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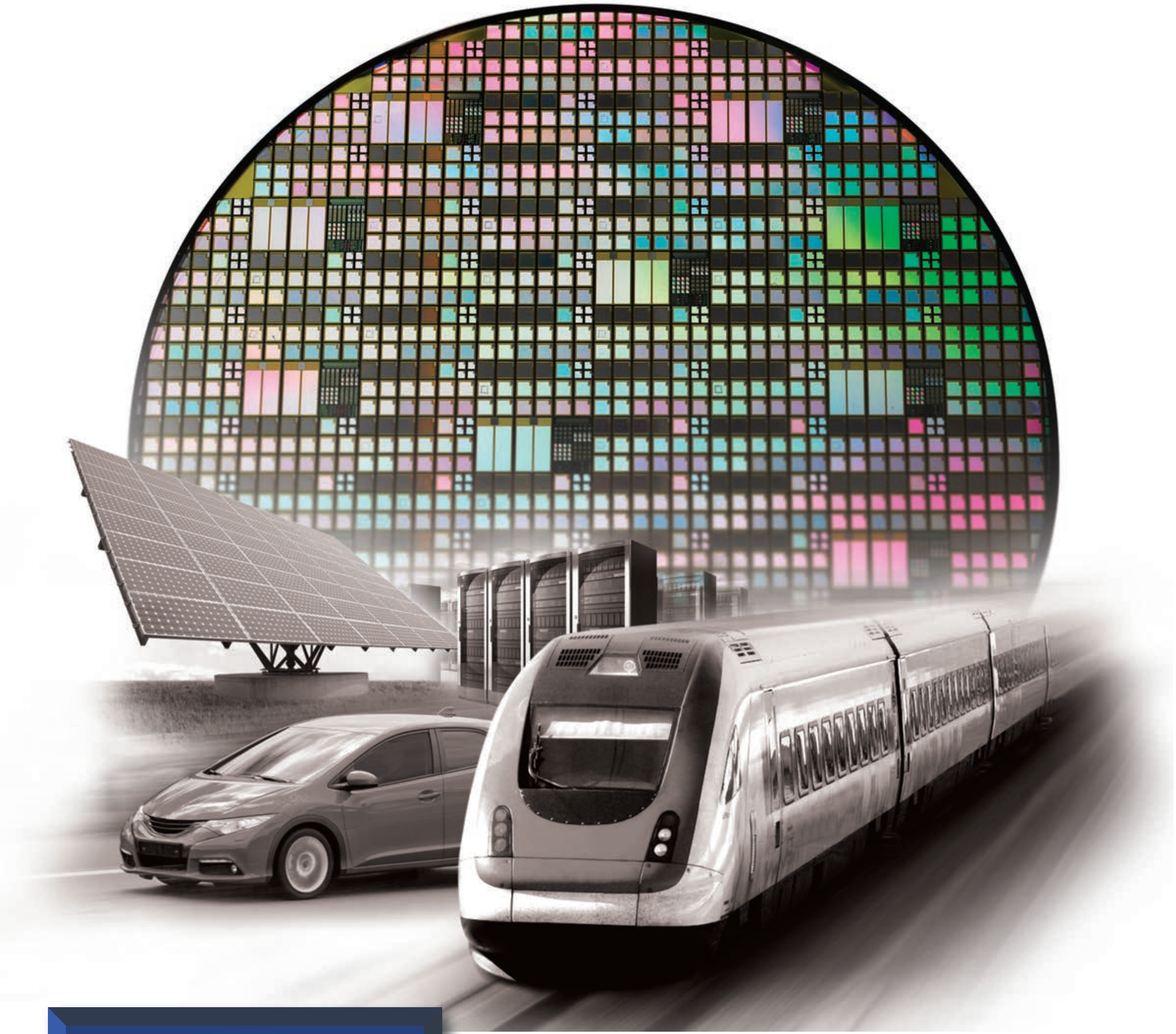
SILICON CARBIDE & CMOS

Leveraging Automotive-Quality 150 mm Si-CMOS Processes Makes SiC MOSFETs More Affordable and Reliable



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Also inside this issue

Opinion | Market News
APEC 2018 | Industry News
LED Power Supply | Website Locator

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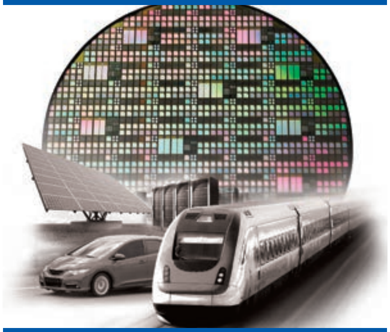
COVER STORY



Leveraging Automotive-Quality 150 mm Si-CMOS Processes Makes SiC MOSFETs More Affordable and Reliable

Silicon is the basis for power semiconductors today. Si MOSFETs allow for operating frequencies well above 25 kHz, but design trade-offs start to limit their advantages at voltages higher than 600 V. In contrast, SiC MOSFETs switch up to five to ten times faster than Si IGBTs and can operate at higher junction temperatures, but at equivalent higher device cost. Silicon-based MOSFETs and IGBTs are the traditional options for semiconductor switches in power converter applications. However, these devices too often limit the performance capabilities of their intended applications. Silicon (Si) IGBTs are suitable for voltage ranges in which a 1200 V-rated part is necessary, but they are limited to a maximum operating frequency of ~25 kHz in hard-switched applications. Si MOSFETs allow for operating frequencies well above 25 kHz, but design trade-offs start to limit their advantages at voltages higher than 600 V. In contrast, the newest Silicon Carbide (SiC) MOSFET switches offer designers of power conversion systems for applications such as photovoltaic inverters, energy storage systems, EV chargers, UPSs, industrial motor drives, and a rapidly growing array of other products significant performance advantages over traditional Si MOSFET and IGBT switches. One way of getting improved SiC MOSFET costs requires a non-traditional wafer processing methodology - processing SiC wafers in parallel with Si wafers in a high-volume Si-CMOS foundry. More details on page 26.

Cover image supplied by Littelfuse, USA

PAGE 6

Market News

PEE looks at the latest Market News and company developments

PAGE 17

APEC 2018

PAGE 22

Industry News

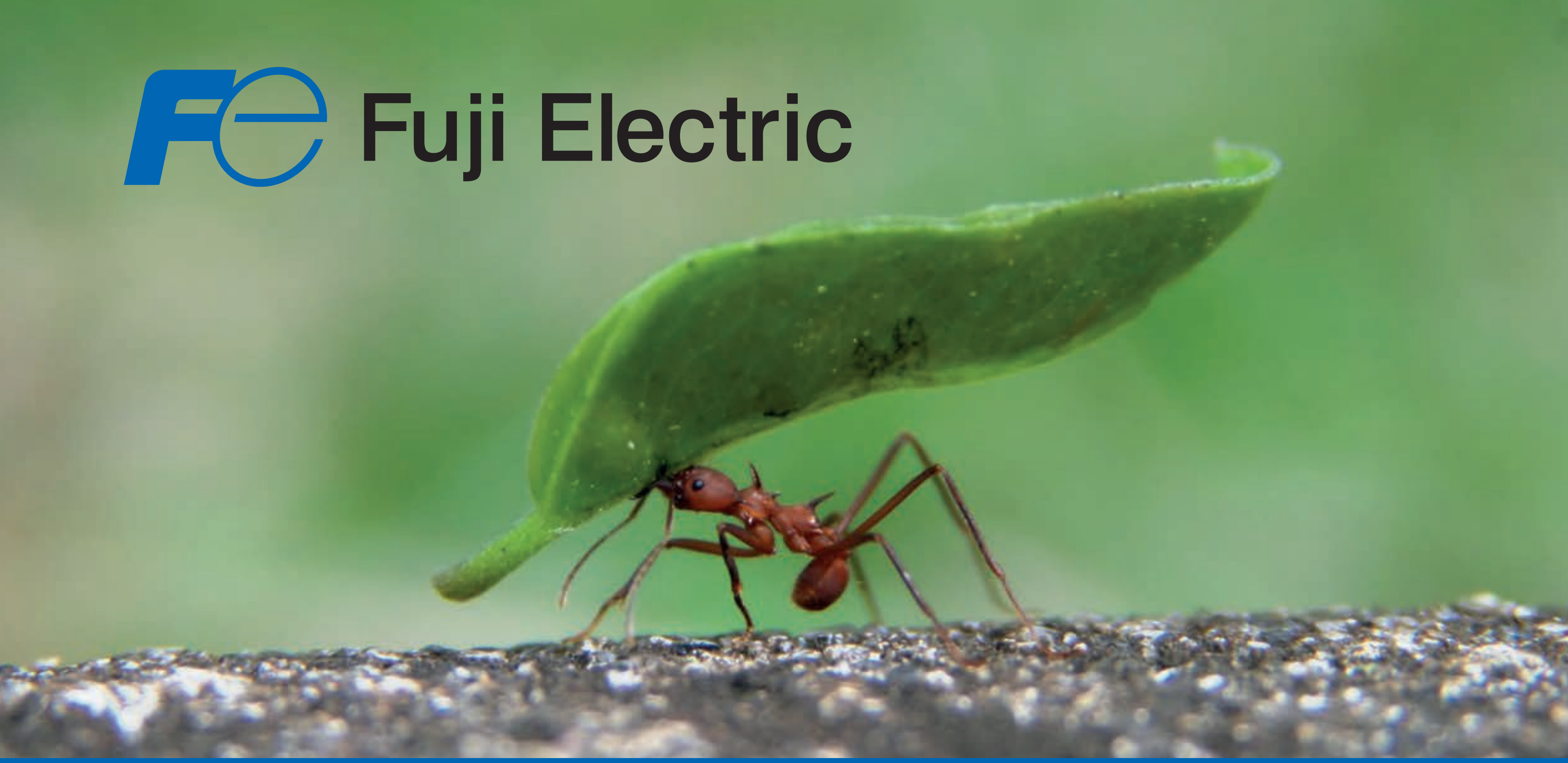
PAGE 29

Integrated Power Solution for Smart Lighting

Smart lighting is considered to be the new frontier of the global lighting industry, as the trend of smart homes, Internet of Things (IoT), and a connected world are the main driving factors in global electronics growth. In terms of major applications of the smart lighting concept, the industry is currently more focused on light intensity dimming, lighting color temperature adjustment, ambient sensing, and monitoring. This article will focus on the power solution for smart lighting- in particular smart light bulbs. **Zhihong Yu, AC/DC Product Marketing Manager, Monolithic Power Systems, USA**

PAGE 33

Web Locator



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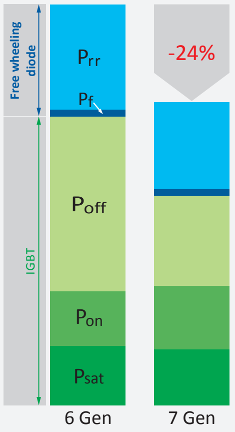

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The Time Has Come

ASilicon Carbide is a compound semiconductor comprised of Silicon (Si) and Carbon (C). Compared to Si, SiC has ten times the dielectric breakdown field strength, three times the bandgap, and three times the thermal conductivity. Both p-type and n-type regions, which are necessary to fashion device structures in a semiconductor material, can be formed in SiC. These properties make SiC an attractive material from which to manufacture power devices that can far exceed the performance of their Si counterparts. SiC exists in a variety of polymorphic crystalline structures called polytypes e.g., 3C-SiC, 6H-SiC, 4H-SiC. Presently 4H-SiC is generally preferred in practical power device manufacturing. Single-crystal 4H-SiC wafers of 4 inches (100 mm) to 6 inches (150 mm) in diameter are commercially available. The raw materials Silicon powder – not sand – and Carbon powder are processed in a special reactor with outcome SiC powder. Crystal growth happens in an evacuated chamber (10-4 mbar) at temperatures around 2200°C and Nitrogen dopant with a rate of around 1 mm/h, compared to Silicon which achieves some mm/min! Micropipes are not a subject for the defect mechanisms in SiC wafers, it's more the dislocations which need to be solved.

SiC devices can be made to have much thinner drift layer and/or higher doping concentration, i.e., they have very high breakdown voltage (600 V and up) and yet with very low resistance relative to Silicon devices. Resistance of high-voltage devices is predominantly determined by the width of the drift region. In theory, SiC can reduce the resistance per unit area of the drift layer to 1/300 compared to Si at the same breakdown voltage. The larger bandgap also means SiC devices can operate at higher temperatures from 150°C to 175°C. This is due mainly to thermal reliability of packages. When properly packaged, they can operate at 200°C and higher. And this is the problem which needs to be solved – today no plastic materials can withstand such high temperatures. This is a research subject for the coming years to be discussed at conferences such as APEC or PCIM. But temperature is not on the highest priority list today, it's more lower switching losses and higher switching frequencies leading to higher efficiency and reduced size of magnetics and cooling, in the end to reduced costs at system level.

At a system level, there are ideally three semiconductor components for high-power solutions like traction inverters, drives and solar inverters: the controller, gate driver and power semiconductor (SiC in this case). It is therefore important to understand how to drive SiC power devices. These switches turn on and off for efficient power transfer across the power-electronics circuit, as dictated by the controller. A key element that acts as an interface between the controller and power device is the gate driver. Think of it as an amplifier that takes the controller signal and amplifies it to drive the power device. Given the superior characteristics of SiC FETs, defining the requirements for gate drivers becomes very critical. Here big new entrants such as Texas Instruments will push the market.

In spite of a price premium over Si MOSFETs and IGBTs, the SiC MOSFET is already seeing significant success due to cost-offsetting system-level benefits; the market share for this technology seems destined to expand rapidly over the next few years as the supply chain matures. One way of getting improved SiC MOSFET costs requires a non-traditional wafer processing methodology: processing SiC wafers in parallel with Si wafers in a high-volume Si-CMOS foundry. Littelfuse and Monolith Semiconductor have pursued this tactic as part of a strategic partnership begun in 2015, and are producing SiC Schottky diodes and MOSFETs in a 150 mm CMOS facility in Texas owned by X-FAB that also fabricates automotive-qualified Si devices. This fabless approach allows to support power converter makers who require customized devices, customers that the major SiC suppliers aren't interested in working with, according to our cover story.

This wafer production method offers a variety of advantages. For example, processing wafers in this CMOS facility allows sharing best manufacturing and quality practices used for automotive-qualified CMOS products and takes advantage of enormous economies of scale. Avoiding the high costs of operating own fab allows for major cost reductions. In addition, fabricating SiC devices on 150 mm wafers rather than on 100 mm wafers (as is typical for SiC devices) allows for much more efficient leveraging of manufacturing costs. Even though processing larger wafers costs more than smaller ones, it also allows spreading the higher cost per wafer over a larger yield of die per wafer.

Some system-solution suppliers still argue that reducing the system size and cost are not sufficient to negate SiC's high component cost. Since SiC-based system development is still at an early stage, the cost will be high for now. With more market adoption, however, it is only natural that SiC costs will come down due to economy of scale, thus realizing the cost benefits at the system level.

APEC 2018 has already shown that after more than 20 years of discussion about the disadvantages and advantages of SiC the advantages are in favor, and this will be continued at PCIM 2018. The time has come for WBG technologies, such as SiC and GaN. Enjoy reading the following pages!

Achim Scharf
PEE Editor

Strong Power Application Support for European Customers

Japanese ROHM Semiconductor is a global company of estimated $3,6 revenue in fiscal year 2018, employing more than 21,300 people in 34 companies worldwide. Recently the company opened an European Power Lab in order to assist its growing power semiconductor business, particularly in Silicon Carbide technology.

ROHM's products range from low power microcontrollers, standard ICs, SiC diodes, MOSFETs and Modules, power transistors and diodes, LEDs to passives components such as resistors, tantalum capacitors and LED display units, thermal printheads in plants in Japan, Korea, Malaysia, Thailand, the Philippines, China and Europe. The European Headquarter is located in Willich-Munchheide near Dusseldorf featuring 200 employees.

Growing SiC investments

"Industrial and Automotive segments are growing within ROHM in terms of revenue by 12 % respective 11 % in our fiscal year 2017/18, representing now 44 % of revenue. The growth in automotive is is mainly due to the upcoming regulations regarding CO_2 emission reduction and more electrification of the car, main drivers are advanced driver assistance systems (ADAS) and the powertrain applications. Our target for the year 2021 is to increase the share of industrial & automotive up to 50 %. Though the company today is more consumer-oriented, we are now transforming our expertise towards the automotive segment, an example is infotainment. Regarding the e-mobility we are adressing on-board chargers, drive inverters, DC/DC converters and compressors. Here we see growth up to 60 % for our IGBTs, Silicon Carbide devices, Gate Drivers and associated microcontrollers. Particularly for Silicon Carbide and Gate drivers we see an increasing demand and thus enhancing our capacity also in ingots by a factor of 16 between 2017 and 2025, including move to 150 mm wafers," outlined Christian André, President ROHM Europe.

"We are enhancing our SiC capacity also in ingots by a factor of 16 in the coming years," outlined Christian André, President ROHM Europe

Nuremberg-based SiCrystal AG (75 employees) supplies the ROHM Semiconductor Group with Silicon Carbide (SiC) wafers on 5,600 m^2 space and additionally 9,600 m^2 expansion area. Here ROHM has a unique advantage, because it covers all SiC-related processes in-house. SiC substrates are the core business of SiCrystal, whoose roots date back to 1994, when a German federally funded project on crystal growth of Silicon Carbide bulk crystals was launched. Subsequently, the company was formed in 1996. The first wafers were commercially available in 1997. The successive take-over of the shares by ROHM was completed in 2010, now holding 74,5 % of SiCrystals shares.

"The raw materials Silicon powder – not sand – and Carbon powder are processed in a special reactor with outcome SiC powder. Crystal growth happens in an evacuated chamber (10^{-4} mbar) at temperatures around 2200°C and Nitrogen dopant with a rate of around 1 mm/h, compared to Silicon which achieves some mm/min! Micropipes are not a subject for the defect mechanisms in SiC wafers, it's more the dislocations which need to be solved", SiCrystal CEO Robert Eckstein stated.

SiCrystals expertise includes the whole process of manufacturing SiC-wafers such as numerical simulation, crystal growth, wafering, characterization and quality control. It offers Silicon Carbide wafers of polytype 4H in 100 and 150 diameter and different quality grades - standard quality wafers meet high demands for production-scale purposes, while engineering grade substrates are the inexpensive alternative for research and development and for process trials.

SiC advantages

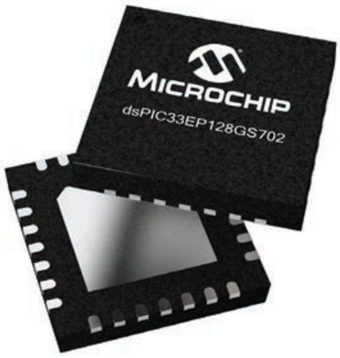
SiC is a compound semiconductor comprised of Silicon (Si) and Carbon (C). Compared to Si, SiC has ten times the dielectric breakdown field strength, three times the bandgap, and three times the thermal conductivity. Both p-type and n-type regions, which are necessary to fashion device structures in a semiconductor material, can be formed in SiC. These properties make SiC an attractive material from which to manufacture power devices that can far exceed the performance of their Si counterparts. SiC exists in a variety of polymorphic crystalline structures called polytypes e.g., 3C-SiC, 6H-SiC, 4H-SiC. Presently 4H-SiC is generally preferred in practical power device manufacturing. Single-crystal 4H-SiC wafers of 4 inches (100 mm) to 6 inches (150 mm) in diameter are commercially available.

SiC devices can be made to have much thinner drift layer and/or higher doping concentration, i.e.,

Digital Power Designs Made Easier

Products, Tools, Software and Reference Designs

Microchip's digital power design suite includes the Digital Compensation Design Tool (DCDT), MPLAB® Code Configurator (MCC), Microchip compensator libraries and design examples.



These four components of the digital power design suite provide the tools and required guidance for developing complete digital power designs. Once the initial simulation model of your design is ready, the DCDT can be used to analyze the design and the feedback transfer function, and to generate compensator coefficients. Device initialization code can be generated with the help of MCC; and the final firmware can be created with some help from the code examples and the code generated from MCC and the DCDT.

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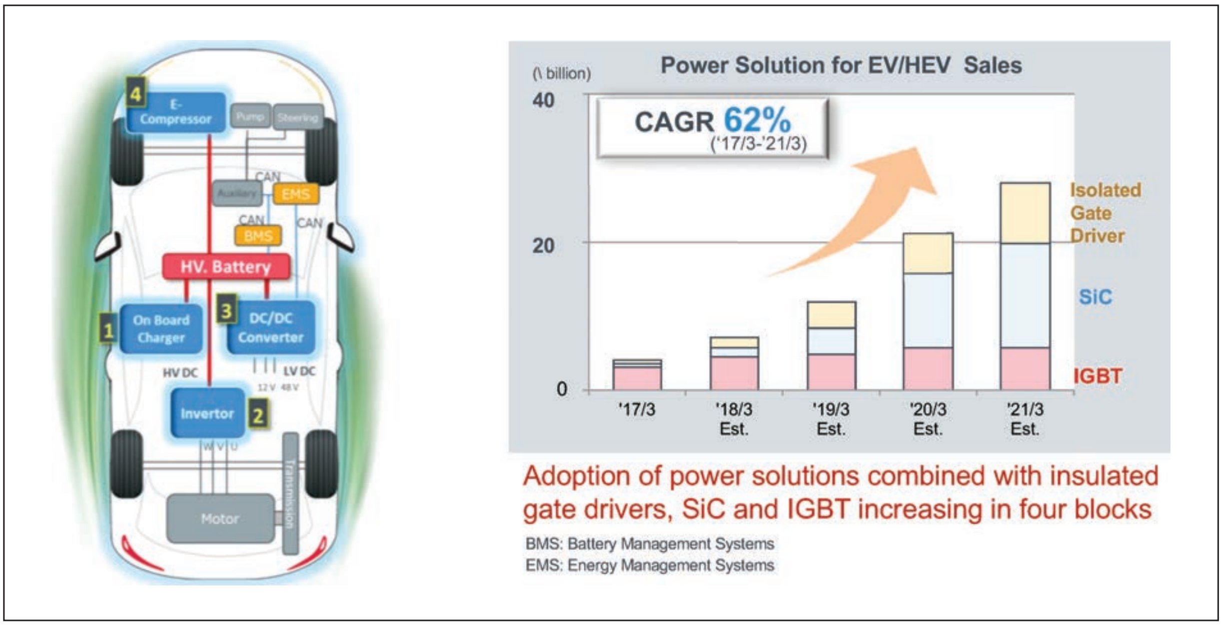


ROHM's prediction for (H)EV power semiconductor applications until the year 2021

they have very high breakdown voltage (600 V and up) and yet with very low resistance relative to Silicon devices. Resistance of high-voltage devices is predominantly determined by the width of the drift region. In theory, SiC can reduce the resistance per unit area of the drift layer to 1/300 compared to Si at the same breakdown voltage. The larger bandgap also means SiC devices can operate at higher temperatures from 150°C to 175°C. This is due mainly to thermal reliability of packages. When properly packaged, they can operate at 200°C and higher.

SiC-MOSFETs are normally OFF voltage-controlled devices. Hence they are easy to drive and incur less gate drive loss. The basic drive method is the same as that for IGBTs and Si-MOSFETs. The off-on gate voltage swing is nominally 0 to 18 V. If high noise tolerance and fast switching are required, negative voltage of approximately -3 to -5 V can also be used.

Although SiC-MOSFETs have lower drift layer resistance than Si-MOSFETs, the lower carrier mobility in SiC means their channel resistance is higher. For this reason, the higher the gate voltage, the lower the on-resistance. Resistance becomes progressively saturated as the gate-source voltage gets higher than 20V. SiC-MOSFETs do not exhibit low on-resistance with the gate voltage of 10 to 15 V which is applied to typical IGBTs and Si-MOSFETs. It is recommended to drive SiC-MOFETs with 18 V in order to obtain adequately low on-resistance.

The threshold voltage of SiC-MOSFET is about the same as Si-MOSFETs, approximately 3 V at room temperature (normally OFF). However, since approximately 8 V or more of gate voltage is required to conduct several amperes of current, SiC-MOSFET can be said to have higher noise immunity than IGBT to accidental turn-on. The threshold voltage decreases with increasing temperature.

SiC devices do not need conductivity modulation to achieve low on-resistance since they have much lower drift-layer resistance than Si devices. MOSFETs generate no tail current in principle.

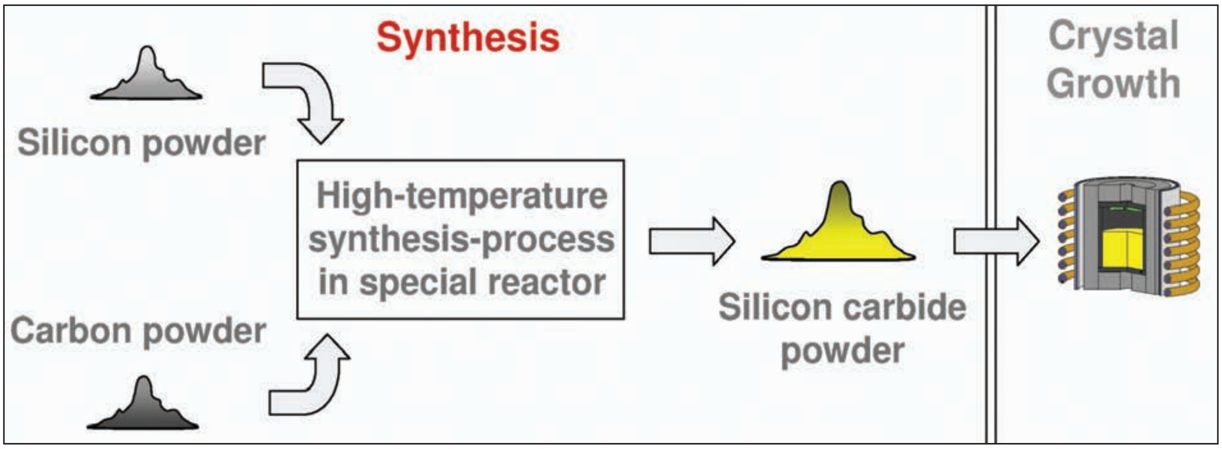
The most distinctive feature of SiC-MOSFETs is that they do not exhibit tail currents as observed in IGBTs. Therefore SiC MOSFETs can have turn-off loss (Eoff) that is approximately 90% smaller.

IGBT's tail current increases with temperature whereas switching characteristics of MOSFETs are nearly independent of temperature. IGBT's high switching loss increases the chip's junction temperature, frequently limiting the switching frequency to 20 kHz or less. The much lower Eoff allows SiC-MOSFETs to switch at much higher frequency, 50 kHz and higher. Size of passives and/or cooling systems thus can be significantly reduced. Compared to 600-900 V Silicon MOSFETs, SiC MOSFETs have smaller chip area (mountable on a compact package) and an ultra-low recovery loss of body diodes.

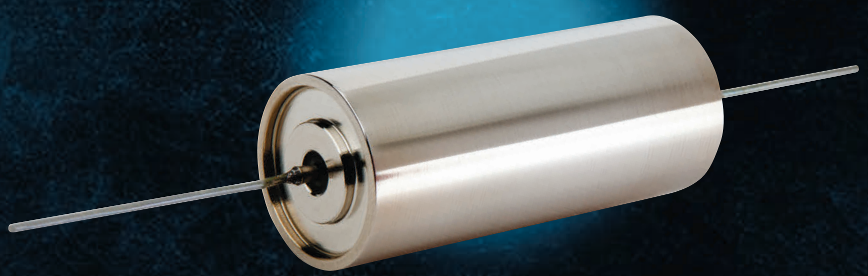
SiC-MOSFET's body diode has recovery performance equivalent to that of discrete SiC-SBDs, but it has higher forward voltage. This fast recovery performance of diodes reduces turn on loss by several tens of percentages. The switching rate depends largely on the external gate resistance. For fast switching, it is recommended to use a small gate resistor of several ohms. The selection of appropriate gate resistance must take surge voltage into account.

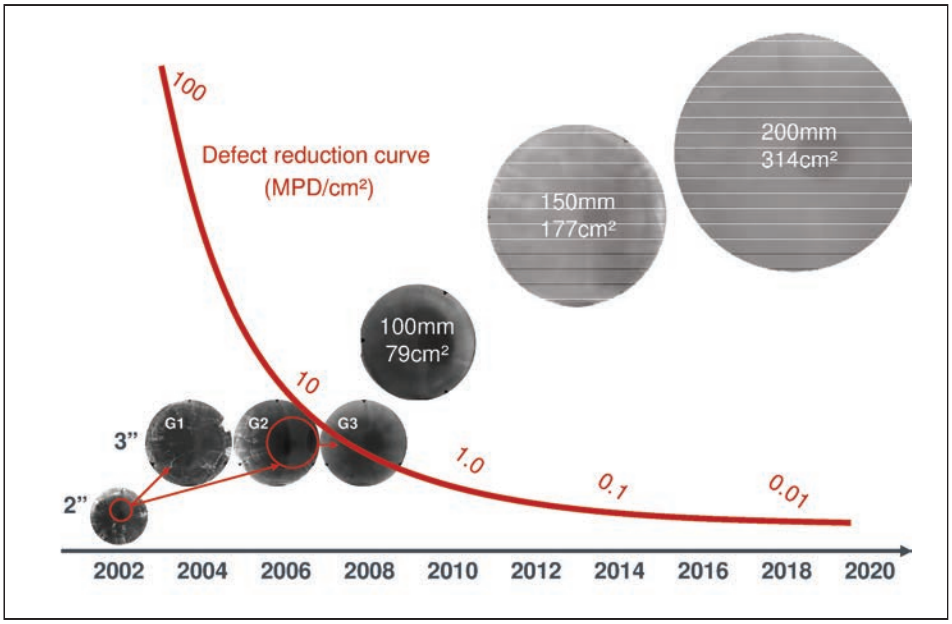
Currently, IGBT modules that combine Si-IGBTs and Si-FRDs are commonly used as power modules to handle high currents and high blocking voltage. SiC modules allow substantial reduction in switching losses associated with Si-IGBT's tail current and Si-FRD's recovery current.

In March 2012 ROHM was the first to mass produce full SiC power modules. Since then, the company developed high-power products up to 1200 V/300 A that have been adopted in a variety



Silicon Carbide ingredients





SiC power wafer quality roadmap

of fields. These latest modules (BSM400D12P3G002 and BSM600D12P3G001) introduced last year utilize a new package design that expands the SiC module lineup to cover the key current range from 100 A to 600 A to meet the growing demand in the IGBT market.

The BSM600D12P3G001 achieves a rated current of 600 A, switching loss is reduced by 64 % (at a chip temperature of 150°C) compared with IGBT modules at the same rated current, improving energy savings considerably. And along with reducing the size of peripheral components through high-frequency operation, the effects of reducing switching loss are greater when driving at high frequencies, contributing to the miniaturization of cooling and other systems. For example, from calculations based on loss simulation in cooling systems, adopting SiC modules can reduce the size of water-cooled heat sinks by up to 88 % compared with equivalently rated IGBT modules.

“Our power lab has 8 kV and some kA capability to assist our customers in designing power semiconductor applications,” said Aly Mashaly, Manager Power Systems at ROHM Europe

Achieving a rated current of 600 A entails not only reducing internal inductance but heat generation as well. By improving the flatness of the base plate section that significantly contributes to the heat dissipation of the module, ROHM was able to decrease the thermal resistance between the cooling mechanism and the customer’s base plate by 57 %. In addition to SiC modules, a gate driver board enables quick evaluation.

For all these reasons, SiC-MOSFETs and modules are increasingly being used in inverters/converters for high-efficiency power conditioners.

Test lab for power components

The European “Power Lab” will demonstrate the deployment of ROHM’s global strategy on the Power semiconductor’s market in Europe, one of the very potential regions for Power devices. Located at the European Headquarter facilities in Willich-Münchheide, the technical and safety approval by TÜV was achieved in 2017. The 300 m? lab’s purpose is the analysis of power components and systems to support customers at application level. To that end, the test lab is equipped with several test benches with a separate high voltage area. “Here we can electrically characterize all of semiconductor components like SiC MOSFETs, SiC diodes, IGBTs, Si Power MOSFETs and Gate driver, just to name some of them, with voltages up to 8000 VDC,” underlined Aly Mashaly, Head of the Power Lab. “And that is necessary, because often the datasheet specs and the behavior of a device differ in real applications!”

Tests on AC/DC, DC/DC, DC/AC and AC/AC converters can be performed under real application conditions up to 15 kVA. Additionally, high-precision measurements of efficiency and losses can be performed with power analyzers. Among this test bench’s special features are an AC power supply (grid emulator) and electronic loads (AC and DC). Maximum voltages under test are 1500 VDC and 400 VAC. Also clearance and creepage distances on board and system levels up to 6000 V are possible.

A calorimetric test bench is for analyzing the thermal behavior of the power discrete devices, modules, electronic boards and complete power electronic systems. Tests at very high current supplies with hundreds of amps and tests under special temperature conditions ranging from -40°C to +180°C as well as humidity tests between 10 % and 98 % can be performed in a climatic chamber.

“Electric vehicles, charging station infrastructure, industrial machinery, solar and wind power plants as well as white goods require more and more

The inverter for season four features embedded full SiC Power modules, making it 43 % smaller and 6 kg lighter than the inverter for season two, incorporating IGBTs power semiconductors to comply with the energy efficiency requirements, which have to be tested and validated at an early stage of the development phase", Mashaly said. "Because there were no suitable test benches on the market, we decided to develop and design the test benches based on our own requirements subsequently. In this way, we ensure the high scalability of the test benches and their flexibility for future modifications." Currently four engineers assist customers in their application-oriented projects.

Playground for new technologies

ROHM Semiconductor has been official technology partner of the VENTURI Formula E team since Season 3 (2016/2017) for designing efficient drive inverters.

Held since 2014, the Formula E is the world's first formula championship for electric cars, and is organized by the Fédération Internationale de l'Automobile. This event serves as a proving ground for the research and development of electric vehicles, and stimulates social interest in these cars. Season four of the Formula E has opened in December 2017 in Hong Kong, followed by races in Marrakesh and Santiago. Further races are planned in Mexico City, Punta del Este (Uruguay), Rome, Paris, Berlin, Zurich and New York, for a total of ten venues. In 2013, Monaco-based VENTURI Automobiles entered the FIA Formula E series under the VENTURI Formula E Team name and became an FIA-approved manufacturer in 2015. The company, employing 15 people including six engineers, supplies full powertrain systems for its Formula E Team. In 2016, the VENTURI Buckeye Bullet 3 set the official top recorded speed achieved by an electrically-driven car of 549 km/h on the Bonneville Salt Flats in Utah.

The key to success in the all-electric racing series is power management - finding the most efficient way of using the energy provided by the battery and applying it on the road. ROHM has developed for season four a dedicated full-SiC power module for the race car's central inverter – the core of Formula E racing cars. "The inverter for season four features embedded full SiC Power modules, making it 43 % smaller and 6 kg lighter than the inverter for season two, incorporating IGBTs. The season three inverter, also supported by ROHM, incorporated SiC freewheeling diodes. For season 4, by adopting a full SiC power module, we were able to bring to reality a lightweight inverter that requires only a minimum amount of space. We now achieve an efficiency of 96 percent from battery to wheel", underlines Franck Baldet, Venturi's CTO. "At the end we speak of energy management by taking into account recuperation at breaking, and the battery which will doubling the capacity at roughly same weight of 360 kg in the next season."

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ABB Partners Formula E

ABB is bringing its name and innovation and technology leadership to the series, which will be now known as the ABB FIA Formula E Championship.

With its expertise in electrification and electric vehicle charging solutions, with a large installed base of fast-charging stations for electric vehicles worldwide, ABB is an ideal industry partner for Formula E. "We are excited to partner with Formula E in writing the future of e-mobility," said ABB CEO Ulrich Spiesshofer. "ABB and Formula E are a natural fit at the forefront of the latest electrification and digital technologies. Together, we will write the next phase of this exciting sports activity and foster high-performance teams. Together, we will write the future – one electrifying race at a time." ABB entered the EV-charging market back in 2010, and today has a fast growing global installed base of more than 6,000 fast chargers.

Alejandro Agag, founder and CEO of Formula E, said: "This is a historic day for Formula E and I am proud to welcome ABB as the title partner of Formula E, with its background and expertise in the field of electrification and digital technologies. Our two companies are synonymous with pushing the boundaries of what is possible. Together, as partners, we will showcase breakthrough technology on a global scale to fans and consumers who follow the ABB FIA Formula E Championship."

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Handshake between ABB's CEO Ulrich Spiesshofer and Alejandro Agag, founder & CEO of Formula E


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Infineon Keeps Pole Position

2017 was a strong year for Infineon. Group revenue rose by 9 percent to more than €7 billion. In particular Automotive, Industrial Power Control, and Power Management & Multimarket contributed to this growth. For the current fiscal year 2018 CEO Reinhard Ploss expects a year-on-year increase in revenue of around 5 percent and a margin of 16.5 percent. With full order books he assumes that the company will again grow profitably in the 2018 fiscal year, Ploss outlined at the Annual General Meeting end of February.

Mobility, renewable energies and efficient use of electricity, digitalization, and data security are the major areas of growth. Infineon will benefit from that in two respects – firstly from the higher quantities of vehicles and secondly from the growing number of semiconductors per vehicle. We expect the number of cars to grow at an average annual rate of globally around 2.2 percent until 2021. Semiconductors worth an average total value of $355 are currently installed in a conventional car. That figure is about twice as high – $695 – in hybrid, plug-in hybrid and electric vehicles. And power semiconductors account for three-quarters of these extra 340 dollars.

A core component of the electric drive are modules such as the HybridPACKs 1/2. It controls the electric engine's speed. First designs were IGBT-based and have been adopted by several car manufacturers such as BMW for the i3 and i8 models. As European premiere Ploss introduced the NIO ES8, a Chinese start-up founded in 2014. The electrical ES8 SUV has seven seats and a power of 480 kilowatts, in other words, around 650 hp. Four of these modules drive the ES8. The SUV incorporates a large number of different semiconductors worth $900.

The latest power module design use Silicon Carbide devices. The advantage is a 30 percent smaller size and doubling the power of the Silicon-based module. The trend toward the e-car is picking up at a tremendous pace. We see that in our order books. Thus our know-how, products and solutions are paving the way for the drive of the future.

Digitalization needs energy – used efficiently and generated environmentally-friendly. In 2014, Google consumed roughly as much power as 1.4 million private German households. That's why energy efficiency is very important for companies like Google, Facebook or Microsoft. They operate data centers containing up to 40,000 servers. The need for computing power will increase even further with the Internet of Things and artificial intelligence.

Energy losses in supplying power can be reduced by using components based on Gallium Nitride. More and more customers are using products from Infineon's CoolGaN family in high-performance power supply units for data centers. CoolGaN provides less energy loss, lower system costs, a more compact design and reduced operating costs. However, switching from Silicon to Gallium Nitride demands significant adjustments to the customer's system architecture. We support them in that – because we understand the system "Power". Another aspect of energy requirements for digitalization - more and more electrical power needs to be generated. Here too, companies like Apple and Google are increasingly recognizing their responsibility. They are using wind and solar power to a growing extent in order to supply their cloud services with electricity.

Renewable energies are an important growth area for Infineon. Let's take the example of solar energy. China is expanding vigorously in this area, in example 2017 was a record year. New solar installations with an output of more than 40 gigawatt were erected, a figure that might even rise to 50 gigawatt in 2018. By comparison - in Germany solar systems with a total capacity of around 40 gigawatt have been installed since the end of the 1990s.

In solar panels, inverters convert the generated direct voltage into alternating voltage to be fed into the grid. Power semiconductors from Infineon have always been key components in the inverter. We are now using components based on Silicon Carbide. Losses in energy conversion can thus be reduced. The inverters can be produced much smaller, lighter and 10 percent cheaper. At the same time, there's an increase in the value of the built-in semiconductors. That's good for the customer and good for Infineon.

We also develop products that complement the function of our power semiconductors. Digitalization and expansion of functionality demand new skills. We have to understand how our customers' systems work. Then we will be able to implement appropriate algorithms and software.

One example of that is our digital motor controller platform iMOTION for industrial systems and domestic appliances. Here we bring together our power semiconductors and logic chips to create a compact solution. In addition, we supply the second generation as standard with a development kit, including software. Our customers only need to define a few parameters.

The new IMC100 series, a family of iMOTION™ motor control ICs., provides a ready-to-use solution for the fast growing market of high efficiency variable speed drives. By integrating the required hardware and control algorithm, the IMC100 enables shortest time to market for any motor system. Additionally, the next generation of Infineon's Motion Control Engine (MCE) further improves the performance of the motor algorithm and adds functionality like ready-to-use PFC algorithms. Key applications for the new iMOTION family are motors for major home appliances, air-condition, fans, and pumps. IMC100 features

LEFT: Infineon's CEO Reinhard Ploss presents the next generation of HYBRIDPACKs featuring Silicon Carbide MOSFETs making them lighter and more powerful

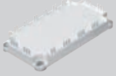
SEMIX 5

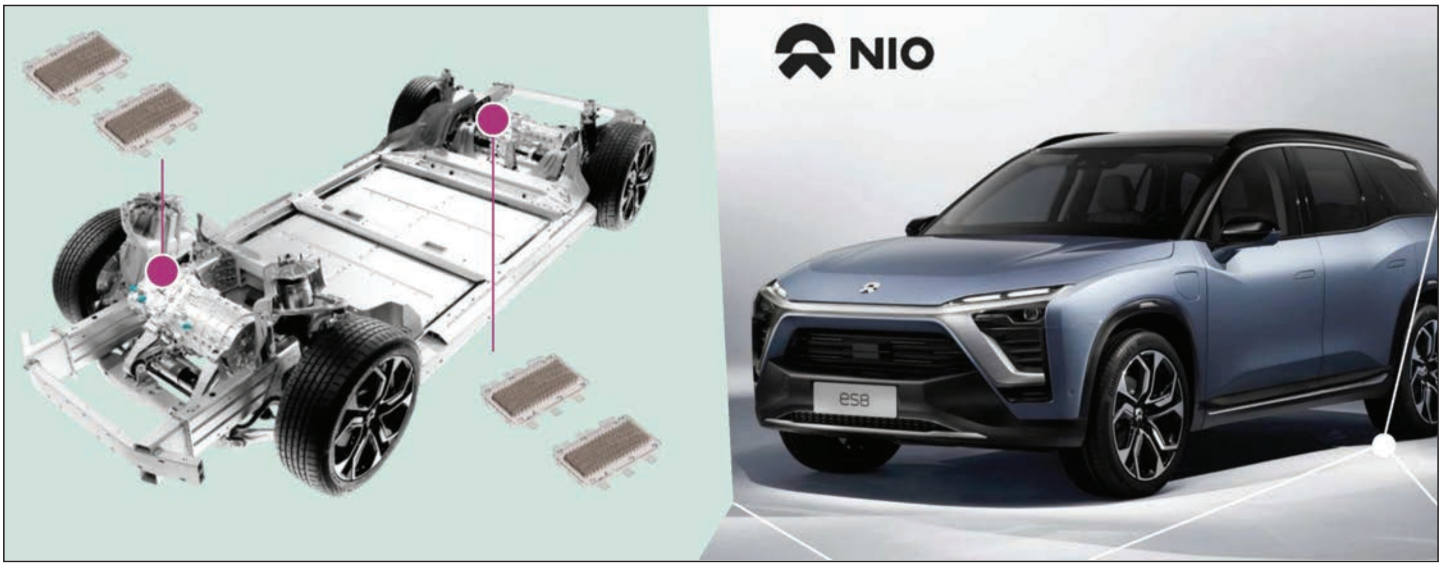
SEMiX 3 PF

SEMiX 3s

SEMiX 33c

SEMiX 6





NIO's ES8 incorpates several IGBT HYBRIDPACKs

Field Oriented Control (FOC) for permanent magnet synchronous motors. It uses space vector PWM with sinusoidal signals to achieve high energy efficiency and can utilize single or leg shunt current feedback. The proprietary PC tools MCEWizard and MCEDesigner reduce the implementation effort for variable speed drive.

The semiconductor industry is currently experiencing strong economic activity. With its 18 factories on three continents, Infineon is positioned to grow further. More than 38,000 people now work for Infineon worldwide. And that figure is rising, also in Germany. We are currently expanding our capacities so that we can keep on growing profitably. We benefit in this from cost advantages, such as in the production of power semiconductors on 300-millimeter thin wafers in Dresden and Villach. Investments in 300-millimeter capacities are far lower than those in 200-millimeter capacities. We have already benefited from this investment advantage for some time and are now also beginning to see an advantage in productivity, and we have now reached the cost cross-over, Ploss stated.

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Infineon and Cree Exchange Technologies

After the failed acquisition of Cree's subsidary Wolfspeed last year Infineon and Cree agreed on a long-term supply agreement for the provision of 150 millimeter SiC wafers.

SiC semiconductors are the basis for most high-efficiency and disruptive system solutions in power conversion and in the electric car. Compared to Silicon-based power semiconductors, SiC devices provide higher energy savings and higher system density from size reduction of the passive components. Over the next few years, in addition to electro-mobility and photovoltaic, SiC products will expand into application fields such as robotics, industrial power supplies, traction and variable speed drives, Infineon believes.

On the other hand, Cree has acquired assets of Infineon's Radio Frequency (RF) Power Business for €345 million. This business holds a leading market position offering transistors and MMICs (Monolithic Microwave Integrated Circuits) for wireless infrastructure radio frequency power amplifiers based on both LDMOS and Gallium Nitride on Silicon Carbide (GaN-on-SiC) technologies.

The transaction expands the Cree Wolfspeed business unit's wireless market opportunity. "The acquisition strengthens our position in RF GaN-on-SiC technologies and provides access to additional markets, customers and packaging expertise," said Cree CEO Gregg Lowe. "Cree is a strong new owner for this portion of our RF business. We will be able to focus our resources more effectively on strategic growth areas and will retain a strong technology portfolio for the wireless market, added Reinhard Ploss.

Wide Bandgap Gains Acceptance

APEC 2018 from March 4 – 8 in San Antonio/Texas provided a highly professional technical program and exposition, the conference began with 18 Education Seminars organized into 6 parallel tracks, followed by 6 Keynotes in the Plenary session. The exhibition featured around 300 companies.

The technical papers were organized into 63 sessions with nearly 600 papers, along with 25 industry sessions featuring an additional 130 presentations. "Besides all of these presentations, sessions and events to attend, I always find that is connecting with my peers, friends and colleagues face-to-face, catching-up with what new things they are working on, and discovering the latest trends in their realm that is the mos trewarding aspect of attending APEC", commented General Chair Eric Persson. I as attendee agree because the most important informations can be gathered in informal personal talks.

APEC 2018 exhibition floor featured more than 300 companies

As in previous years SiC and GaN played a major role in the conference sessions as well as on the exhibition floor, but the focus has been shifted from basic technologies towards applications.

At the Plenary Session two European speakers referred to the advantages of SiC. Johann W. Kolar, ETH Zurich, talked about the 'Vienna Rectifier and Beyond'. Twenty years ago at APEC 1998 a single stage isolated three-phase PWM rectifier system was introduced. The topology is a unidirectional three-phase three-switch three-level PWM modulator or a three-phase diode bridge with an integrated boost converter. It is useful wherever six-switch converters are used for achieving sinusoidal mains current and controlled output voltage, when no energy feedback from the load into the mains is available. In practice, use of the Vienna Rectifier is advantageous when space is at a sufficient premium to justify the additional hardware cost. "Future designs are based on SiC MOSFETs to increase efficiency and reduce size and weight considerably", Kolar pointed out.

Also ABB's Principal Scientist, Muhammad Nawaz, highlighted the advantages of SiC in future power converters for the windmills or electrical drives.

More power for SiC

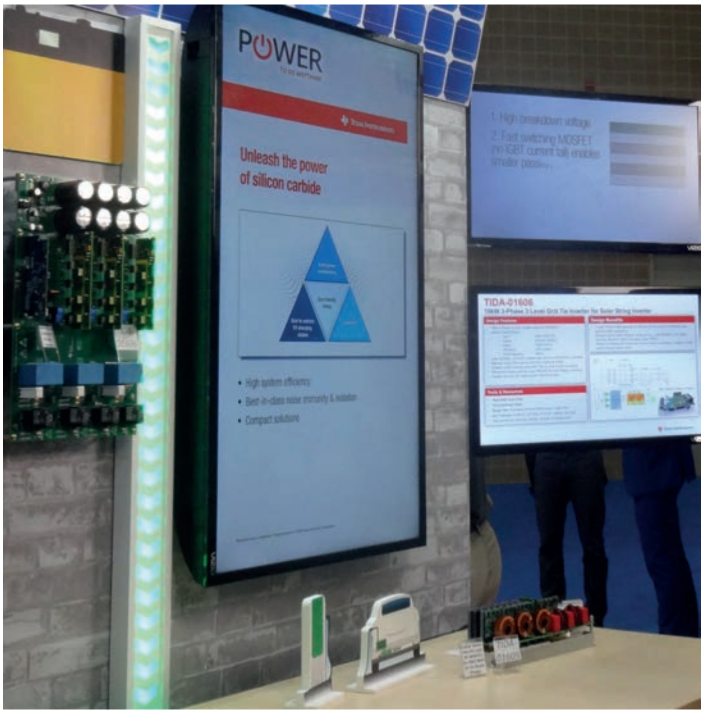
IXYS Corporation, which was acquired by Littelfuse **(www.littelfuse.com)** in January 2018, and Monolith Semiconductor Inc., a fabless developer of SiC technology in which Littelfuse holds a controlling interest, exhibited their growing power semiconductor portfolio. The IXYS acquisition adds new technologies for the manufacturing of power modules, high-temperature/low-loss discretes, medium- and high-power thyristors, fast recovery diodes and rectifiers, industrial IGBTs, MOSFETs, driver and control ICs, and optical and solid-state relays. These new product lines complement existing Littelfuse technologies, which include low-power thyristors, ignition IGBTs, and SiC Schottky diodes and MOSFETs. "During the last few years, IXYS and Littelfuse have been expanding their product platforms to pursue many of the same markets. The IXYS acquisition gives Littelfuse customers a single source for power semiconductors, so no matter what the application is, we can support it with the delivery and application support customers need on a global scale", commented Corey Deyalsingh, Director Power Semiconductors at Littelfuse. "With the support of the PowerAmerica Institute, X-FAB, through collaboration with Monolith, is accelerating the commercialization of SiC power devices by leveraging the economies of

Entry of the APEC 2018 exhibition floor

Littelfuse's Director Power Semiconductors Corey Deyalsingh (left) and Monolith Semiconductor's CEO Sujit Banerjee explained the planned power semiconductor roadmap

scale, automotive quality standards, and equipment set that X-FAB uses for its Silicon wafer fabrication line into its SiC foundry model. X-FAB currently fabricates wafers for ten different SiC companies in the same facility, each with its unique set of device designs and process sequences. By consolidating the resources necessary and the demand from both Silicon and SiC customers, X-FAB can produce 6-inch SiC wafers at the same rate as some of the world's leading integrated device manufacturers that operate captive fabs. This gives us a competitive advantage," added Sujit Banerjee, CEO Monolith Semiconductor.

At APEC a 1200 V SiC N-channel MOSFETs was added to the first-generation portfolio of power semiconductor devices. Shown were also a Dynamic Characterization Platform for characterizing SiC device switching behavior and the Gate Drive Evaluation Platform for studying the optimal device driving conditions for specific applications. Also Texas Instruments exhibited its 10 kW, 1 kV, 3-phase, 3-level SiC-Based Grid Tie Inverter Reference Design for a transformer-less solar string inverter with 99 % peak



TI's 10 kW, SiC-based grid tie inverter reference design for a transformer-less solar string inverter with 99 % peak efficiency

efficiency and 50 kHz switching using Monolith SiC MOSFETs at Littelfuse's and TI's booth.

UnitedSiC **(www.unitedsic.com)** announced the UJ3C series of cascoded 650 V SiC FETs (manufactured also by X-FAB) as drop-in replacements for Silicon Superjunction MOSFETs. Available in standard TO-220, TO-247 and D2PAK-3L packages, they operate with standard Si-MOSFET gate drive, offering low on-resistance at 27 mΩ and gate charge. Used for power factor correction and DC/DC conversion in both hard-switched and ZVS-switched systems, applications include electric vehicle (EV) chargers, power supplies, motor drives and renewable energy inverters. The maximum drain current (ID) ratings for these SiC cascoded transistors ranges from 31 A to 85 A. A built-in low Qrr body diode eliminates the need for an anti-parallel diode. Anup Bhalla, UnitedSiC's VP of Engineering said, "With ESD-protected gates (HBM class 2) and strong avalanche capability these SiC FETs are both more economical and more rugged that GaN devices with comparable ratings. In the most demanding applications, such as EV charging, we are now seeing a clear preference for SiC technology for both new designs and to replace silicon Superjunction MOSFETs in existing systems."

ON Semiconductor's **(www.onsemi.com)** released family of 650 V SiC diodes includes surface mount and through hole packages ranging from 6 A to 50 A. All of the diodes provide zero reverse recovery, low forward voltage, temperature independent current stability, high surge capacity and positive temperature coefficient. The company also plans to release SiC and GaN FETs in the near future.

GaN is going higher power levels

EPC **(www.epc-co.com)** launched the EPC2112 and EPC2115 enhancement-mode monolithic GaN power transistor with integrated driver. The EPC2112 is a 200 V, 40-mΩ eGaN FET plus gate driver. The EPC2115 is an IC with dual 150 V, 70-mΩ eGaN FETs plus gate drivers. Both products are capable of operating up to 7 MHz and are available in low inductance 2.9 mm x 1.1 mm

BGA surface-mount passivated die. The integrated driver is specifically matched to the eGaN device to yield optimal performance under various operating conditions. Performance is further enhanced due to the small, low

GaN Systems' CEO Jim Witham presents a newly launched Insulated Metal Substrate inductance footprint. Monolithic integration eliminates interconnect inductances for higher efficiency at high frequency. This is especially important for high frequency applications such as resonant wireless power, and high frequency DC/DC conversion. As design examples for these new ICs, two differential class-E amplifier development boards are available. The EPC9089 is an AirFuel compatible class 4 (33 W) and uses the EPC2112. The EPC9088 is a class 3 (16 W) amplifier using the EPC2115. The EPC2112 is also featured in a new demonstration board, the EPC9131, for a 300 kHz SEPIC converter low voltage DC/DC application.

The company also introduced two GaN power modules for DC/DC conversion, increasing efficiency across the 48 V to point-of-load power architecture. The EPC9205 is a high-power density PCB-based power module for 48 V – 12 V conversions while the EPC9204 address the 20 V conversion with an ultra-thin profile PCB-based power module. The EPC9205 is an 80 V, 10 A PCB-based power module featuring the 100 V EPC2045 eGaN FET for "plug and play" evaluation of the high performance gained with GaN power transistors.

GaN Systems **(www.gansystems.com)** announced an expansion of the company's GaN power transistors (supplied by TSMC) with new products focused on industrial, automotive, and renewable energy applications. To mention is the 100 V, 120 A, 5 mΩ GaN E-HEMT GS-010-120-1-T, suited for the growing 48 V applications in the automotive, industrial, and renewable energy industries which require power systems with high power levels in smaller size form factors. The transistor is footprint-compatible with the 100 V, 90 A GS61008T, enabling to add further power by substituting the GS-010-120-1-T without changing the board. The new GS-065-120-1-D 120 A, 650 V GaN E-HEMT increases the power density of 20 to 500 kW power conversion systems, including automotive traction inverters, very high power on-board chargers (OBC), large-scale energy storage systems, and industrial motor drives. "This is the most pivotal GaN product on the market to be optimized for modules and is compatible with both embedded and traditional module technology," stated Jim Witham, CEO of GaN Systems. For the consumer and data center applications, several integrated half-bridge with driver have been highlighted. New design tools including several evaluation boards such as the newly launched Insulated Metal Substrate (IMS) Evaluation Platform, which provides a flexible, low cost, high power development platform for high-efficiency power systems with 3 kW or higher applications, have been shown.

Navitas Semiconductor **(www.navitassemi.com)** introduced its GaNFast™ power ICs, based on the TSMC 650 V GaN Process, enabling the 'Mu One', a universal 45 W power adaptor with a 14 mm ultra-slim profile. GaN power IC (half-bridge with driver) is combined with USB-PD power delivery protocol and a type C connector to realize a slim adapter that can charge a laptop or fast-charge a smartphone. "GaN power ICs have up to 20x the performance of Silicon chips. By operating at high frequency and increased efficiency, GaNFast power ICs reduce the size, weight and cost of components such as transformers, heatsinks, and printed-circuit boards. This is a significant achievement to pack this much power in such a low-profile outline", said Gene Sheridan, Navitas CEO. The company additionally announced the smallest mobile adapter enabled by GaNFast power ICs. The 27 W Active Clamp Flyback design delivers 5x greater power than standard smartphone chargers and is 2x higher power density. With universal input voltage capability and a Type C connector with USB-PD 3.0 and Qualcomm Quick Charge™ 4.0 features, this lightweight reference design delivers an extremely portable charging solution.

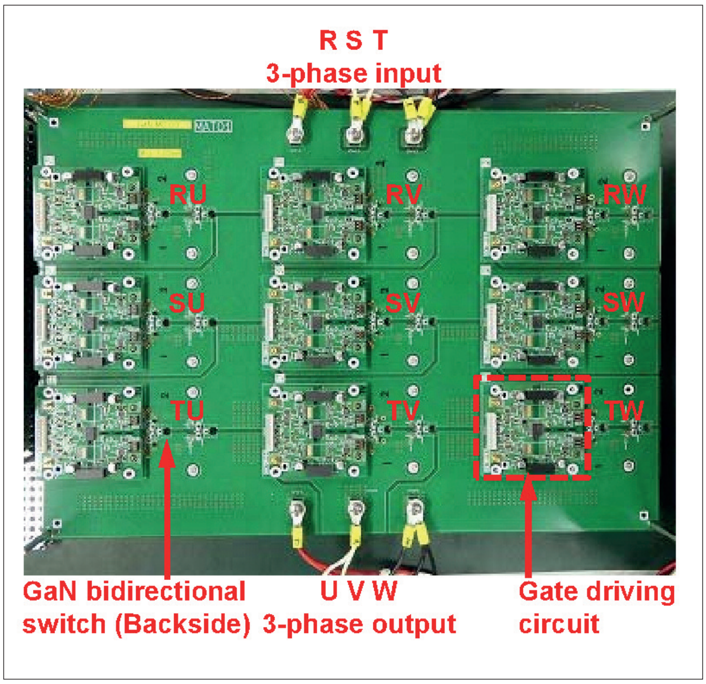
Dialog Semiconductor **(www.dialog-semiconductor.com)** also introduced such a 650 V GaN half-bridge already last year. But this year's focus was on GreenPAK™ SLG46824 and SLG46826 Configurable Mixed-signal ICs (CMICs), following the acquisition of Silego Technology. These devices support in-system programming using a simple I?C serial interface. This allows the installation of an un-programmed GreenPAK on the PCB, and supports programming of the Non-Volatile Memory (NVM) in-system, for

Navitas' CEO Gene Sheridan presented a travel adapter based on its 650 V GaN half-bridge

easy system checkout. This flexibility is also beneficial in the production environment, as it is easy to modify the configuration or add functionality to these devices by programming the non-volatile memory on the production line. The NVM on this device is specified for 1,000 erase/write cycles. Additionally, the SLG46826 includes 2 kbits of EEPROM emulation memory that can replace an I?C-Compatible Serial EEPROM on the customer's board, supporting storage of backup configuration data, a checksum or a serial number. Available in a 2.0 x 3.0 mm 20-pin STQFN package, both CMICs are equipped with low power consumption analog and digital resources like analog comparators (ACMPs), an internal voltage reference, power-on reset, and more advanced digital resources, like multi-function macro-cells. Running the low power analog comparators with the internal low power voltage reference consumes 2.5 µA typical for two ACMPs that are continuously monitoring external signals.

Texas Instruments **(www.ti.com)** announced two GaN FET drivers for designs in speed-critical applications such as light detection and ranging (LIDAR) and 5G radio-frequency (RF) envelope tracking. The LMG1020 and LMG1210 can deliver switching frequencies of 50 MHz while improving efficiency and enabling five times smaller solution sizes previously not possible with Silicon MOSFETs. With a minimum pulse width of 1 ns, the LMG1020 60-MHz low-side GaN driver enables high-accuracy lasers in industrial LIDAR applications. The small wafer-level chip-scale (WCSP) package of 0.8 mm by 1.2 mm helps minimize gate-loop parasitics and losses.

The LMG1210 is a 50-MHz half-bridge driver designed for GaN FETs up to 200 V. The device's adjustable dead time control feature is designed to improve efficiency by as much as 5 % in high-speed DC/DC converters, motor drives, Class-D audio amplifiers as well as other power-conversion applications. Designers can achieve high system-noise immunity with highest common-mode transient immunity (CMTI) of more than 300 V/ns. The company also introduced several new power management chips that enable designers to boost efficiency and shrink power-supply and charger solution sizes for personal electronics and handheld industrial equipment. Operating at up to 1 MHz, TI's new chipset combines the UCC28780 active clamp flyback controller and the UCC24612 synchronous rectifier controller to help cut the size of power supplies in AC/DC adapters and USB Power Delivery chargers in half. For battery-powered electronics that need maximum charging efficiency in a small solution size, the bq25910 6-A three-level buck battery charger enables up to a 60 % smaller-solution footprint in smartphones, tablets and electronic point-of-sale devices.



Panasonic's GaN 3?3 matrix converter with nine GaN bidirectional switches and gate driving circuits

Finally, high-efficient three-phase to three-phase matrix converters using GaN bidirectional switches with both high current and high breakdown voltage were discussed by Panasonic at the conference. The GaN switch with dual gates works as a bidirectional switch by a single device, while a conventional bidirectional switch consists of four devices by two IGBTs and two diodes. In addition, the GaN bidirectional switch is also free from the voltage offsets for the current conduction so that the GaN-based matrix converter enables small size and highly efficient AC/AC conversion. Improvement of the device performance including the recessed gate enables low on-state resistance with stable operation free from current collapse. The maximum drain current reaches 100 A together with breakdown voltage of 1340 V. The fabricated three-phase to three-phase matrix converter exhibits the maximum conversion efficiency of 98 % at 1 kW output power with the expectation that the maximum output power can reach 10 kW or more by the high current device.

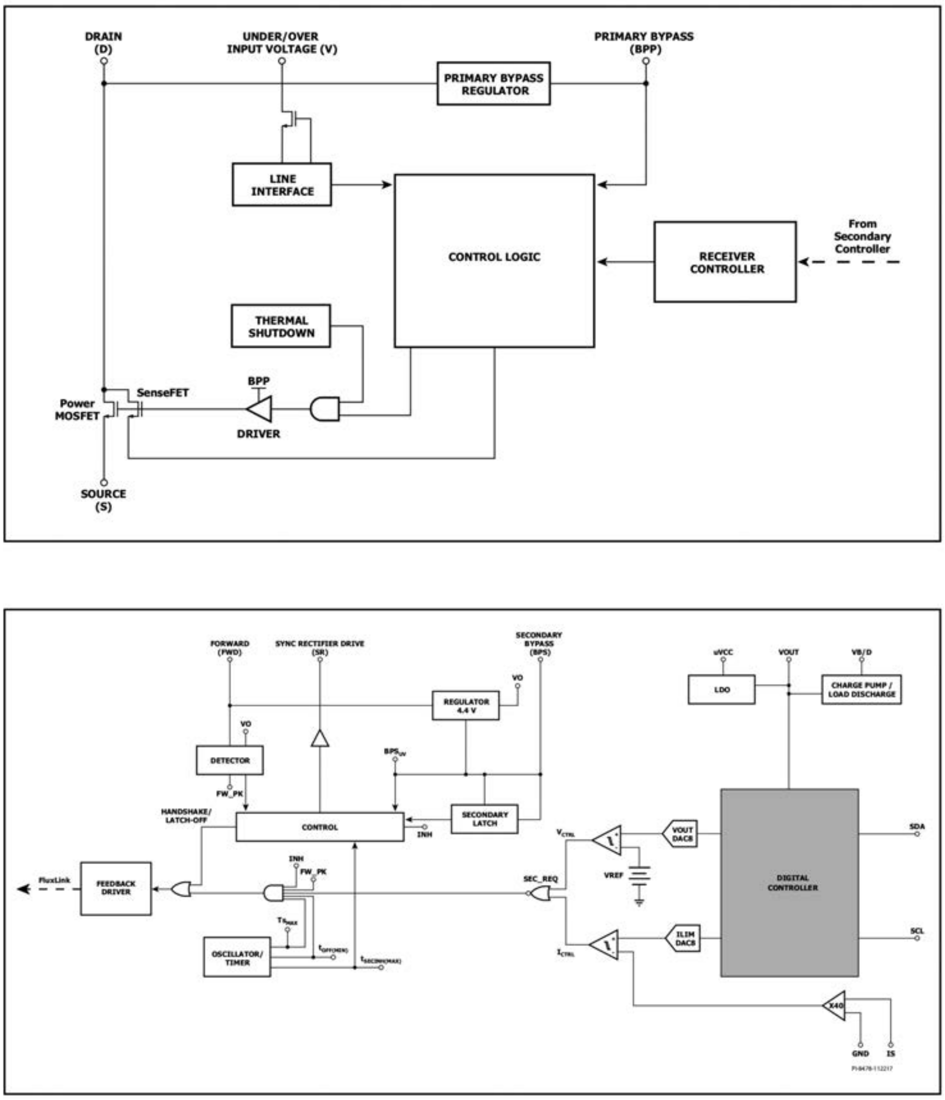
More on APEC 2018 news in our next issue. AS

Dynamically Configurable Off-Line Switcher IC Supports USB PD 3.0 + PPS

Power Integrations announced at APEC 2018 its InnoSwitch3-Pro family of configurable off-line CV/CC and CP flyback switcher ICs. Capable of delivering up to 65 W and achieving up to 94 % efficiency across line and load conditions, the new devices permit precise, dynamically adjustable, control of voltage (10 mV step) and current (50 mA step), via a two-wire I^2C interface. Devices may be paired with a microcontroller or take inputs from the system CPU to control and monitor the off-line power supply. Applications include virtually any rapid-charging protocol, including USB Power Delivery (PD) 3.0 + PPS, Quick Charge™ 4/4+, AFC, VOOC, SCP, FCP and other industrial and consumer battery chargers, dimmable LED ballast drivers and field-configurable industrial power supplies.

InnoSwitch3-Pro power-conversion ICs include a microprocessor V_{CC} supply - eliminating the need for an external LDO to power the microcontroller; also included is an N-channel FET driver which may be used to enable or disable the main power output. Together with integrated bus voltage, current and fault-reporting telemetry and dynamically configurable protection functions such as OTP, line OV/UV, output OV/UV, and short-circuit, the BOM count for a sophisticated offline power supply is significantly reduced and design complexity is radically simplified.

The IC employs the high-speed digital communications technology called FluxLink™, plus synchronous rectification, quasi-resonant switching and a secondary-side feedback sensing and feedback control circuit. Devices are CQC certified, UL recognized and TUV (EN60950) approved to bridge the isolation barrier; the products' InSOP™-24D package also provides a low-profile, thermally efficient solution with extended creepage (>11.5 mm) and clearance between primary and secondary sides for high reliability, surge protection and ESD robustness.



Innoswitch3 primary (upper) and secondary controller block diagram

Primary and secondary controller details

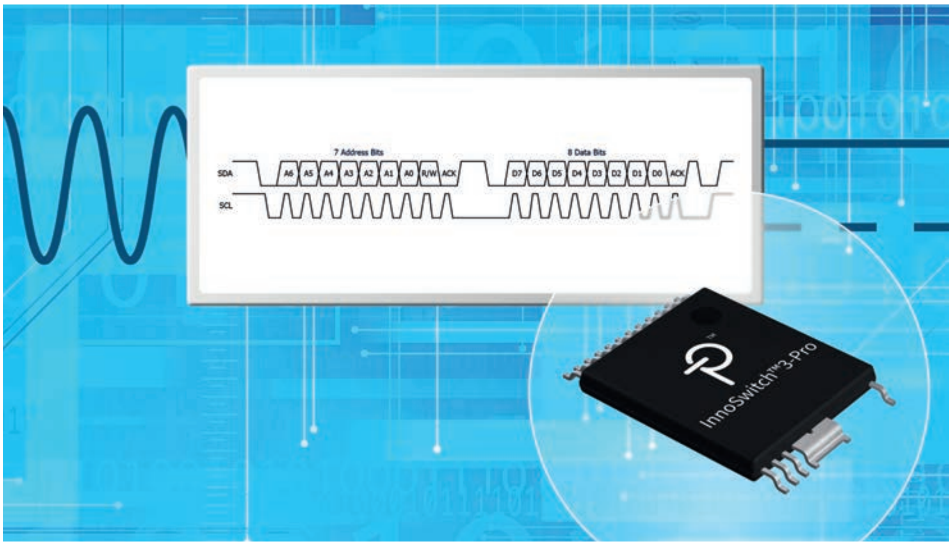
The primary controller is a Quasi-Resonant (QR) flyback controller that has the ability to operate in continuous conduction mode (CCM). The controller uses both variable frequency and variable current control schemes. The primary controller consists of a frequency jitter oscillator; a receiver circuit magnetically coupled to the secondary controller, a current limit controller, 5 V regulator on the PRIMARY BYPASS pin, audible noise reduction engine for light-load operation, bypass over-voltage detection circuit, a lossless input line sensing circuit, current limit selection circuitry, over-temperature protection, leading edge blanking, secondary output diode/SR FET short protection circuit and a 650 V / 725 V power MOSFET.

The secondary controller consists of a transmitter circuit that is magnetically coupled to the primary receiver, an I^2C interface to control power supply parameters and telemetry functions, a 4.4 V regulator on the SECONDARY BYPASS pin, synchronous rectifier MOSFET driver, QR mode circuit, oscillator and timing functions, and a host of integrated protection features.

As shown in the block diagram, the IC is powered through regulator 4.4 V block by either V_{OUT} or FW connections to the SECONDARY BYPASS pin. The SECONDARY BYPASS pin is connected to an external decoupling capacitor and fed internally from the regulator block. The FORWARD pin also connects to the negative edge detection block used for both handshaking and timing to turn on the SR FET connected to the SYNCHRONOUS RECTIFIER DRIVE pin. The FORWARD pin is used to sense when to turn off the SR FET in discontinuous mode operation when the voltage across the FET on resistance drops below the $V_{SR(TH)}$ threshold.

In continuous conduction mode (CCM) operation of the SR FET is turned off when the feedback pulse is sent to demand the next switching cycle, providing synchronous operation,

InnoSwitch3-Pro 65 W configurable off-line CV/CC and CP flyback switcher IC achieving up to 94 % efficiency



free of any overlap for the FET turn-off while operating in continuous mode. The output voltage is regulated on the VOUT pin and defaults to 5 V at start-up. The external current sense resistor connected between ISENSE and SECONDARY GROUND pins regulates the output current in constant current regulator mode.

Quasi-resonant mode switching

In order to improve conversion efficiency and reduce switching losses, the device features a means to force switching when the voltage across the primary switch is near its minimum voltage when the converter operates in discontinuous conduction mode (DCM). This mode of operation is automatically engaged in DCM and disabled once the converter moves to continuous-conduction mode (CCM).

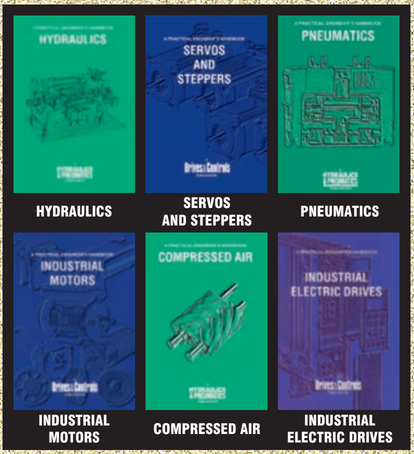
Rather than detecting the magnetizing ring valley on the primary side, the peak voltage of the FORWARD pin voltage as it rises above the output voltage level is used to gate secondary requests to initiate the switch "ON" cycle in the primary controller. The secondary controller detects when the controller enters in discontinuous-mode and opens secondary cycle request windows corresponding to minimum switching voltage across the primary power MOSFET.

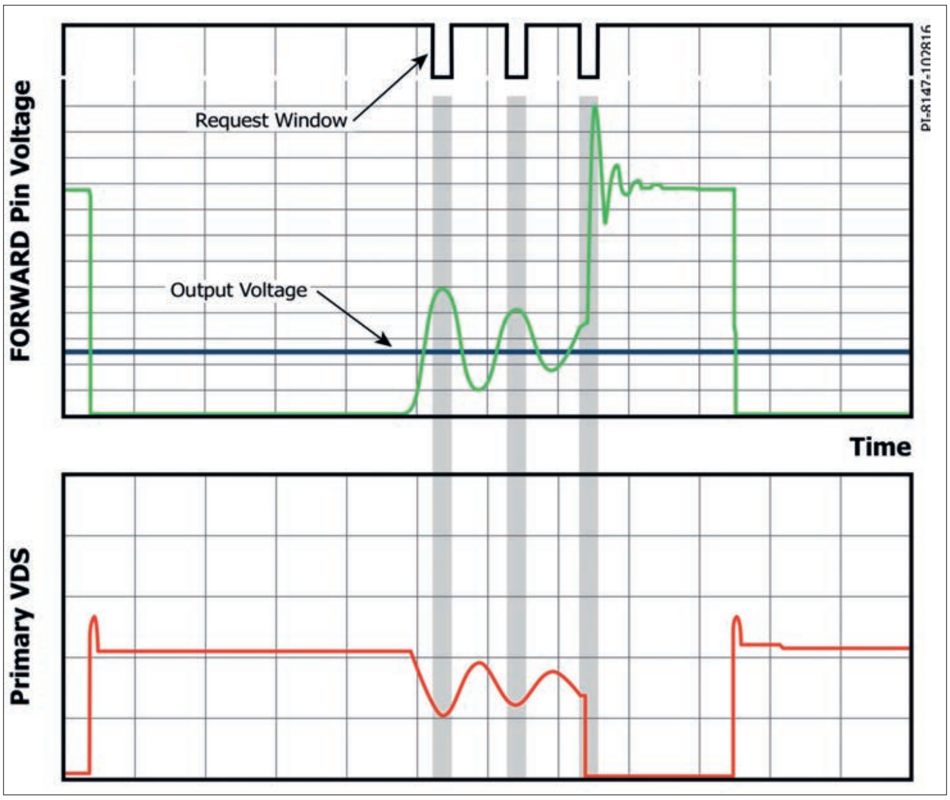
Quasi-Resonant (QR) mode is enabled for 20 ms after DCM is detected. QR switching is disabled after 20 ms, at which point switching may occur at any time a secondary request is initiated. The secondary controller includes blanking of ~1 ms to prevent false detection of primary "ON" cycle when the FORWARD pin rings below ground.

Programmable voltage and current

The operating voltage and current set points are set fully programmable through I^2C interface. The output voltage is user-programmable with a range from 3 V to 24 V. The fast response feedback loop of the IC features 10 mV (ΔV_{OUT}) voltage change resolution. The programmable current set point features 20 % to 100 % operating range, with a programming step size of 0.8 % of full

scale current. Below 5 V and for load current less than 50 mA, voltage command step size of 10 mV may result in non-montonicity since operating





Intelligent quasi-resonant mode switching

frequency is very low.

The internal LDO generates 3.6 V uVCC for MCU which simplifies the system design. An internal driver guarantees turn-on of an N-channel MOSFET series bus switch with source voltage as high as 24 V. The VB/D pin which enables the bus switch is also configurable as the discharge path for the load.

User programmable protection features include output under-voltage (UV) and over-voltage (OV) protection and over-temperature protection. The UV/OV thresholds are dynamically programmable. Users can program three responses to these protections, including auto-restart, latch-off and no-response. An auto-restart (AR) or latch-off (LO) response does not inherently open the series bus switch. The I²C master must send a command to open it if this is the desired behavior.

The secondary controller also features generation of an interrupt signal if one or more of the faults is detected. The SCL pin is pulled down for ~55 ms to generate an interrupt for MCU. In the case when the MCU loses communication with the secondary controller, a watchdog timer triggers a reset to reassert a safe 5 V condition and opens the series bus switch.

The controller communicates to the MCU to report back the status of the power supply. Output voltage and current is measured by internal ADC and available to MCU through I²C. The telemetry features also covers CV, CC and constant power set points, OV/UV thresholds, all protection settings, interrupt status, and complete fault status.

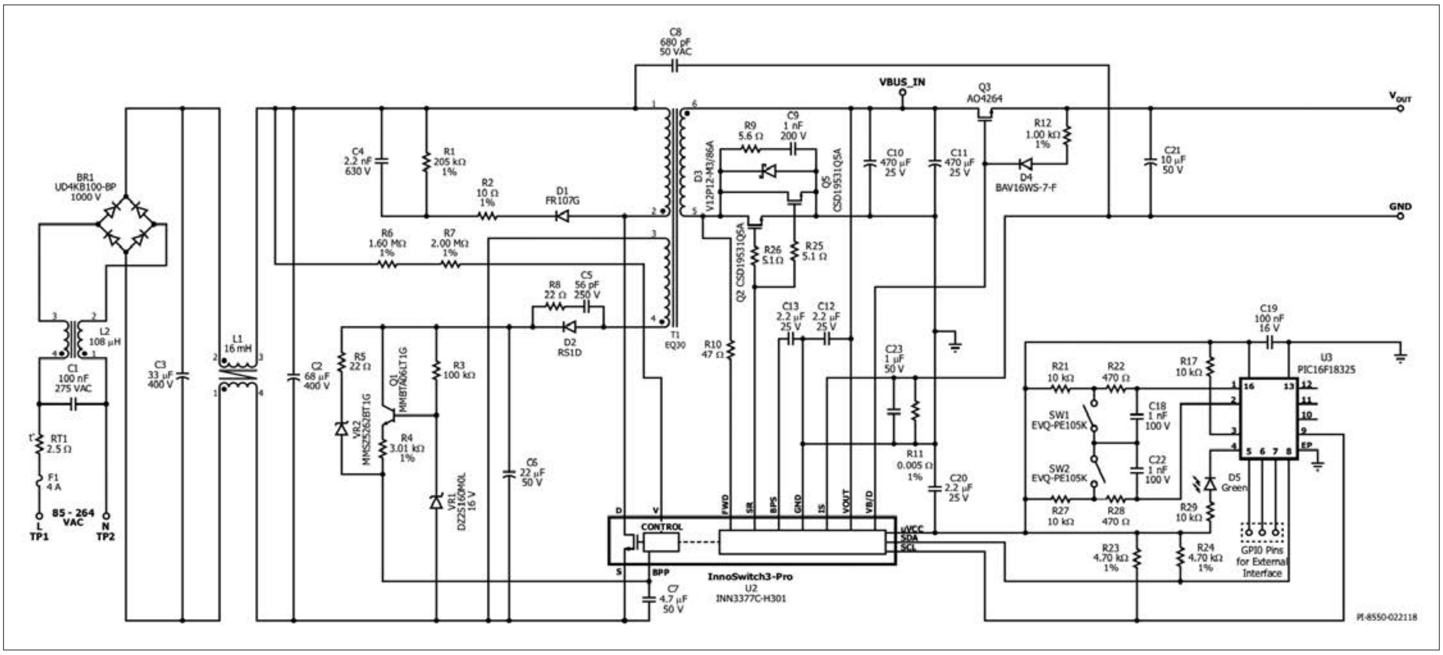
Application example

A 3 V – 8 V, 5 A; 8 V – 20 V constant power 40 W programmable power supply using the INN3377C IC features as an application example. The power stage is controlled by a general purpose PIC16F18325 microcontroller. This design features DOE Level 6 and EC CoC 5 compliance.

Common mode choke L1 and L2 provides attenuation for EMI. Bridge rectifier BR1 rectifies the AC line voltage and provides a full wave rectified DC. Thermistor RT1 limits the inrush current when the power supply is connected to the input AC supply. Fuse F1 isolates the circuit and provides protection from component failure.

One end of the transformer primary is connected to the rectified DC bus; the other end is connected to the drain terminal of the integrated MOSFET in the InnoSwitch3-Pro IC (U1). A low-cost RCD clamp formed by diode D1, resistors R1, R2 and capacitor C4 limits the peak Drain voltage of U1 at the instant of turn-off of the MOSFET inside U1. The clamp helps to dissipate the energy stored in the leakage reactance of transformer T1.

The InnoSwitch3-Pro IC is self-starting, using an internal high-voltage current source to charge the PRIMARY BYPASS pin capacitor (C7) when AC is first applied. During normal operation, the primary-side block is powered from an auxiliary winding on the transformer T1. Output of the auxiliary (or bias) winding is rectified using diode D2 and filtered using capacitor C6. Resistors R3 and R4



Constant power 40 W programmable power supply (3 V – 8 V, 5 A; 8 V – 20 V) application example

along with Q1 and VR1 form a linear regulator circuit to limit the current being supplied to the PRIMARY BYPASS pin of the InnoSwitch3-Pro IC (U1) irrespective of the output voltage. The Zener diode VR2 along with resistor R5 provides latching OVP in the event of an output over-voltage condition.

In a flyback converter, output of the auxiliary winding tracks the output voltage of the converter. In the event of an over-voltage at the output of the converter, the auxiliary winding voltage increases and causes breakdown of VR2. This causes a current to flow into the PRIMARY BYPASS pin of U1. If the current flowing into the PRIMARY BYPASS pin increases above the I_{SD} threshold, the InnoSwitch3-Pro IC controller will latch-off and prevent any further increase in output voltage.

The secondary-side of the IC provides output voltage and output current sensing along with drive to a MOSFET providing synchronous rectification. The secondary output of the transformer is rectified by MOSFETs Q2, Q5 and filtered by capacitors C10 and C11. High frequency ringing during switching transients that would otherwise create radiated EMI, is reduced via a RC snubber, R9 and C9. Current sharing of the two FETs Q2 and Q5 are obtained by adding the resistors R25 and R26 in series with the gates of the respective FETs.

The gate of Q2 and Q5 are turned on by secondary-side controller inside IC U1, based on the winding voltage sensed via resistor R10 and fed into the FORWARD pin of the IC. In continuous conduction mode of operation, the MOSFET is turned off just prior to the secondary-side requesting the start of a new switching cycle from the primary. In discontinuous or continuous mode of operation, the power MOSFET is turned off when the voltage drop across the MOSFET falls below a threshold of $V_{SR(TH)}$. Secondary-side control of the primary-side power MOSFET avoids any possibility of cross conduction of the two MOSFETs and provides reliable synchronous rectification.

The secondary-side of the IC is self-powered from either the secondary winding forward voltage or the output voltage. Capacitor C13, connected to SECONDARY BYPASS pin of U1 provides decoupling for the internal circuitry. Capacitor C12 is needed between the VOUT pin and the SECONDARY GROUND pin for ESD protection of the VOUT pin.

During CC operation, when the output voltage falls, the device will power itself from the secondary winding directly. During the on-time of the primary-side power MOSFET, the forward voltage that appears across the secondary winding is used to charge the SECONDARY BYPASS pin decoupling capacitor C13 via resistor R10 and an internal regulator. This allows output current regulation to be maintained down to the minimum auto-restart threshold set by the I2C interface. Below this level the unit enters auto-restart until the output load is reduced.

Output current is sensed by monitoring the voltage drop across resistor R11 between the IS and SECONDARY GROUND pins. A threshold of approximately 32 mV reduces losses. A decoupling capacitor C23 is needed between the IS and SECONDARY GROUND pin to improve CC accuracy. Once the internal current sense threshold is exceeded, the device regulates the number of switch pulses to maintain a fixed output current. When the output current is below the CC threshold, the device operates in constant voltage mode. The output voltage is set by the I^2C interface.

www.power.com/products/innoswitch/innoswitch3-pro

Leveraging Automotive-Quality 150 mm Si-CMOS Processes Makes SiC MOSFETs More Affordable and Reliable

Silicon IGBTs are suitable for voltage ranges in which a 1200 V-rated part is necessary, but they are limited to ~25 kHz in hard-switched applications. Si MOSFETs allow for operating frequencies well above 25 kHz, but design trade-offs start to limit their advantages at voltages higher than 600 V. In contrast, SiC MOSFETs switch up to five to ten times faster than Si IGBTs and can operate at higher junction temperatures, but at equivalent higher device cost. One way of getting improved SiC MOSFET costs requires a non-traditional wafer processing methodology - processing SiC wafers in parallel with Si wafers in a high-volume Si-CMOS foundry. **Dr. Sujit Banerjee, CEO Monolith Semiconductor and Corey Deyalsingh, Director of Power Semiconductor at Littelfuse, USA**

Silicon-based MOSFETs and IGBTs are the traditional options for semiconductor switches in power converter applications. However, these devices too often limit the performance capabilities of their intended applications. Silicon (Si) IGBTs are suitable for voltage ranges in which a 1200 V-rated part is necessary, but they are limited to a maximum operating frequency of ~25 kHz in hard-switched applications. Si MOSFETs allow for operating frequencies well above 25 kHz, but design trade-offs start to limit their advantages at voltages higher than 600 V.

In contrast, the newest Silicon Carbide (SiC) MOSFET switches offer designers of power conversion systems for applications such as photovoltaic inverters, energy storage systems, EV chargers, UPSs, industrial motor drives, and a rapidly growing array of other products significant performance advantages over traditional Si MOSFET and IGBT switches. SiC MOSFETs switch up to five to ten times faster than Si IGBTs and can operate at higher junction temperatures. Because they can switch on and off so quickly, they enable higher switching frequencies and therefore allow those designing inverters and other power converters to shrink the size and weight of other components in the system, which significantly improves power density and weight without penalizing system efficiency.

In spite of a price premium over Si MOSFETs and IGBTs, the SiC MOSFET is already seeing significant success due to cost-offsetting system-level benefits; the market share for this technology seems destined to expand rapidly over the next few years as the supply chain matures. One way of getting improved SiC MOSFET costs requires a non-traditional wafer processing methodology: processing SiC wafers in parallel with Si wafers in a high-volume Si-CMOS foundry. Littelfuse and Monolith Semiconductor have pursued this tactic as part of a strategic partnership begun in 2015, and are producing SiC Schottky diodes and MOSFETs in a 150 mm CMOS facility in Texas owned by X-FAB that also fabricates automotive-qualified Si devices. This fabless approach allows us to support power converter makers who require customized devices—customers that the major SiC suppliers aren't interested in working with.

Fabless wafer production

This wafer production method offers a variety of advantages. For example, processing wafers in this CMOS facility allows sharing best manufacturing and quality practices used for automotive-qualified CMOS products and takes advantage of enormous economies of scale. Avoiding the high costs of operating our own fab allows for major cost reductions. In addition, fabricating SiC devices on 150 mm wafers rather than on 100 mm wafers (as is typical for SiC devices) allows for much more efficient leveraging of manufacturing costs. Even though processing larger wafers costs more than smaller ones, it also allows spreading the higher cost per wafer over a larger yield of die per wafer.

From a materials and equipment standpoint, SiC wafer processing is fundamentally compatible with CMOS processing. At the X-Fab facility, standard CMOS process steps are reused wherever possible, including implant masking steps and top-level interconnects. However, several challenges remain, including the requirement for high-temperature processing and the need to integrate CMOS and SiC-specific processing steps; for example, all metal and dielectric stacks must be compatible with a standard CMOS fab. SiC-specific processes were developed using CMOS production tools for certain steps like contacts, gate oxidation among others. The only steps for which special SiC-specific tools are used are implant activation and certain ion implantation steps. The semi-transparent nature of SiC wafers and the difference in wafer thickness vs. the facility's usual Silicon wafers required modifying or optimizing the mechanical wafer handling procedures for several process steps.

Validating defect density and yield

Despite these challenges, Littelfuse and Monolith are confident of the quality of the SiC wafers we're producing because of

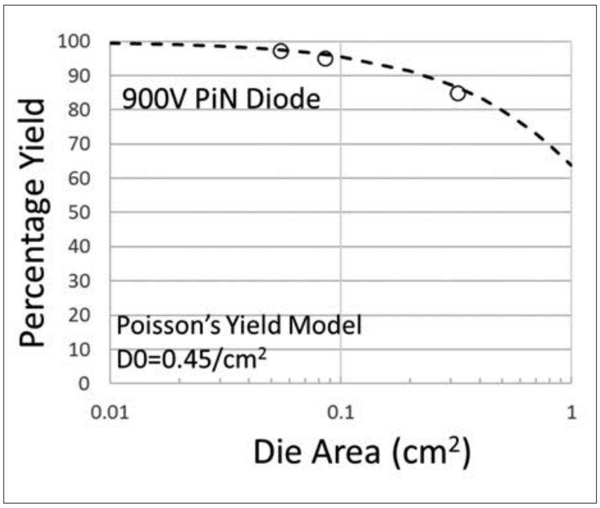


Figure 1: Percentage yield vs. die area for 900 V PiN diodes (yield is modeled using Poisson's model, assuming defect density of 0.45/cm?)

specific testing we've conducted to validate defect density and yield. For example, we designed and fabricated a test chip containing SiC Schottky and large-area PiN diodes with die sizes ranging from 0.054 cm^2 to 0.45 cm^2 on our epitaxial wafers. Wafer level characterization of both the 900 V SiC Schottky diodes and the 900 V PiN diodes was performed on 100 % of the die on all wafers. The yields for the devices of three different die sizes were calculated based on the yields of key electrical parameters: forward voltage (V_F) drop, reverse leakage current at full rated voltage (I_R), and breakdown voltage (V_{BR}).

The percentage yield of the PiN diodes of three different die sizes – 0.32, 0.08, and 0.05 cm^2 is plotted in Figure 1 using the Poisson's Yield model and a good fit is obtained for a defect density assumption of 0.45 defects/cm^2. The decrease in yield for the larger area PiN diodes is primarily due to the impact of starting material defects and process induced defects on I_R or V_{BR}. The Schottky diode yield followed a similar trend, with a slightly larger impact of defects on the yield, particularly for the larger area diodes. This defect level gives approximately a 30 % reduction in yield for an 8x increase in die size.

The high quality of our starting material (epitaxial SiC wafers) and CMOS processing is also reflected in the quality of the 1.2 kV MOSFETs fabricated in the fab. This was demonstrated through long-term reliability testing, in which the devices exhibited no signs of degradation over the entire 1000-hour testing cycle, as shown in Figures 2 and 3.

To illustrate the system-level advantages that power converter designers can achieve using SiC devices rather than Si devices, we have designed and built a 5 kW buck converter, which converts a higher voltage input to a lower voltage output. The operation of the converter with a silicon IGBT and a Littelfuse/Monolith SiC MOSFET was compared head to head. The results, plotted in Figures 4 and 5, illustrate that at 25 kHz, the Si IGBTs were rapidly approaching thermal runaway at the 5 kW power level. Thus, it's safe to assume the Si IGBT could not satisfy any higher power or a higher switching frequency at the 5 kW power level. Additionally, these figures demonstrate superior SiC MOSFET performance in terms of efficiency; even at 25 kHz, which is in the realm of switching frequencies commonly satisfied by Si IGBTs.

These efficiency and temperature characteristic plots demonstrate that SiC MOSFETs are not only capable of offering

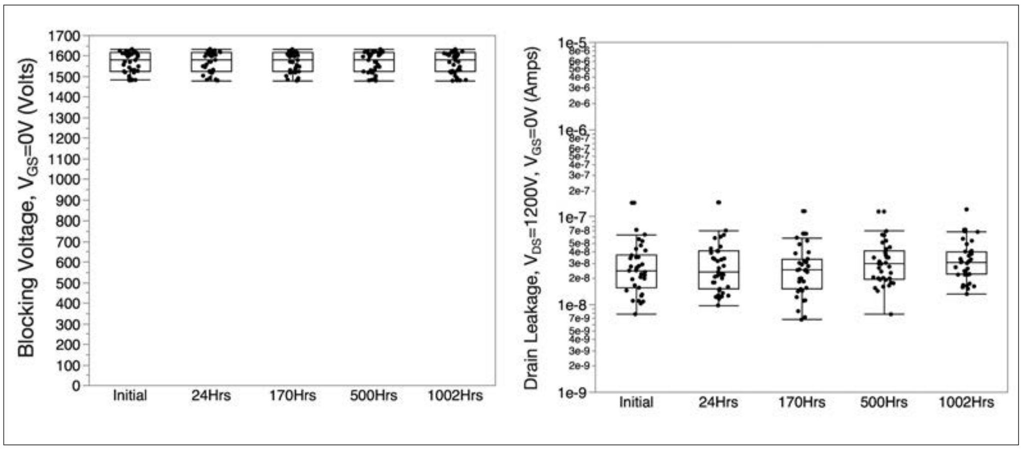


Figure 2: Results of high temperature reverse bias testing at 175°C (breakdown voltage at V_{GS} = 0 V, leakage current at V_{DS} = 960 V)

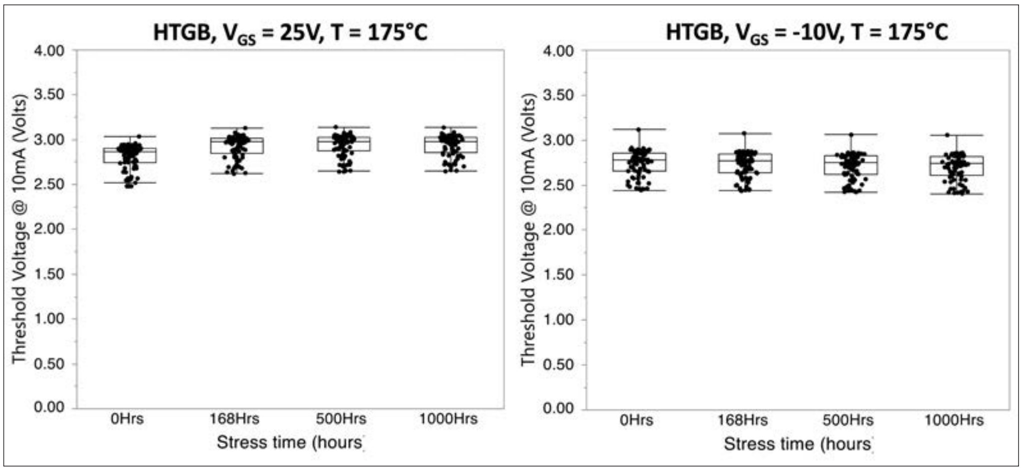
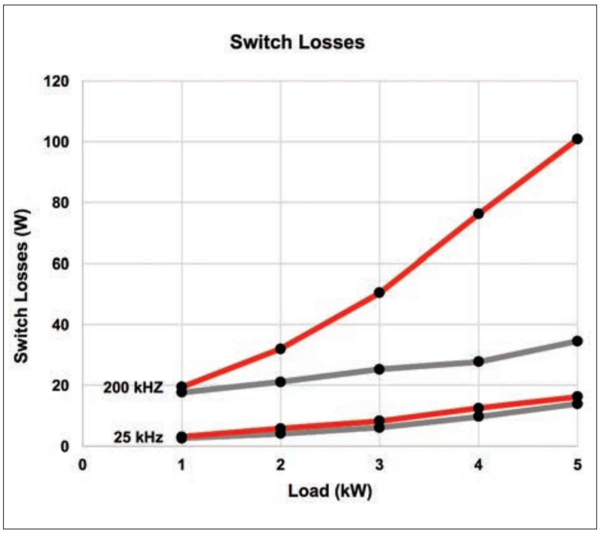


Figure 3: Results of high temperature gate bias (HTGB) testing at 175°C (V_{GS} = -10V and at V_{GS} = +25 V)



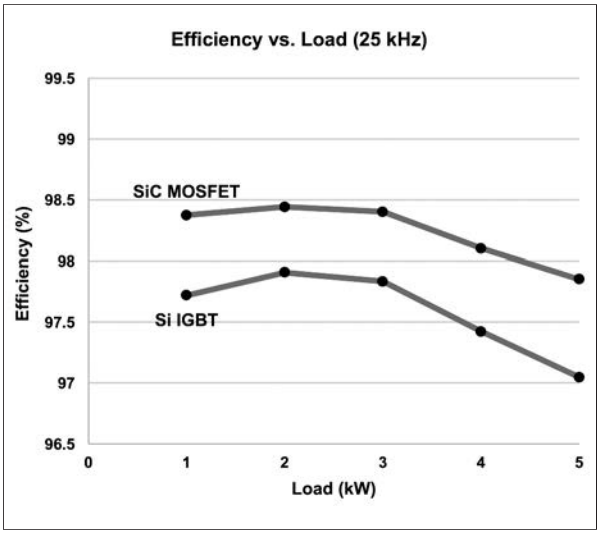
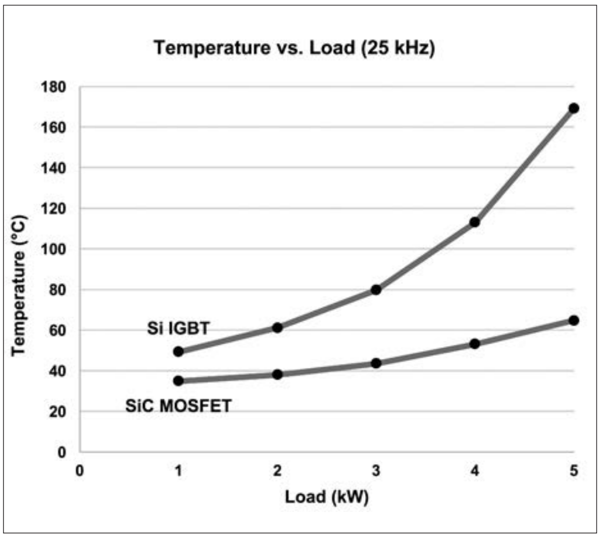


Figure 4: Efficiency vs. load for 25 kHz operating point

Figure 5: Temperature vs. load for 25 kHz operating point



LEFT Figure 6: Switch losses vs. load of simulated converter, showing Si IGBT in red and SiC MOSFET in gray (Note - bench top testing of Si IGBT based converter at 200 kHz is not possible)

improved power density by opening the gateway to higher switching frequencies, but they can also compete with Si IGBTs at lower switching frequencies due to their relatively low on-state resistance. Unlike the IGBT-based converter, the SiC-based converter could also comfortably operate at 200 kHz with >98 % efficiency (Figure 6).

The future of power semiconductors will depend on device producers willing to embrace the core principles of providing their customers with devices designed to enhance speed, agility, and flexibility. For SiC MOSFETs to achieve their full potential in power conversion applications, their producers must be willing to work with designers to encourage exploration of the technology's potential. Thus Littelfuse and Monolith Semiconductor have developed a Dynamic Characterization Platform (DCP) to help designers streamline the incorporation of SiC power devices into their systems.

New tools empower power converter designers

The process of designing a SiC-based power converter can be very different than designing with Si power devices. The Dynamic Characterization Platform (DCP) shown in Figure 7 supports evaluating a SiC MOSFET's switching performance with extreme accuracy on a per-cycle basis using a double-pulse, clamped inductive load (CIL) test. The DCP lets designers extract a full suite of switching characteristics associated with a device, including gate charge, switching times, and switching energies. Switching test waveforms provide insight into device behavior and how designers can implement them into their configurations to optimize performance.

Tomorrow's power semiconductors

Littelfuse has recently introduced 1200 V SiC Schottky diodes and 1200 V, 80 mΩ MOSFETs to the market. In 2018 and beyond, these devices will be scaled to higher current levels, various voltage ratings: 650 V, 900 V and 1700 V, and several discrete package options. We also intend to develop power modules with low parasitic inductance that can take advantage of the faster switching speeds that SiC devices support.

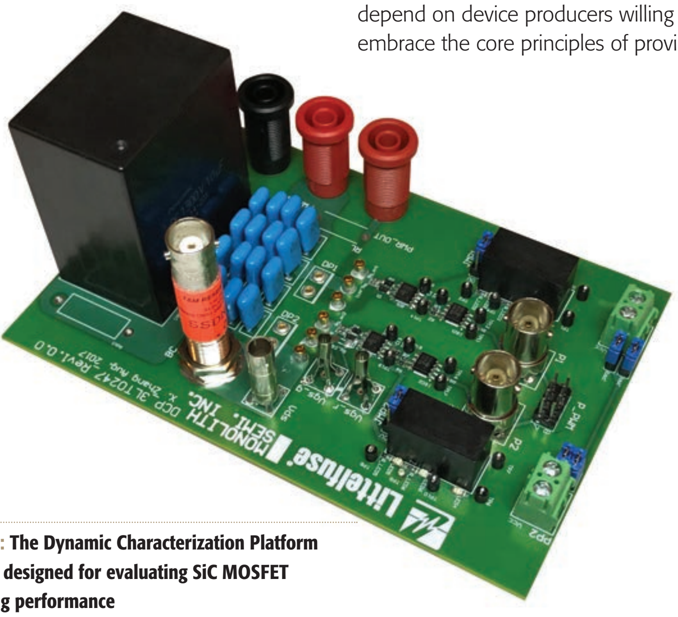


Figure 7: The Dynamic Characterization Platform (DCP) is designed for evaluating SiC MOSFET switching performance

Integrated Power Solution for Smart Lighting

Smart lighting is considered to be the new frontier of the global lighting industry, as the trend of smart homes, Internet of Things (IoT), and a connected world are the main driving factors in global electronics growth. In terms of major applications of the smart lighting concept, the industry is currently more focused on light intensity dimming, lighting color temperature adjustment, ambient sensing, and monitoring. This article will focus on the power solution for smart lighting- in particular smart light bulbs.

Zhihong Yu, AC/DC Product Marketing Manager, Monolithic Power Systems, USA

Government initiatives regarding the installation of the smart lighting system, the popularity and affordability of wireless control, and growing awareness regarding the benefits of smart lighting systems are other key factors boosting the demand for smart lighting solutions globally. According to a 2017 study from Research and Markets, the global smart lighting market is projected to witness a compound annual growth rate of 25.44 % to reach a total market size of $21.2 billion by 2022 from $6.8 billion in 2017 [1]. In the future, smart lighting applications can extend way beyond this range, the smart lighting devices can be used as a hub, integrated as key component of IoT systems and smart home/smart automation networks [2].

Referring to the teardown reports of some of commercially available smart light bulbs (such as Cree Connected Bulb [3] or Philips Hue [4]), the main structure of these bulbs are fairly similar (see Figure 1). A constant-current (CC) LED driver (such as the MPS MP4027) drives the main LEDs in addition to a constant-voltage (CV) buck driver (such as the MPS MP15x and MP17x) and provides either 5 V or 3.3 V to power the Zigbee/Wifi/Bluetooth/other transceiver IC and main microprocessor. The microprocessor in addition to the transceiver IC allows end users to control the lighting remotely using a mobile device. This control module sends a pulse-width modulation (PWM) or other digital signal (such as I²C) to control the dimming of the LED driver.

While this topology seems ideal, this power stage faces two challenges: further minimizing the solution size and further decreasing standby power loss.

A19 and PAR bulb sizes follow industry standards and will not increase. Adding smart lighting functions to normal light bulbs means that the designer must squeeze more electronics into the same space, which is a big challenge, and the space limit may force designers to use fewer LEDs or use less LED power for easier thermal management. Sometimes, designers must adopt customized PCB shapes to fit all required electronics, which add to assembly cost.

Additionally, customers and legislation agencies are gradually noticing the importance of standby power consumption. Designers are expected to design smart lighting devices with super-low standby power to make the product attractive or sellable in certain regions with stringent energy consumption standards. For example, the European CoC Tier2 requires all external power supplies under the 49 W power rating to have a standby loss of no more than 75

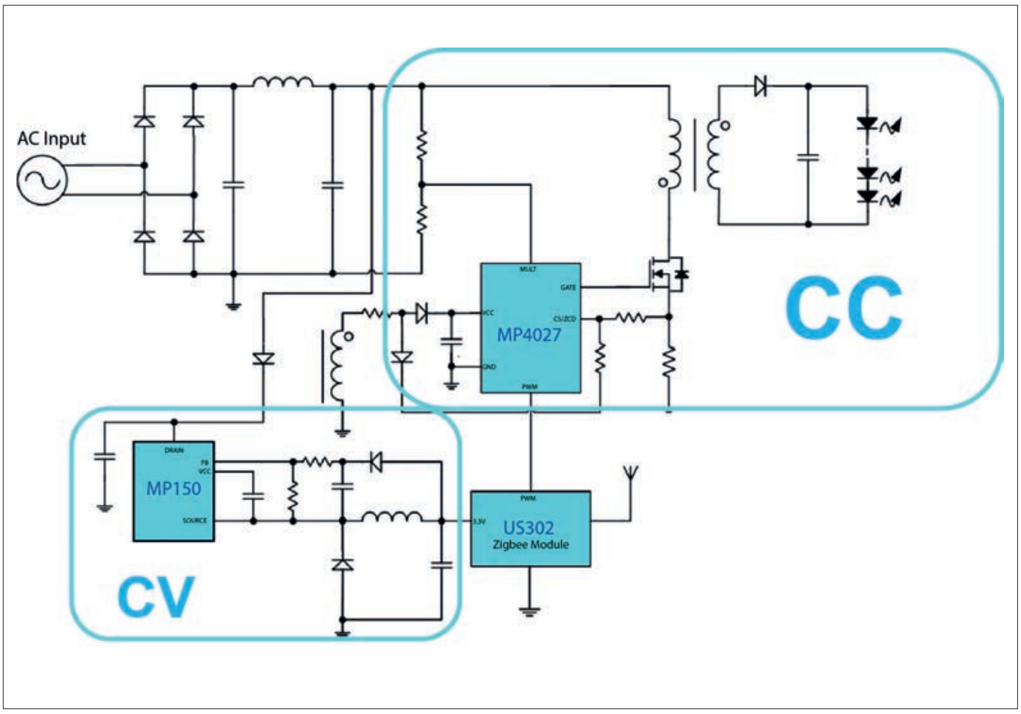


Figure 1: Current popular smart lighting power structure

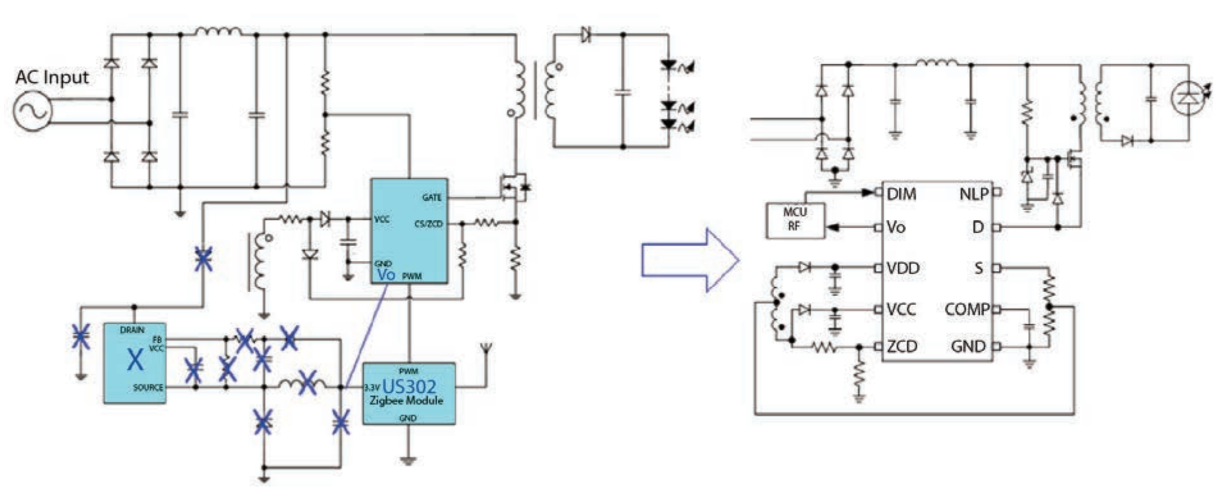


Figure 2: **Transition from existing power stage to new power solution for smart light bulbs**

mW. Smart lighting products are in the same way expected to meet certain energy specs in the near future [5] . Currently, many smart light bulbs have high standby loss due to wireless circuitry power usage, which is inevitable, and therefore the standby loss can only be saved from the power stage.

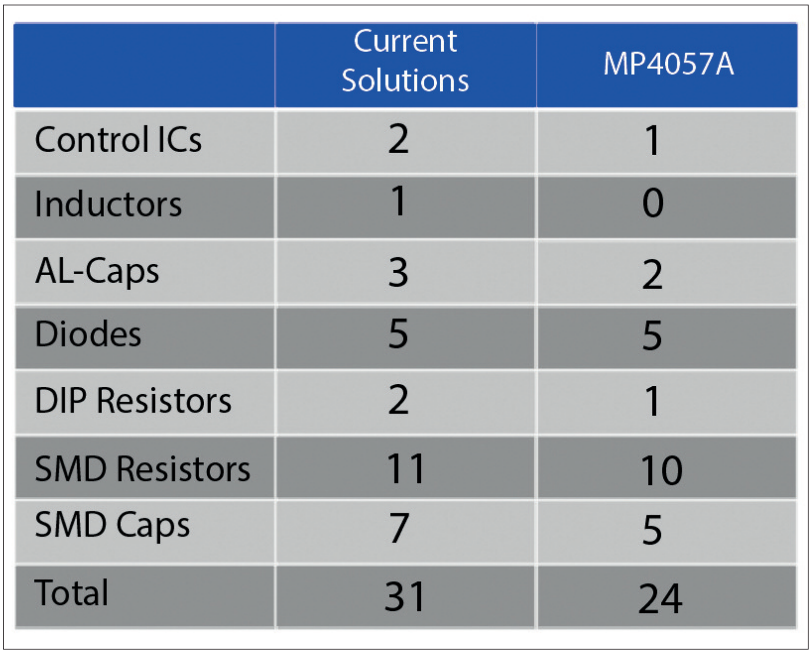
To further shrink the size of smart lighting circuits and lower standby loss, a better integrated total power solution is presented in Figure 2. Here, the CV and CC circuits can be merged into a single-chip solution, shrinking the circuit BOM and standby loss.

By adopting the solution shown in Figure 2, circuit designers can eliminate one control IC, one external inductor, and other resistors and capacitors, cutting PCB space and BOM cost by at least 20 – 30 % in the power section of a smart light bulb (see Figure 3).

Furthermore, this solution can achieve less than 20mW of system standby power since the power section is highly integrated and more IC blocks can be left in the hibernating status at power off with an optimized, minimal operating frequency at no or light load.

The operation mode of the MP4057A is summarized in Figure 4. During start-up, V_{DD} is supplied by the N_Forward winding. Then the IC determines whether it should run in CV mode (to power the MCU only while the LED remains off) or CC mode (to power both the MCU and LED) by monitoring the DIM pin, which is controlled by the MCU itself.

During CV mode (DIM pin is low), V_{CC} acts as the supply to the IC. The ratio of N_flyback and Ns winding can be adjusted so the LED will not light up in CV mode. There is also a smart frequency modulation algorithm implemented to ensure low standby power and fast transient response to LED load changes, as



	Current Solutions	MP4057A
Control ICs	2	1
Inductors	1	0
AL-Caps	3	2
Diodes	5	5
DIP Resistors	2	1
SMD Resistors	11	10
SMD Caps	7	5
Total	31	24

Figure 3: **BOM comparisons between existing power stage and new power solution**

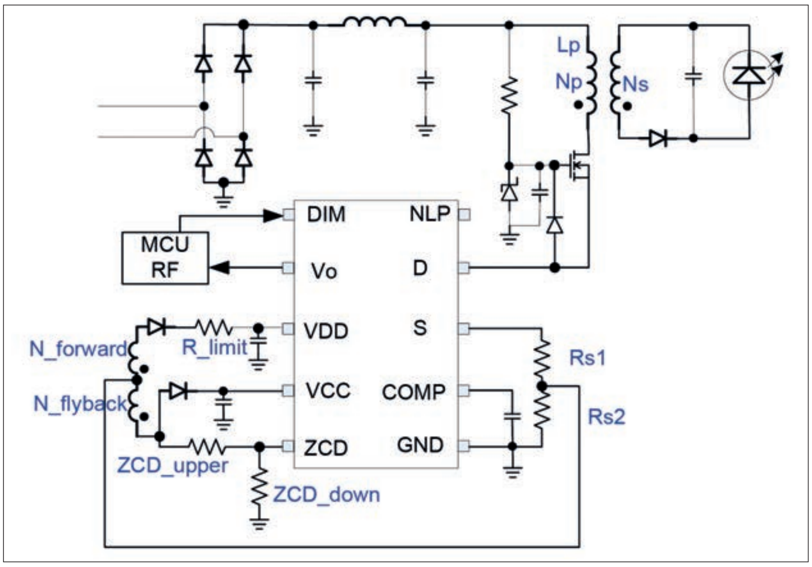


Figure 4: **Control method reference**

well as ensuring there is no voltage drop at the MCU power, and no LED flickering during CV/CC transition.

If DIM senses the PWM signal from the MCU to control dimming, then the IC enters CC mode. The feedback voltage is modulated by reading DIM to modify the LED current based on the DIM duty cycle while keeping the CV output constant. As under CC mode, the MCU Vo pin must also be high enough, hence the IC is limited to a 5 % minimal LED dimming depth to provide enough voltage to drive the MCU. The V_o power loop is decoupled from the main LED current loop by setting the ratio of current sense resistors (Rs1 and Rs2).

For LED current control, this solution implements a constant on-time (COT) control method, which also guarantees a high power factor. The on/off transition occurs during valley switching (by sensing through a zero-current detection (ZCD) pin) to eliminate turn-on loss and diode reverse-recovery loss, which is also referred to as transition mode control. The IC also includes other features, such as minimum off time (to improve EMI), leading-edge blanking, over-voltage protection (OVP), over-current protection (OCP), over-temperature protection (OTP), and more.

Figure 5 shows LED load efficiency and power factor performance, and Figure 6 shows a very linear PWM dimming performance. Figure 7 shows an 8W reference design circuit board suitable for all kinds of PAR lamps. For ordering information, MP4057A offers 3.3 V for MCU power, while MP4057B offers 5 V.

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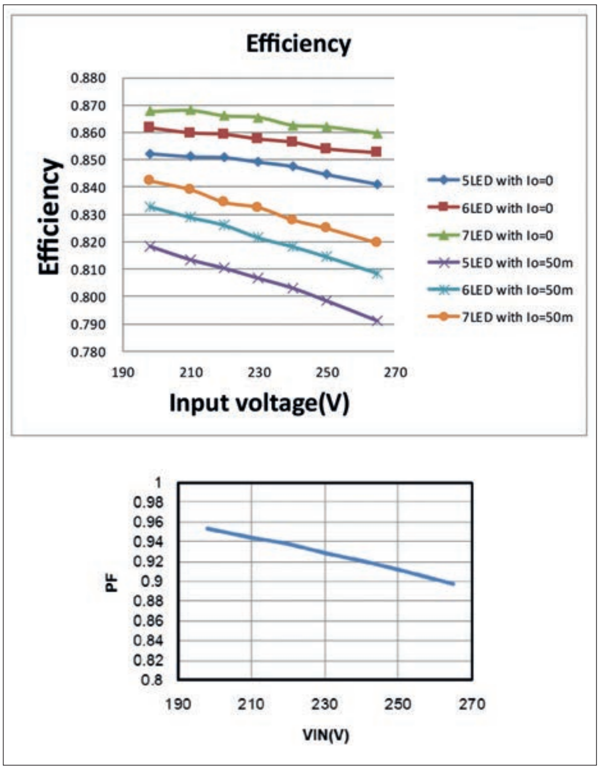
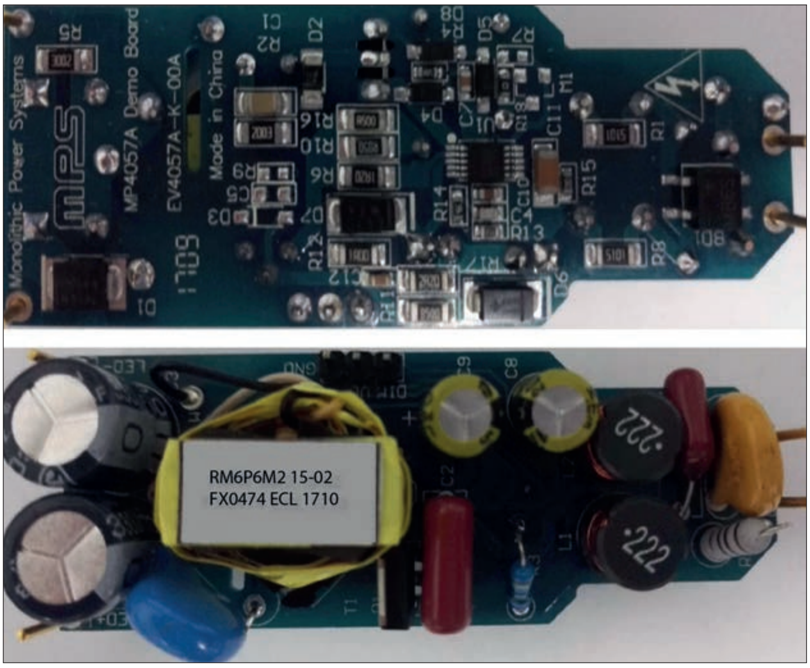


LEFT Figure 5: LED load efficiency and typical power factor

LEFT Figure 6: PWM dimming ratio



LEFT Figure 7: Evaluation Board EV4057A-K-00A: (L x W x H) 66 mm x 25 mm x 15 mm; 230 VAC/50 Hz Input, Isolated Flyback Converter, V_{LED} = 21V, I_{LED} = 0.37 A, V_o = 3.3 V, I_o = 50 mA

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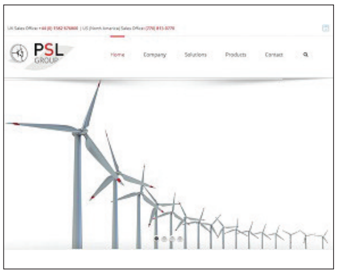

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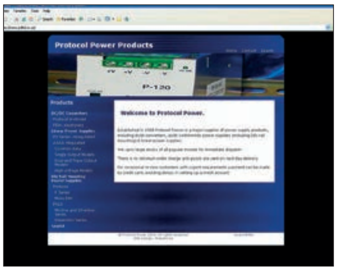

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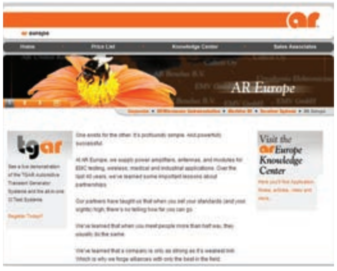

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