoC, and Energy Star typically cover a wide range of applications, and others such as 80PLUS are for specific applications, like PC power. **Zhihong Yu, AC/DC & Lighting Product Marketing Manager, Monolithic Power Systems, Dallas, USA**

For some of the standards, traditionally, only the efficiency and PF at full load were listed, but the efficiency and PF at zero to low load have become more important in recent years for nearly all standards, whether it be for residential use or commercial/industrial use. Some standards directly point to low-load performance, and others may specify the average requirement across all load ranges. Such standards force most original equipment manufacturers (OEM) to improve their end products1. It is very desirable for PC power vendors to meet Gold, Platinum, or even Titanium specs of over 90 % efficiency at 50 % load without much additional cost.

As the new standards continue pushing for higher performance limits, OEMs usually take different approaches, such as spending more to get better discrete FETs and diodes, or researching new topologies. However, in the PFC field, a recent market research report that covers more sophisticated bridgeless or interleaved PFC suggests that these topologies will always have a small market share, even beyond 2019. This is mostly because they require more switches/magnetic, which adds to complexity and cost, among other concerns.

The most common PFC topology in the market is by far the traditional, hard-switched, single-phase boost converter that runs at either discontinuous conduction mode (DCM), critical conduction mode (CrM), or continuous conduction mode (CCM). These have all been well-studied for decades at most power IC and power supply companies. However, based on traditional topologies and control modes, they can still meet even the most demanding energy standards without paying a higher price.

Rating	Symbol	Unit
	Continuous Conduction Mode (CCM)	• Always hard-switching • Inductor value is largest • Minimized rms current
	Discontinuous Conduction Mode (DCM)	• Highest rms current • Reduce coil inductance • Best stability
	Critical Conduction Mode (CrM)	• Largest rms current • Switching frequency is not fixed

ABOVE: Figure 1. **Various traditional Boost PFC operation modes (Source: Onsemi Power Factor Correction Handbook)**

How to optimize efficiency at light load for single-phase PFCs

For DCM, CrM, and CCM, the difference is if the inductor current reaches zero during one switching cycle (see Figure 1).

For each operation mode, there are certain pros and cons. Designers usually choose either CrM or CCM at full load. CrM usually applies constant on-time control, and the operating frequency changes to maintain boundary mode operation. Although it has the benefit of soft switching, the high peak current leads to a large magnetic design; therefore, this topology is mostly used at <150 W. CCM

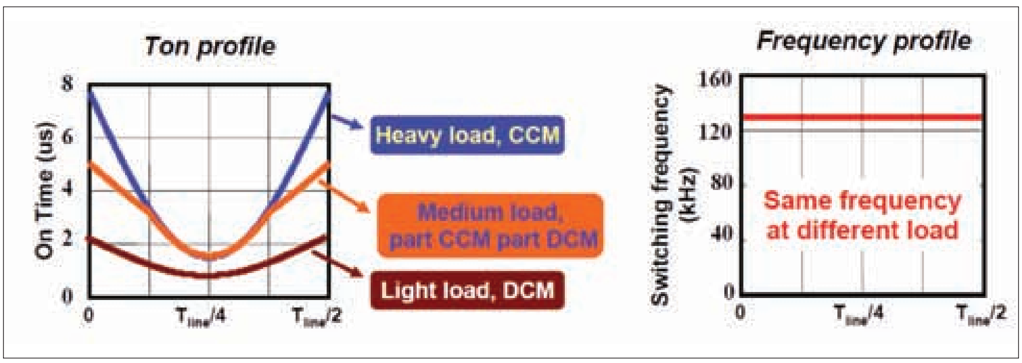


Figure 2. **Traditional CCM PFC turn-on time and frequency change over one AC cycle**

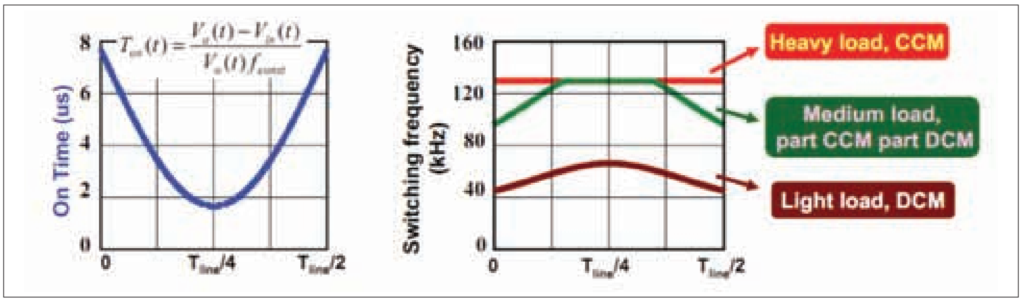


Figure 3. New PFC control strategy – fixed turn-on time and variable frequency control

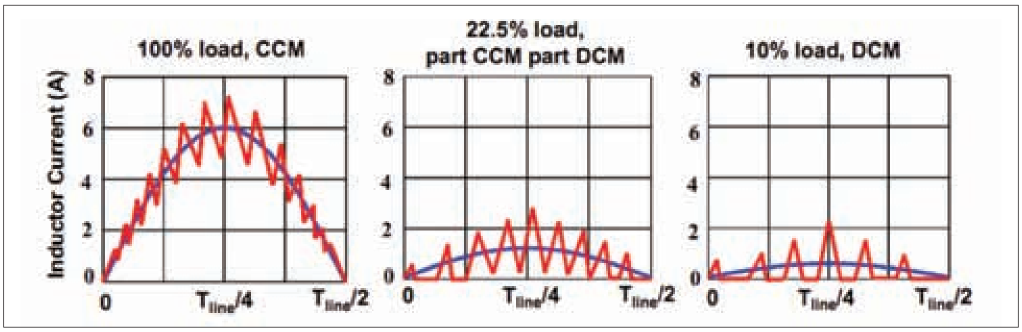


Figure 4. Inductor current waveforms of adaptive on-time PFC at different load conditions

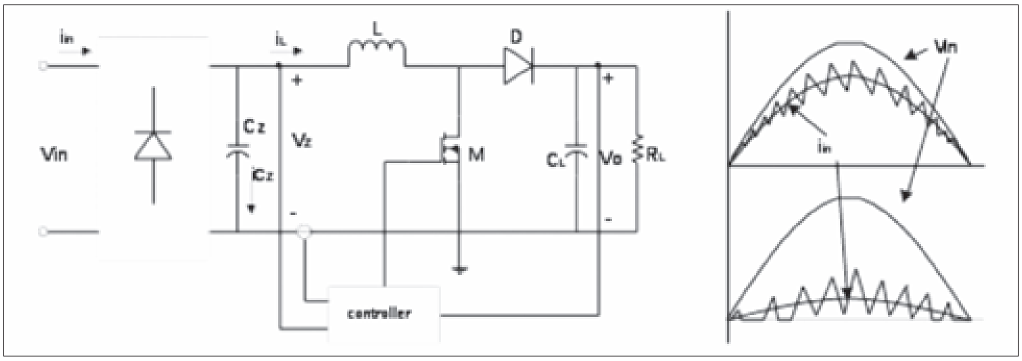


Figure 5. Current distortions due to input capacitor for boost converter

has the benefits of fixed frequency and the lowest RMS current and ripple, which ensures the lowest amount of stress on the power components. The continuous current nature also makes filtering design easier; therefore, this topology is preferred in >150 W applications.

Figure 2 shows the on time profile and switching frequency profile within a half line cycle of a CCM control scheme. The PWM modulator maintains a constant switching frequency regardless of load, so the turn on time of the converter is decreased at light load. One drawback of CCM control, however, is that the high, fixed switching frequency at light load leads to poor light-load efficiency. Only when the load drops to minimum or no load is CCM control able to enter burst mode to save on efficiency. In general, efficiency under CCM can be desirable at 30-100 % or <1 % load, but not optimized from 1-30 % load.

For the new control strategy we are proposing in Figure 3, the turn-on time only varies with the instant input voltage, but it remains the same at different load. With this strategy, the switching frequency of the PFC converter is kept constant at heavy loads to keep the benefit of CCM, but reduces at lighter loads to enter DCM operation (see Figure 3, Figure 4).

This control strategy was first realized with MPS' new PFC + LLC combo controller, the HR1200. This is also applied in MPS' stand-alone PFC controller, the MP44040. The efficiency of the HR1200 PFC stage was measured on a universal input, 12V, 20A output evaluation board across the entire load range.

Features	Benefits
GUI for configurable parameters through I^2C	Add to design flexibility, fast development cycle
EEPROM enabled resettable configurations	Last-minute design change without hardware changes
Patented CCM/DCM control and power factor compensation	High efficiency and high power factor at low load
HV start-up current source and X-cap discharger	Low no-load loss
Live function and performance monitoring	Easy debugging
Provides a unique part number for each customer project	Customer design IP protection

Table 1. Key Features and Benefits of MP44040 and HR1200

Single IC solution to achieve the best single-phase PFC performance

In a PFC boost converter, there inevitably is a small capacitor beyond the input rectifier stage, which is used to supply the high-frequency portion of the inductor current via the shortest path and act as an EMI filter. This capacitor must be chosen at the minimum rated input voltage. For CCM

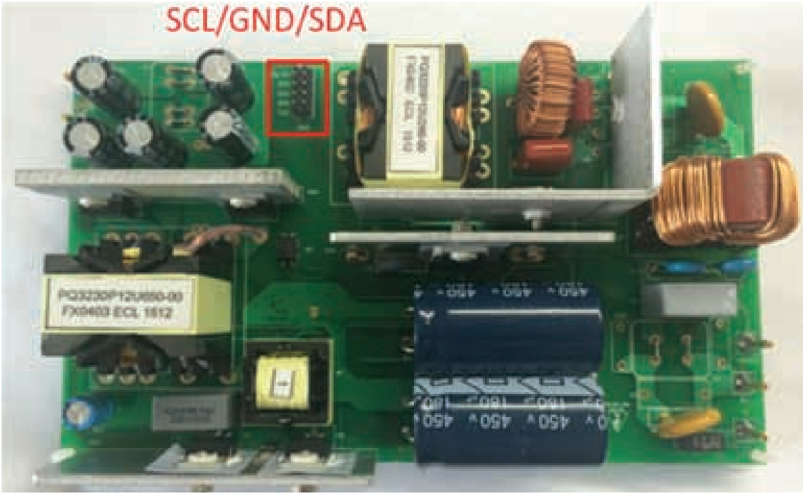


Figure 6. HR1200 PFC + LLC 240W evaluation board

PFCs, only the inductor current (i_L) is sensed and controlled to be in phase with the input voltage (VIN). However, as the input current $i_{in} = i_L + i_{cz}$, where i_{cz} is the input capacitor current, there is inevitably some current distortion created by the input capacitor (see Figure 5). At a higher V_{IN}, I_{CZ} becomes larger. I_L is smaller at high line compared to low line, so under the condition of the same load, PF is worse at high line.

As most current flows through the inductor at mid-to-peak load, the input capacitor's current distortion is also proportionally smaller, so the PF can be >0.9 with a universal input. However, since IC is not load-dependent at light load, it becomes relatively high and PF becomes worse. Such behavior is also commonly known in other PFC ICs. The actual PF performance may differ from this figure for the actual design, but the trend is always valid.

Naturally, in order to improve PF at low load and high line, we must provide a means to compensate for the capacitor current to the inductor current reference. Instead of the traditional way of matching IL in the same sinusoidal shape as V_{IN}, we will match I_{IN} with V. Since the analog current sensing on the capacitor current requires more components and adds to complexity, we can introduce the digital compensation method without adding extra cost.

MPS has created a digital, stand-alone, CCM/DCM, mix-mode PFC controller (MP44040) and a digital PFC + analog LLC combo controller (HR1200) that both apply the CCM/DCM mix mode and PF compensation technologies and use a graphic user interface (GUI) to configure all major PFC functions. The features and benefits of these parts are summarized in Table 1.

An evaluation board (Figure 6) and various supporting documents are offered to help customers become familiar with this digital platform. The HR1200-based PFC + LLC EVB is rated at 85-265 VAC at input, and 12 V/20 A at output. The EVB is equipped with an I?C-to-USB adaptor, allowing customers to optimize their designs by changing all GUI settings and monitoring live performance differences. For mass production, the configuration can be programmed at the factory with a special part number.

Benchmarking Three-Level Power Factor Correction Topologies

Power factor correction has long been a staple of UPS, SMPS and embedded drive devices. In recent years, a number of newly designed PFC topologies have hit the market. Now engineers are spoiled for choice: With so many more options, it is getting harder to pick the right topologies and components. This paper benchmarks three topologies—the Vienna rectifier, the symmetrical boost PFC and the neutral boost PFC—for the purpose of comparison. To this end, it factors two of the industry's key concerns, efficiency and cost, into the equation. **Baran Özbakir, Vincotech, Munich/Unterhaching, Germany**

The power factor (PF) is the ratio of the active power to the apparent power drawn by an electrical load. In other words, it is a measure of how efficiently the current is being converted into useful work. The PFC shapes the input current to synch it up with the input voltage, the aim being to maximize the real power drawn from the input. In the perfect PFC circuit, the input current is in phase with the input voltage without any harmonics.

Research on power factor correction circuits has been stepped up in recent years, especially for high-power applications [1]. There are recommendations and regulations for power electronics to limit harmonics on the power mains, and an important part of this is reducing harmonics from the converter side. Generally engineers try to achieve low circuit complexity and low component stress, high power density, high efficiency, high robustness/reliability, and controllability of the output voltage [2].

Three-level, boost type PFC is an enticing solution for high power density and high efficiency. The three-level topology's great advantage is that it reduces voltage stress on the power semiconductor, which cut the losses and costs of power semiconductors and move toward higher switching frequencies. It is common practice to combine three single-phase modules in an AC system, thereby achieving the required output power level with three-phase PFC.

PFC topologies

The Vienna rectifier is a unidirectional pulse-width modulation (PWM) rectifier as shown in Figure 1. It was first proposed by J.W. Kolar and developed with F.C Zach at the Technical University Vienna [3]. The Vienna rectifier is used mainly in telecom power supplies, UPS and input stages of AC drive converter systems.

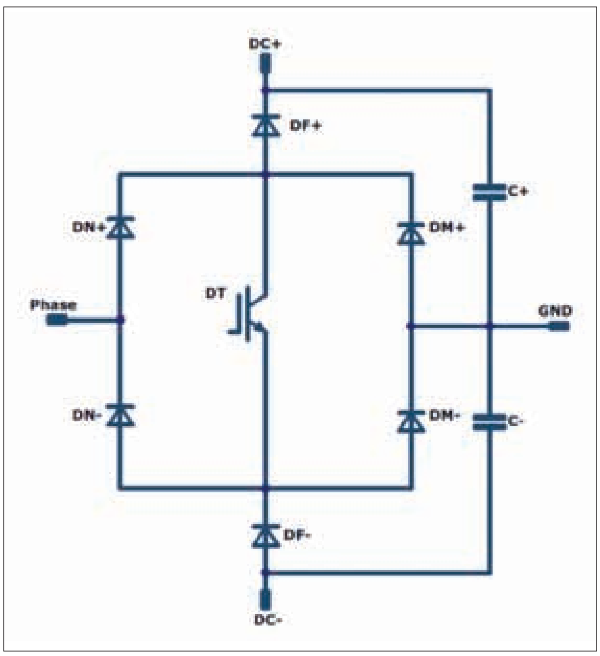


Figure 1. The Vienna rectifier schematic

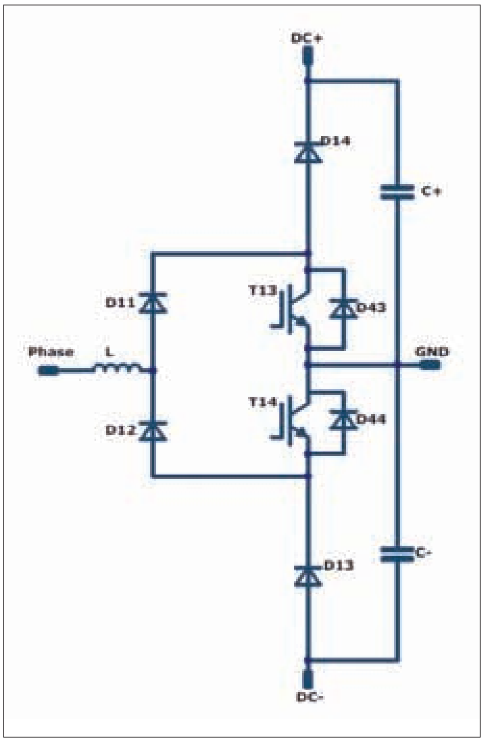
Its specifications and working properties at a glance are 1 switch (DT), 4 rectifier diodes (DN+, DN-, DM+, DM-), and 2 fast diodes (DF+, DF-). DT works at both half waves and DF+ and DF- are the pairs of DT. Voltage drop at excitation - 1x IGBT + 2x rectifier diode; voltage drop at boost (freewheeling) - 1x rectifier diode + 1x fast diode.

The Vienna rectifier's biggest advantage is that is equipped with just one switch, which cuts costs and simplifies control. On the down side, static loss is relatively high during the excitation period. On top of that, the switch works at both half waves of the mains input current, and engineers need to carefully consider the thermal behavior.

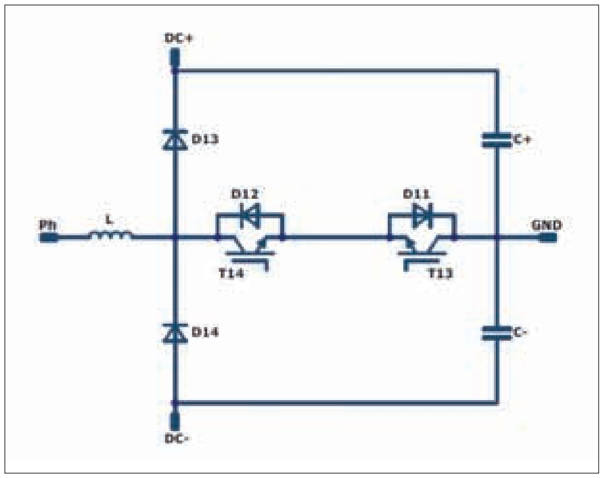
The symmetric boost PFC (SPFC, Figure 2) is a mainstay topology widely used in several applications such as UPS, welding, and power supplies. Its specifications and working properties at a glance are 2 fast switches (T13-T14), 2 rectifier diodes (D11, D12), 2 fast diodes (D14, D13), and 2 protection diodes (D43, D44). D11 and D12 work during one full half-wave - T13/D14 and T14/D13 are the pairs. Voltage drop at excitation 1x IGBT + 1x rectifier diode - voltage drop at boost (freewheeling) 1x rectifier diode + 1x fast diode.

Although the SPFC topology is equipped with two switches—that is, one more than the Vienna rectifier—its static losses are still low during the excitation period.

The Neutral Boost PFC (NPFC, Figure 3) is another commonplace topology used mainly for UPS applications. Its



RIGHT Figure 2. **Symmetric boost PFC schematic**



ABOVE Figure 3. **Neutral boost PFC schematic**

specifications and working properties at a glance are 2 fast switches (T13-T14), 2 rectifier diodes (D11, D12), and 2 fast diodes (D14, D13). T13/D14 and T14/D13 are the pairs. Voltage drop at excitation 1x IGBT + 1x rectifier diode - voltage drop at boost (freewheeling) 1x fast diode.

The NPFC topology also has one more switch than the Vienna rectifier, but the D13 and D14 diodes switch between DC+ and DC-, which increases switching and static losses.

Benchmarking the topologies

Six different power module designs were created, characterized and simulated to enable comparisons of the various topologies' costs and efficiency. The simulation parameters are $V_{in} = 240\ V_{RMS}$, $I_{in} = 14\ A_{RMS}$, $V_{OUT} = 700\ V_{DC}$ - these are representative of typical three-phase applications.

Figure 4 graphs the topologies' efficiency from 4 kHz to 50 kHz for comparison. To this end, the semiconductors' efficiency was calculated to benchmark the various types of power modules and see how the different designs measure up. Figure 5 charts the normalized cost of power module designs.

As the efficiency chart would indicate, the NPFC topology with MOSFETs and SiC diodes appears to be most efficient solution throughout the frequency range. The NPFC topology with fast IGBTs and Si diodes performs well up to around 12 kHz, at which point it drops off and soon after intersects with the Vienna rectifier's curve. The SPFC topology with fast IGBTs and SiC diodes comes in second in the performance stakes. The SPFC topology with fast IGBTs and Si diodes keeps pace with the Vienna rectifier (a fast IGBT and SiC diodes) up to around 36 kHz.

The SPFC topology with fast IGBTs and fast Si diodes serves as the reference for cost comparisons. The Vienna rectifier, with a price tag just under the reference price, has the cost advantage. The NPFC topology with MOSFETs and SiC diodes is the most expensive solution, costing 3.4 times as much as the reference design. The SPFC topology offers the best compromise between cost and efficiency, which makes it the overall winner.

Conclusions

Although the NPFC topology with MOSFETs and SiC diodes achieves the highest efficiency, it is also the most

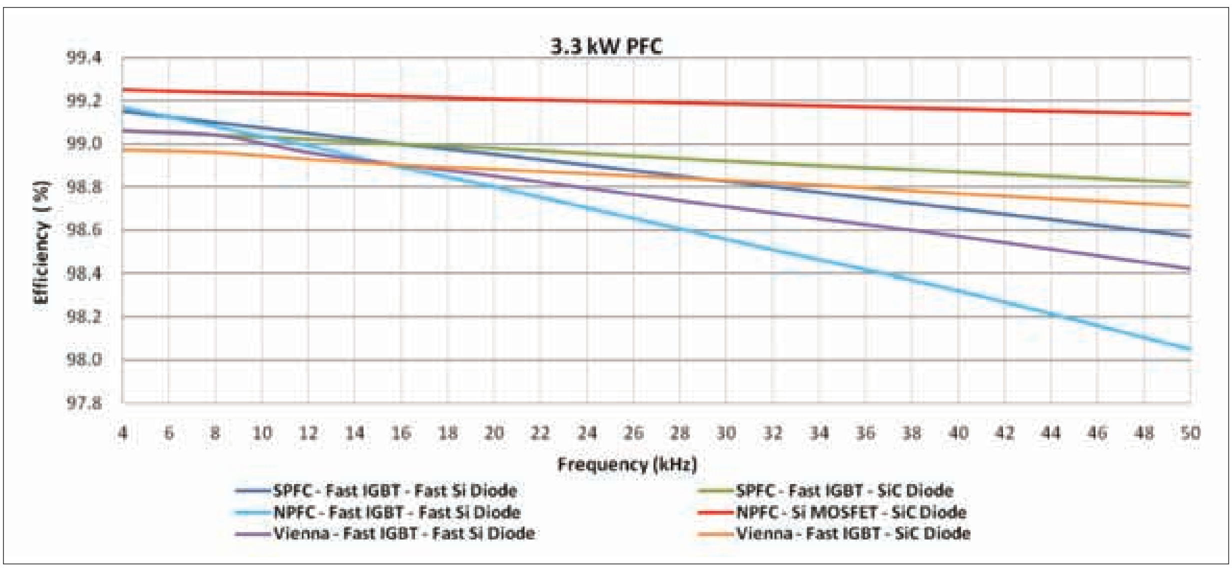


Figure 4. **Efficiency comparison**

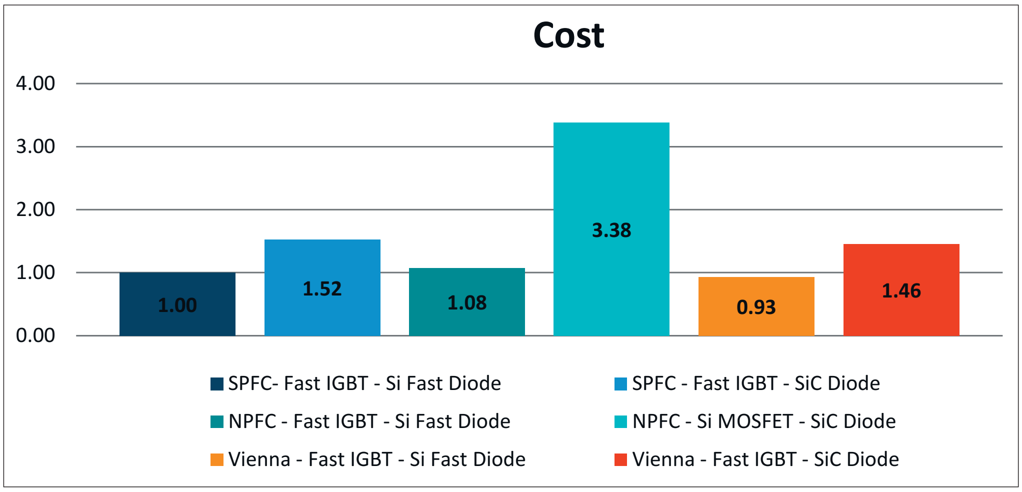


Figure 5. Cost comparison

expensive solution. The NPFC solution is more efficient than the Vienna rectifier up to around 12 kHz when IGBTs and Silicon diodes are used. The Vienna rectifier with a fast IGBT and fast Si diodes and the SPFC solution with fast IGBTs and fast Si diodes are cost-efficient solutions. If we consider the conditions for real-world applications, the frequency range from 12 to 36 kHz is where the best trade-off between efficiency and cost can be made. This is precisely where the SPFC topology comes out on top. This conclusion is confirmed by an emerging trend in the UPS and ESS (energy storage system) markets, where power modules featuring this promising SPFC topology are on the rise. Vincotech anticipated this development and now offers the flowSPFC 0 family of power modules for up to 100 A, with higher power modules to soon follow.

Literature

[1] Jingtao Tan, Zhiqiang Jiang Li C. Yang Li L. Yang Li ; Ying, Jianping: Single-Phase Three-Level Boost Power Factor Correction Converter; IEEE (2007)

[2] Johann W. Kolar, Hans Ertl, Franz C. ZACH.: Design and Experimental Investigation of a Three-phase High Power Density High Efficiency Unity Power Factor PWM (VIENNA) Rectifier Employing a Novel Integrated Power Semiconductor Module; IEEE (1996)

[3] Kolar J.W., Zach F.: A Novel Three-Phase Utility Interface Minimizing Line Current Harmonics of High-Power Telecommunications Rectifier Modules; IEEE (1994)

What MTBF Really Means

When electronic systems fail or cease to operate correctly it doesn't matter whether the component concerned is a glamorous processor or the workhorse power supply – either compromises the end product and damages the manufacturer's reputation. And it is not just outright failure that can cause a problem, poor design and marginal components can also result in performance issues that are difficult to track down and diagnose. **Jeff Smoot, VP of Application Engineering, CUI, Tualatin, USA**

What OEMs and their end-customers are seeking is reliability but there are many facets to reliability that need to be understood along with the measures that may be used to define it. One such measure is "mean time between failure", commonly abbreviated to MTBF. Here, in the context of power supplies, we set out to understand MTBF, recognize how it can help in designing reliable products and, most importantly, realize it should not be used to predict the actual life of a product.

Defining reliability

Before we can hope to improve the reliability of a power supply, we need to understand that reliability is the probability that an individual unit of the product, operating under specified conditions, will work correctly for a specified period of time. This is not the same as failure rate, which is the proportion of manufactured units that will fail in a given time interval e.g. one failure from 1 million units in one hour. Failure rate is further complicated because typically it varies over the life of a product, following the so-called "bathtub" curve that exhibits a higher failure rate early and late in the product's life, as shown in Figure 1.

The intrinsic failure rate of a component, denoted λ, is defined as its failure rate during the constant failure rate part of its life-cycle. This in turn allows the definition of reliability, denoted $R_{(t)}$, over time t, as $R(t) = e^{-\lambda t}$.

MTBF and 37 percent

The inverse of failure rate, 1/λ, provides what is known as the mean time to failure, or MTTF. However, while MTTF is technically the more correct term, MTBF (mean time between failures) is the more commonly used equivalent term, especially in the power industry.

The relationship between reliability, failure rate and MTBF give rise to some interesting observations. For example, a component with an intrinsic failure rate of 10-6 failures/hour (which is the same as an MTBF of 1 million hours) has a 90.5 % probability of not failing within the first 100,000 hours. However this falls to 60.6 % for the first 500,000 hours and the probability of the component lasting 1 million hours of use decreases to 36.7 %, as illustrated by Figure 2.

What this is really saying is that there is only a 37 % confidence level that a component will last as long as its MTBF rating. It can also be seen that half the components in a group will have failed after just 0.69 of the MTBF. This realization becomes even more pertinent when extended from individual components to systems, for example taking account of all the components in a power supply where the failure rates of all components must be summed as $\lambda_A = \lambda_{1n1} + \lambda_{2n2} + \ldots + \lambda_{ini}$.

The number of components employed in a system, or sub-system such as a power supply, clearly reduces the overall MTBF. While selecting components with good MTBF figures can mitigate this result, it does highlight the intuitive conclusion that a system's reliability can be no better

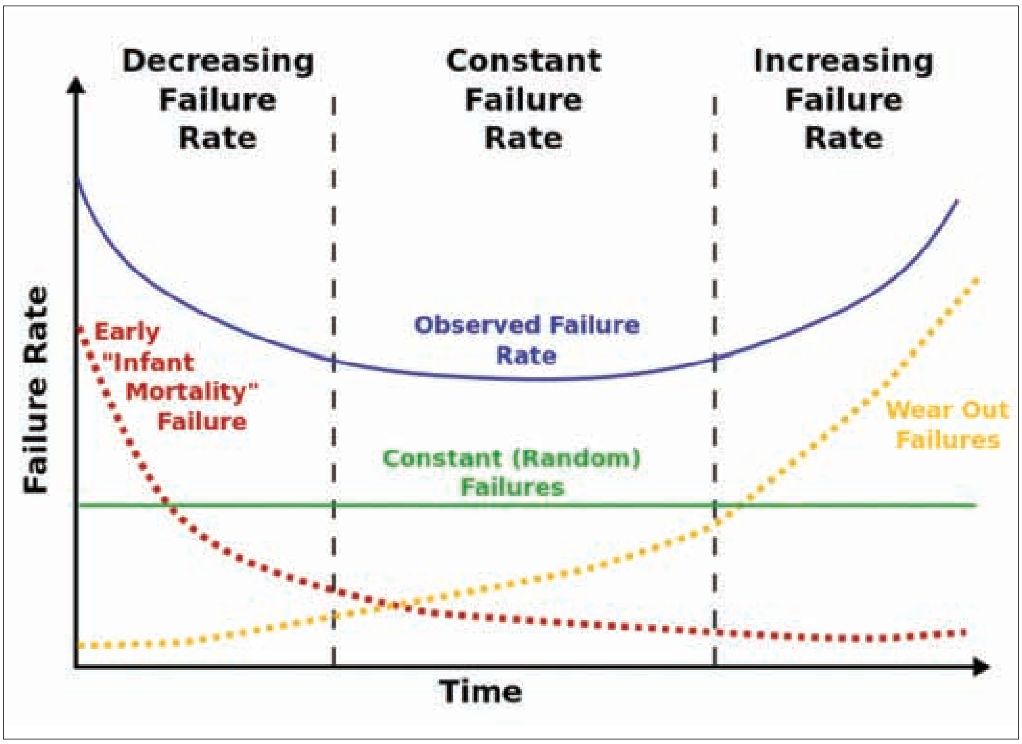


Figure 1. The "bathtub" curve showing failure rate plotted against time through the three life-cycle phases of infant mortality, useful life and wear-out

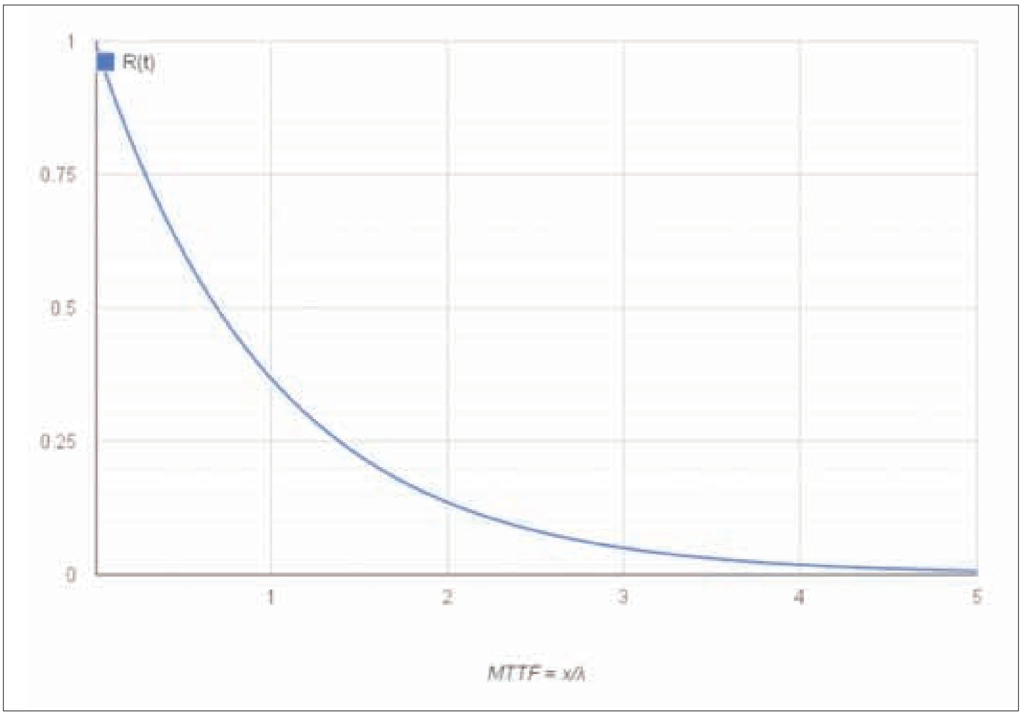


Figure 2. **Curve showing the probability that a component is still operational over time**

than it's least reliable component. Hence focusing on the weaker components can pay dividends.

An important takeaway from the above discussion is that the MTBF figure should not be used to predict the actual life of a power supply (or other component or system). This is a common mistake customers often make in attempting to interpret a product datasheet. Firstly, to reiterate the conclusion reached above, "there is only a 37 % confidence level that a component will last as long as its MTBF rating", added to which it is important to understand how an MTBF figure is arrived at, as we will see next.

Calculating MTBF

Determining the failure rate or MTBF of a component or system is key to understanding a product's potential reliability. With a new product design some means of estimating or predicting life expectancy is required – simply building lots of units and running them for many hours under normal operating conditions is not a realistic method of obtaining meaningful results. That said, the use of accelerated life tests, where a product is operated at elevated temperature and under other stress conditions, can provide useful data and can also reveal areas of design weakness. The same is true for data obtained from the real service operation of equipment, which in turn contributes to an overall appreciation of a product's reliability.

During development though, the only method available to a designer for calculating failure rate of an endproduct is prediction. This approach relies on component failure rate and expected life data provided by one of several standard databases, such as the US Navy's MIL-HDBK-217 handbook, British Telecom's HRD5 database or the Telcordia (formerly Bellcore) technical reference TR-332.

Whichever resource is chosen it is important to use it consistently, recognizing that their differing prediction methodologies were developed for different end-application requirements. For example, MIL-HDBK-217 focuses on military and commercial applications while, not surprisingly the Telcordia and BT methods are oriented to telecommunications designs and applications. The MIL approach depends on many component parameters and allows for voltage and power stresses to yield MTBF data. The Telcordia method depends on fewer component parameters but takes account of other data from laboratory tests, burn-in results and field tests. Also Telcordia produces FIT, or "failures in time", numbers where one FIT equals one failure per billion (10^9) device-hours (equivalent to about 114,115 years) based on statistical projections from accelerated test procedures.

Unfortunately none of the aforementioned methodologies or sources of data guarantee absolute accuracy as each are based on assumptions that, at best, are somewhat inaccurate. One assumption is that the database is current and valid whereas the reality is these databases are quite old and don't have data on newer components. In this case, the designer may have to go with the calculation method that best suits his purpose and either use data for the nearest equivalent part or rely on whatever reliability data the component manufacturer may provide, which may need to be treated with caution.

Conclusions

Product reliability is important and while some consumers may show blind faith in trusting reputable manufacturers, most would rather have the reassurance of a guaranteed product life. This in turn comes from manufacturers having confidence in their designs and in the components used to build those products. As shown, it is important to avoid naively falling into the trap of wrongly assuming that the MTBF figure equates to the expected life of a product. Employing MTBF calculations allows the use of a consistent approach for comparisons to be made between products. The accuracy of the MTBF results, and thus the significance of the comparison, is heavily dependent upon the consistency of the assumptions and data bases used for the calculations.

Concrete Binded Magnets for Large Power Inductors

The increasing demand for more and clean energy has led to a rising need for large inductive components. This poses a challenge to providing magnetics optimized for cost, size and performance. MAGMENT power inductors and transformers introduced at PCIM 2016 are based on a new technology for both a novel material and an innovative magnetic design. **Mauricio Esguerra, Magment Unterhaching, Germany**

The high demand has sparked the development of both improved magnetic materials (e.g., powder cores, amorphous), winding technologies (e.g., copper foil, flat wire) and optimized core geometries. This has yield a high refinement, pushing the limits of an otherwise conventional way of making inductive components. However, advancement in small steps maybe not enough to cope with the market expectations driven by the renewables revolution.

MAGMENT (MAGnetic ceMENT) power inductors and transformers are based on a patented concrete with magnetisable particles embedded in a cement matrix manufactured in a pressure-less process. Its features are (Figure. 1 and 2) permeability in the same range as powder core materials;

high DC-bias capability; saturation reached only at very high fields, very low core losses; high thermal conductivity to efficiently dissipate heat; and concrete-like mechanical robustness in a very broad temperature range.

Initial permeability	μ_i	@ 25°C		40 ± 10%
Flux density	B_{max}	@25°C, 25kA/m	[mT]	350
Curie-Temperature	T_C		[°C]	> 210
Resistivity	ρ	DC	[Ω m]	20
Density	γ		[kg/m³]	3750
Realtive core losses	P_V	@50kHz, 100mT	[kW/m³]	300
Specific heat	c_p		[J/kg K]	700
Thermal conductivity	λ		[W/mK]	3
Young's modulus	E_t		[MPa]	25 000
Compressive strength	f_c		[MPa]	20
Tensile strength	f_t		[MPa]	2

Figure 1: Technical data for MAGMENT MC40 material grade

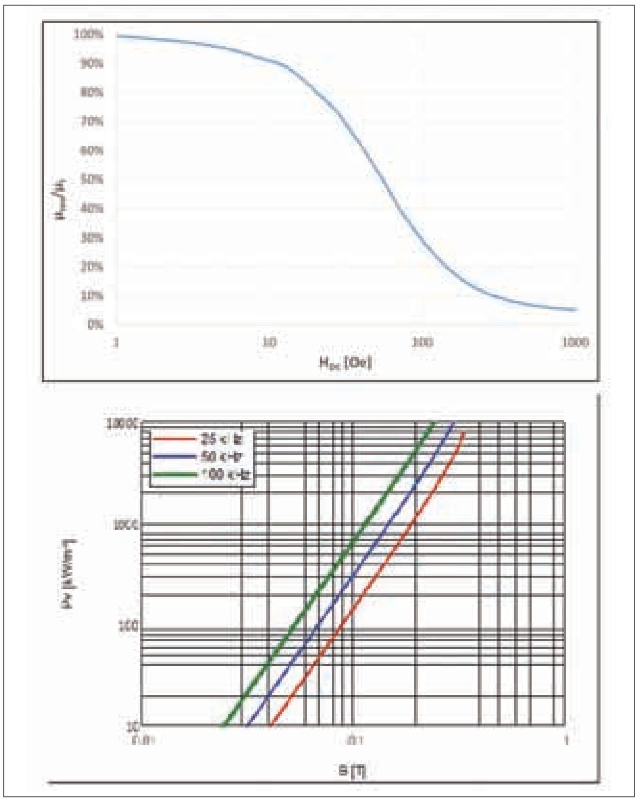


Figure 2: DC-bias vs field strength and specific core losses vs flux density

Wind and magnetic pour process

These unique and outstanding properties allow the design of rugged inductive components with a distributed air gap for minimized winding losses by completely surrounding the coil by the MAGMENT material. This ensures a complete magnetic filling of the available volume within the housing yielding maximum performance and cooling. As compared to the conventional manufacturing of winding cores and sealing with a potting material, the flowability of the concrete materials allow a "wind and magnetic pour" process, which goes along with absolute shape and size flexibility. This allows to both tailor components to minimize material utilization and to any given space constraints by a special magnetic design algorithm yielding lowest cost as compared to any other inductive technology.

Figure 3 shows an example for a MAGMENT inductor and Figure 4a

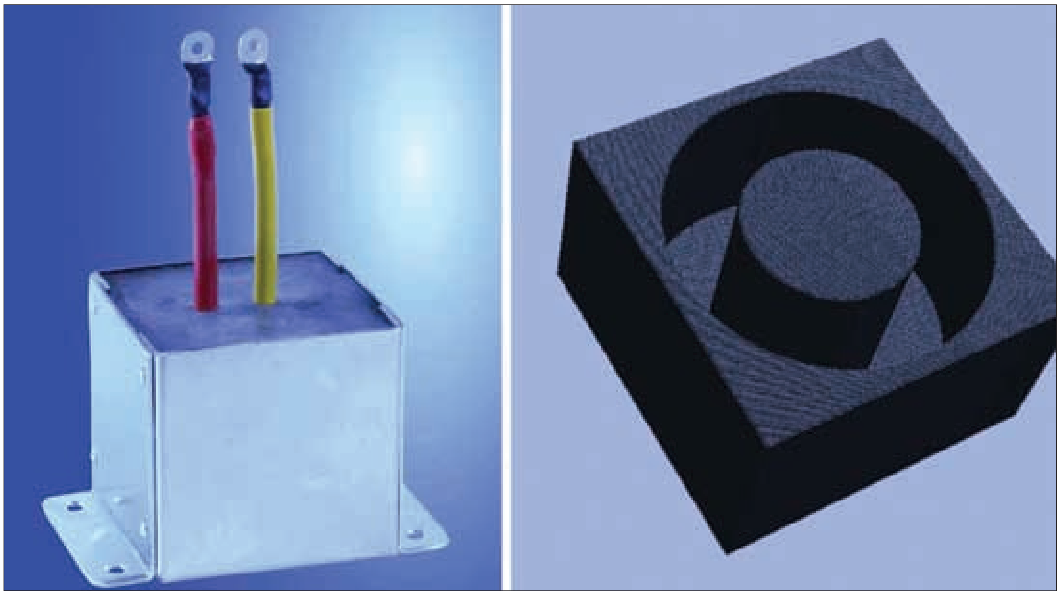


Figure 3: **MAGMENT inductor (left) depicting its magnetic material shape (right)**

Target parameters: inductance L, rated current I, resistance R_{DC}

Conventional	MAGMENT
DESIGN STEPS	
1. Select core shape (E, RM, U...)	1. Select/design coil former
2. Select core size (E25, RM8,...)	2. Layout of winding window
3. Select suitable coil former	3. Design housing
4. Layout wire in winding window	
5. Select housing	
6. Select potting material	
PROPERTIES	
Core sizes available only in steps (E55,E65,..)	No shape or size limitation
Limited size availability	
Stacking for simple shapes only (E, U, R)	
Winding filling factor limited	Winding 100% surrounded by magnetic material
Partial magnetic filling of housing	Potting material = magnetic material

Figure 4: **Comparison MAGMENT vs. conventional inductors**

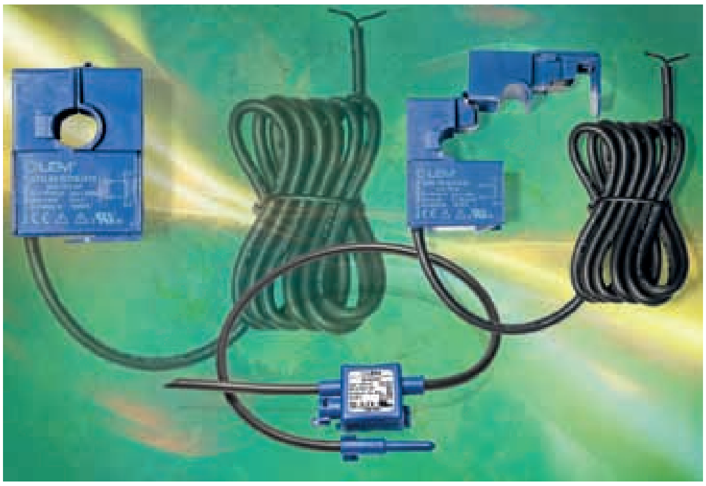
comparison with a conventional inductor. The automated design process starts with the calculation of the MAGMENT inductor design parameters for given target parameters (inductance L, rated current I and DC resistance RDC). The design algorithm looks for the dimensions giving the lowest material cost and hence the most compact design. In case outer dimensions would be constrained by device space requirements, the algorithm would take this into consideration. Based on the output design parameters a suitable coil former is chosen and the winding laid out. The housing containing the inductor is then designed according to the outer dimension of the MAGMENT material block.

The resulting magnetic effective parameters (Figure 5) show the clear advantage over conventional inductors. As a general rule and due to the complete magnetic filling of the available space the ratio Ae/le is much larger for MAGMENT inductors. In a relative comparison of inductors with the same inductance and either the same (a) magnetic path, (b) cross section or (c) volume the MAGMENT inductors show always a superior performance (inductance, core and winding losses) as well as cost.

Beyond the technical superiority of the product as such, there are other aspects pertaining production and logistics. We have devised our production to have all inductor manufacturing processes under one roof. This allows to have short lead times and simplified stock holding of base materials allowing the quickest possible turnaround time from design-in to shipping.

Design case	l_e [mm]	A_e [mm²]	V_e [mm³]	No. of turns	Core loss [W]	Cost [€]
a	=	>	>	<	<	<
b	<	=	<	<	<	<<<
c	<	>	=	<<	<	<<

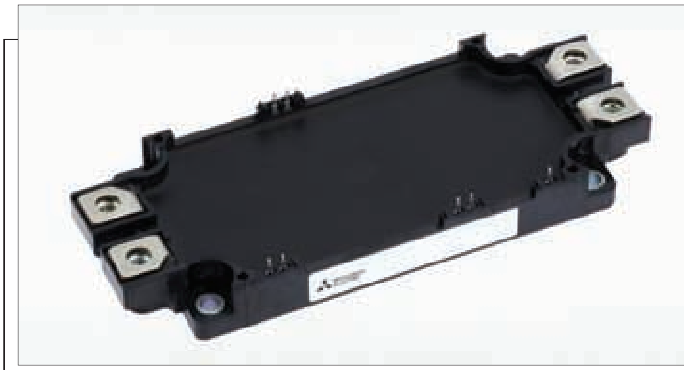
Figure 5: **Inductor parameters relative comparison MAGMENT vs. conventional for an inductor with the same inductance value and one effective parameter a) magnetic path, b) cross section, c) volume**



Rogowski Current Sensor for Currents up to 10,000 A

LEM has developed the "ART" Rogowski current sensor to measure current of up to 10,000A AC and beyond. The ART achieves IEC 61869 Class 1 accuracy without the need for additional components like resistors or potentiometers, which can drift over time. In addition, the ART benefits from "Perfect Loop" technology, a unique patented coil clasp that eliminates the inaccuracy caused by sensitivity to the position of the conductor inside the loop as well as providing a "Twist and Click" closure. An internal shield is provided as standard to guard against external fields, improving accuracy and optimizing performance for small current measurements. The ART series provides the same ease of installation as existing split-core transformers, but with the benefits of being thinner and more flexible. Dimensioned in 70, 125 and 175 mm diameter for the aperture – the ART can be mounted quickly by simply clipping on to the cable to be measured. Contact with the cable is not necessary, and the ART ensures a high level of safety as well as providing a high rated insulation voltage (1000 V Cat III PD2 – reinforced). The ART also allows disconnection of the coil to be detected through the use of a security seal passed through a specially designed slot, making it really useful when used with a meter. It can be used in applications requiring a protection degree up to IP 67.

www.lem.com



IGBT Modules Using 7th Generation IGBTs

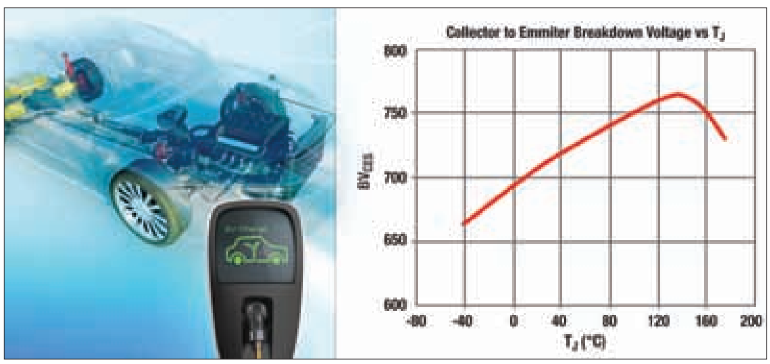
Mitsubishi Electric announced that sample shipments of 17 new models of the T-series power modules featuring 7 gen IGBTs are scheduled for September delivery. The lineup is expanded by 17 models with 1.7 kV rating, the new models include 12 NX-type standard-type package models ranging from 75 A to 300 A. The expanded lineup provides for AC 690 V / DC 1000 V PV system inverters. With an improved internal structure, the latest package technology enhances the reliability of the existing standard-type package while keeping compatibility to it. An insulation and copper base integrated in the substrate, along with an improved internal electrode construction, help to increase the thermal cycle life, i.e. the life proven in a stress test of relatively long-term temperature cycling between two case temperatures, and to lower the internal inductance, leading to a more reliable equipment performance. With regard to the standard-type package, the internal inductance is reduced by 30 % compared with a 6 gen module thanks to an improved internal electrode construction. The Thick-Metal-Substrate-technology removes the solder layer and increases the thermal cycle life. The package can be downsized by decreasing the baseplate area by 24 % from 80 × 110 mm to 62 × 108 mm, increasing the thickness of the copper pattern and improving the thermal conductivity. The optional PC-TIM module is based on a Phase Change Thermal Interface Material, a high thermal conductivity grease which becomes solid at room temperature and softer with rising temperature eliminating the need for thermal grease.

www.mitsubishichips.eu

Automotive Grade IGBTs

Fairchild offers new automotive-grade 650 V discrete and bare die IGBTs and diodes for hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and electric vehicles (EV). These IGBTs and diodes are ideal for traction inverters, a core component of all HEVs, PHEVs and EVs that convert the batteries' electricity from DC into AC required by the vehicles' drive motors. All of these new discrete and bare die IGBTs and diodes use advanced third generation Field Stop Trench IGBT technology and a soft fast recovery diode qualified to automotive-grade standards and have additional features and options. This new FGY160T65SPD_F085 and FGY120T65SPD_F085 discrete IGBTs are well-suited to traction inverters and other HEV/PHEV/EV powertrain components that require high power density and high reliability. Bare chips PCGA200T65NF8, PCRKA20065F8, PCGA300T65DF8, and PCRKA30065F8 are for automakers and automotive parts suppliers building their own power modules. The bare die IGBTs are also available with integrated monolithic current sense and temperature sense to provide additional levels of protection – they can be customized to meet special requirements. Options include changing the gate pad size and location to accommodate different diameters of aluminum wire, resizing the die, and customizing the breakdown voltage and other electrical parameters. A solderable top metal version is also available and is designed for advanced wire bondless assembly technologies such as soldering technologies as sintering. Fairchild is also expanding its portfolio with a new automotive-grade module currently in development, which integrates IGBTs, freewheeling diodes and gate drivers in one electrically-isolated package. It is suited for auxiliary motor control applications such as oil pumps and AC compressors. The power module is sampling now and will be available in production quantity in June.

www.fairchildsemi.com



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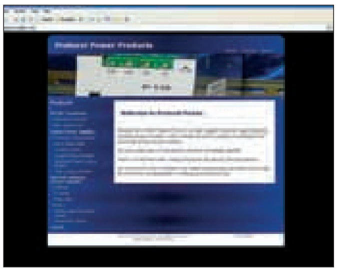

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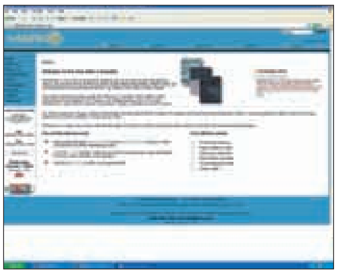

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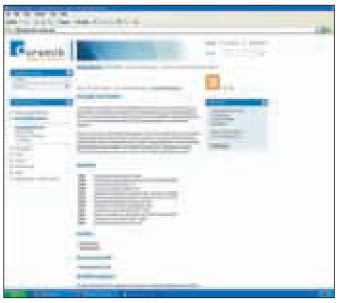

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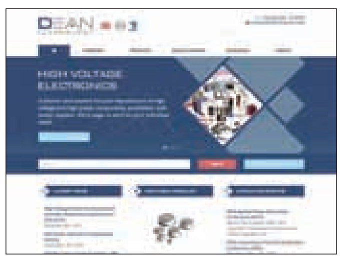

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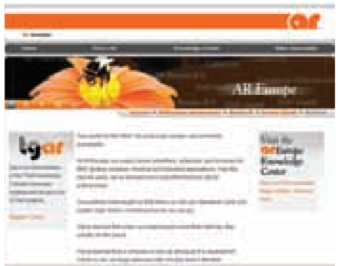

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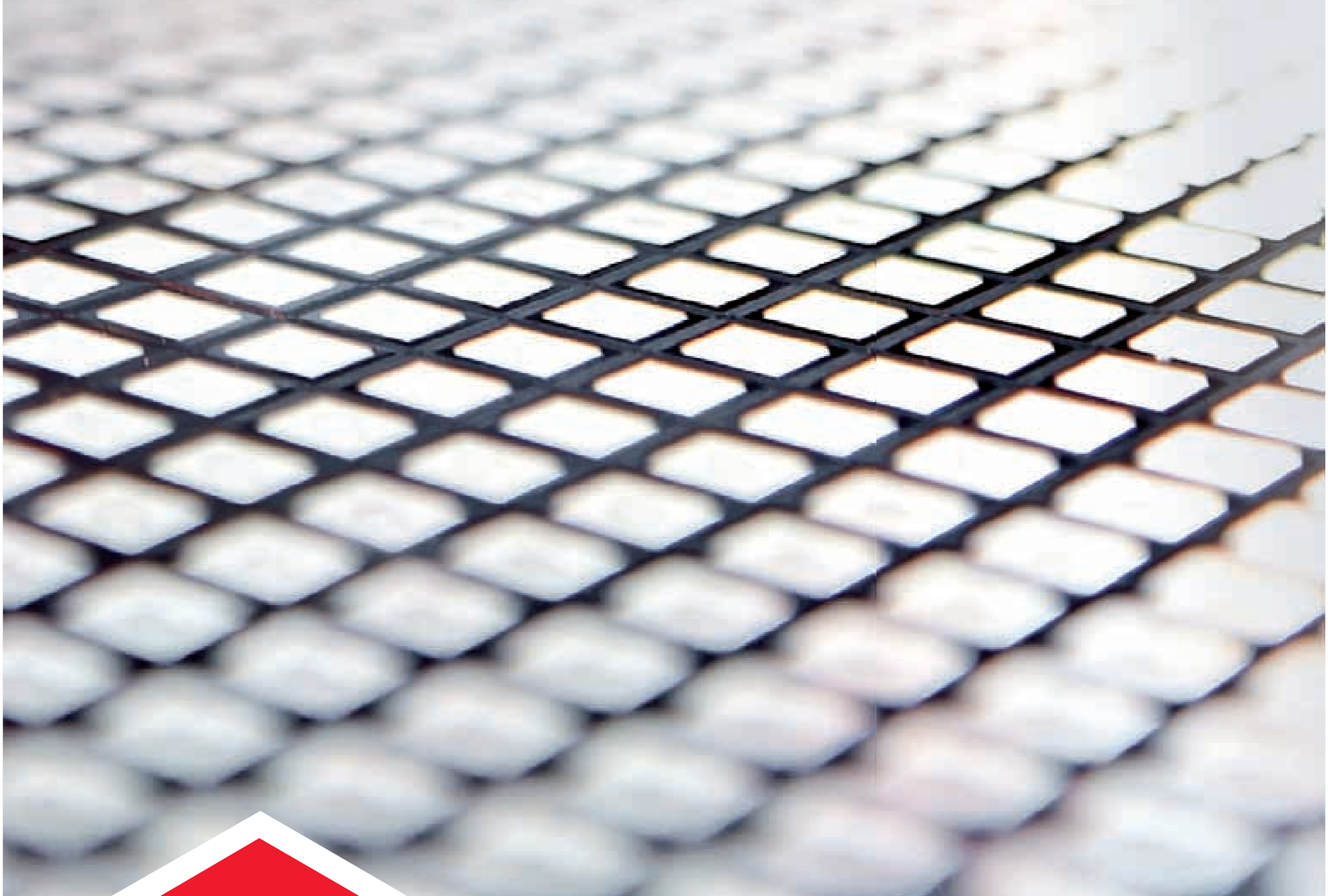

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