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SILICON CARBIDE

IEGT Plus SiC - A Hybrid Approach to Inverter Efficiency and Performance Improvement

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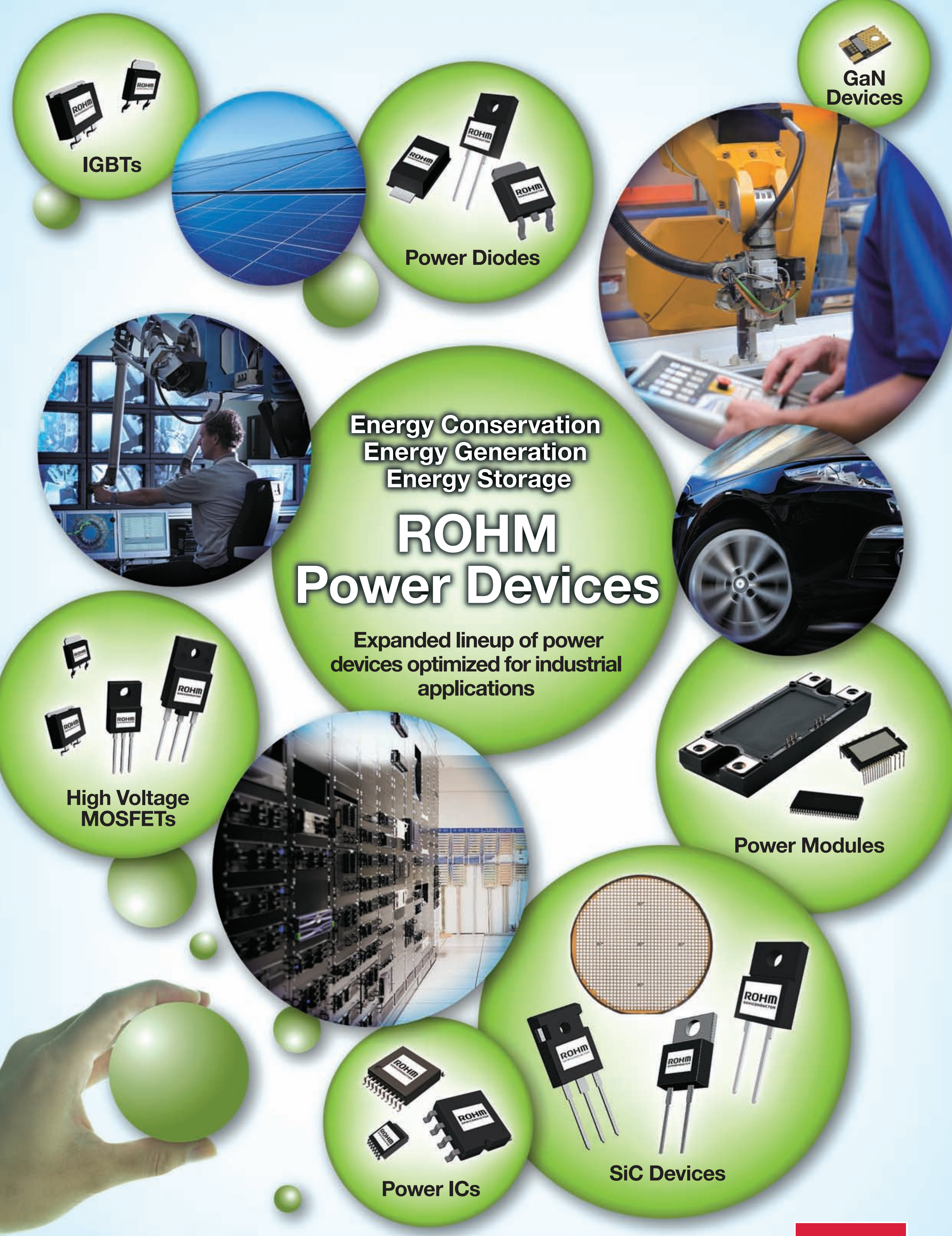
Also inside this issue



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COVER STORY

IEGT Plus SiC - A Hybrid Approach to Inverter Efficiency and Performance Improvement

Toshiba Electronics Europe now offers a hybrid N-channel IEGT (Injection-Enhanced Gate Transistor) module that features an embedded Silicon Carbide (SiC) fast recovery diode (FRD). The high-efficiency PMI (Plastic case Module IEGT) will help designers to save energy, space and weight in high-power switching, inverter and motor control applications. Rated at 1700 V/1200 A, the half-bridge MG1200V2YS71 is intended for switching applications in industrial, rail traction, renewable energy and electricity transmission and distribution systems. The module incorporates two IEGTs, each with its own embedded SiC diode. Use of a SiC diode leads to a significant decrease in reverse recovery current and a corresponding decrease in turn-on loss. As a result the new PMI offers a reverse recovery loss up to 97 % lower than a module with a conventional Silicon diode. This improvement in efficiency allows for smaller cooling efforts and overall equipment size.
Full story on page 14.

Alternative to Silicon?

Silicon Carbide is now commonly accepted as a reliable and pertinent alternative to the Silicon world. Most power module and power inverter manufacturers have already included it in their roadmap as an option or as a firm project. However time-to-market differs from application to application. Despite a quite depressed market last year, PV inverters have proven their appetite for SiC devices in 2012. They are the biggest consumer of SiC devices together with PFCs. In 2011 and 2012 SiC diode business was the most buoyancy due to microinverter applications, but according to market research both JFET and MOSFET will quickly catch-up and become dominant in revenue by 2016. SiC device (bare-dies or packaged discretes) market reached about $75 million in 2012 with a sharp domination by Infineon and CREE, however the competition is little by little grabbing market share with STMicroelectronics and ROHM closing the loop. Most recently Ixys and Toshiba entered the market with SiC diodes.

We have reported on the achievements in SiC and also GaN extensively, but at every conference progress can be noted. AT EPE ECCE 2013 early September in Lille Virginia Tech presented a paper comparing the static and dynamic characterizations results of various SiC devices for temperatures ranging from 25 to 200°C. Specifically, commercial and sample transistors from Cree, GE, ROHM, Fairchild, GeneSiC, Infineon, and SemiSouth (disappered from the market) were tested. The results showed that the ROHM SiC MOSFET and Infineon SiC normally-on JFET had the highest specific on-resistances (based on the total die area), while the Fairchild SiC BJT experienced the lowest. The on-resistance of the BJT also proved to have the weakest temperature dependence. Regarding the dynamic characterization results, SemiSouth's SiC normally-off JFET showed the lowest total switching energy losses when plotted against load current, that's why this device was referenced in various PV inverter prototypes.

The PEMC group of the University of Nottingham presented results of SiC Power MOSFETs in PV inverters. In particular, their stable performance against switching frequency and temperature enables high flexibility in overall system design, trading off between efficiency and power density requirements and goals. The results of the benchmarking exercise between an all SiC and a mixed Si/SiC solution indicates that use of a mixed SiC and Si solution, with IGBTs and Schottky diodes as the bi-directional switch, is competitive in performance to that of a fully SiC Power MOSFET based on relatively low heat-sink temperatures and switching frequencies, with severe limitations on design flexibility and optimization at system level. Also, the results point out interest in the availability of SiC power MOSFETs in voltage classes lower than 1.2 kV, too, for the needs of bi-directional switched neutral-point-clamped (BSNPC) three level inverter, in which, for the first time, SiC Power MOSFETs of different voltage ratings (1200 and 600 V) are used. Indeed, here, if reference is made to a comparison of 600 V IGBT with Schottky diodes against 600V SiC MOSFETs alone, the additional cost burden due to SiC as opposed to Si can be realistically estimated to be a factor 2 to 3 (keeping in mind that IGBTs require a higher current rating diode, as discussed above) for the implementation of the bi-directional switch. Such cost difference is readily compensated mainly by an increase of the switching frequency which enables a significant reduction of the output filter inductor value.

One of the main benefits of SiC devices is their high temperature operating capability which makes them very attractive for power electronics solutions with operating junction temperature above 180°C The package of a conventional power module represents one of the main bottlenecks to fully exploit the high temperature capability of the SiC devices. A first step to operate at high temperatures is improved reliability of the ceramic substrate and die attach at elevated temperatures. Thus ABB assessed selected materials and assembly technologies for power modules with the capability to operate at high temperatures. According to the research Si3N4/Cu ceramic substrates showed the best robustness against aggressive liquid-liquid thermal shock cycling in the interval of -50°C to 190°C. No delamination of Cu-metallization was observed after 2500 cycles and only a very small increase of the surface roughness was detected. A sintered SiC die attach was also without typical edge delamination up to tested 1500 cycles. AlN/Al DBA and AMB substrates were less robust against cycling compared to Si3N4/Cu substrates. On the other hand only very weak delamination of the sintered chips was observed despite a significant increase of the surface roughness.

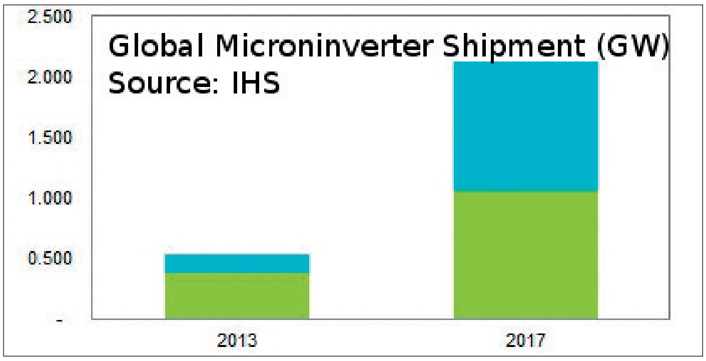
Bosch gave a paper which for the first time the interactions of a copper metallization with a SiC device analyzed and optimized with respect to an interconnection via copper wire bonds. In this aspect a multilayer structure with an AlSiCu adhesion promoter and a TiN diffusion barrier as well as a 23 μm thick electroplated copper layer, showed the best performance in the peel-tests, in the bonding test as well as in the passive temperature cycles. Long time annealing experiments at 250°C indicate only very slow reactions between the copper and the SiC device, which generally proves reliable application of the SiC semiconductor with a Cu-metallization at temperatures up to 250°C. With respect to the temperature storage and passive temperature cycles, no significant degradation of the Cu wire-bond connection could be measured. A copper metallization together with copper wire bond connections are a very promising interconnection technology for improving the lifetime and enabling higher junction-temperatures of SiC devices up to 250°C.

Thus SiC could become an alternative to Silicon, but as always the Silicon empire strikes back!

In this issue some achievements in SiC are presented. Enjoy reading!

Achim Scharf
PEE Editor

Solar Industry Set to Rebound



The sun is finally rising on the global solar business, with growing demand in developing regions helping to ignite the first increase in industry-wide capital spending in 2014, according to market researcher IHS.

Global capital spending by producers of PV modules, cells, ingots, wafers and polysilicon is expected to rise by 30 % in 2014 to reach $3.0 billion. This will mark the first time that expenditures have increased since 2011, when they grew 8 %. The projected growth will bring to an end a two-year period when spending dropped by a stunning 72 % in 2012, and by an anticipated 36 % this year. During this period, PV industry capital spending will plunge by a gut-wrenching total of $10.6 billion, falling to $2.3 billion in 2013, down from $12.9 billion in 2011. Spending has fallen in recent years because of massive overcapacity and oversupply, which has sent prices down throughout the supply chain. However, a sustained increase in capacity from emerging economies is set to spur the 2014 recovery. Current and potential trade conflicts concerning Chinese PV products could drive production to other locations, such as South America, Southeast Asia, Africa and the United States.

More important for power electronics - the global market for microinverters will expand by a factor of 4 from 2013 through 2017 as microinverters are adopted in greater numbers outside the United States while new markets also rush to take advantage of the devices' improved efficiency and features compared to conventional inverters. Microinverters can increase the energy harvest of a system compared to conventional string or central inverter devices, which convert power from multiple solar panels.

While 2013 is forecast to be the first year that microinverter shipments grow to more than 500 MW, it also will be a challenging year for suppliers in terms of competition and pricing. Enphase Energy retained its position as the world's dominant microinverter supplier in 2012 with a large share of the residential PV market in the United States. "A number of new market entrants are releasing products, including the two largest PV inverter manufacturers, SMA and Power-One. This

intensifying competition will result in microinverter prices dropping by 16 percent in 2013. Despite this double-digit price decrease, strong shipment growth will drive microinverter market revenue to increase to more than $250 million in 2013. And although prices will continue to fall in the coming years, IHS predicts that revenue will reach $700 million in 2017", PV market analyst Cormac Gilligan commented.

A new trend for suppliers is to offer complete solar modules that integrate microinverters, products known as "AC modules." Some microinverter makers are partnering with module suppliers to produce these devices. SolarBridge Technologies and Enecsys Ltd. are some of the major suppliers now offering AC modules, and these companies have entered into a number of partnerships with module suppliers. "AC modules allow module suppliers to differentiate themselves from the competition while allowing microinverter makers to take advantage of the module suppliers' sales channels," Gilligan noted. "They also allow faster installation time as the microinverter is installed at the module factory rather than on-site, which can be a compelling reason for the adoption of microinverters". IHS predicts that AC module shipments will more than quadruple in 2013 and continue growing to account for 32 percent of total global shipments in 2017.

www.ihs.com

SiC Market Accelarates

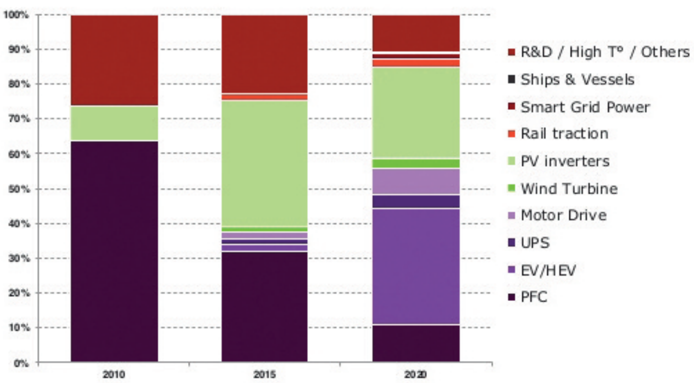
Started late in 2011, the power electronics downturn in 2012 was quite severe, exhibiting -20 % negative growth. The market suffered from the global economic downturn combined with external factors like China controlling what happened in some selected markets (Wind turbine or Rail traction projects that have been stopped or postponed). However, the SiC device market kept on growing with a +38% increase year to year.

SiC technology is now commonly accepted as a reliable and pertinent alternative to the Silicon world. Most power module and power inverter manufacturers have already included it in their roadmap as an option or as a firm project. However time-to-market differs from application to application. Despite a quite depressed market last year, PV inverters have proven their appetite for SiC devices in 2012. They are the biggest consumer of SiC devices together with PFCs.

In 2011 and 2012 SiC diode business was the most buoyancy due to microinverter applications, however Yole Développement is confident that both JFET and MOSFET will quickly catch-up and become dominant in revenue by 2016. SiC device (bare-dies or packaged discretes) market reached about $75 million in 2012 with a sharp domination by Infineon and

Distribution of SiC devices market over time for main applications: PV inverter will dominate by 2015

(Source: SiC Market 2013: Technology and Market for SiC Wafers, Devices and Power Modules report, May 2013, Yole Développement)



CREE again, however the competition is little by little grabbing market share with STMicroelectronics and Rohm closing the loop.

There are now more than 30 companies worldwide which have established a dedicated SiC device manufacturing capability with related commercial and promotion activities. Virtually, all other existing Silicon-based power device makers are also more or less active in the SiC market but at different stages. 2012 has seen the ramp-up of some companies, such as Rohm, MicroSemi, GeneSiC or STMicro, facing the giants CREE and Infineon, prefiguring a new market shaping in the coming years. Four new companies - Raytheon, Ascatron, IBS and Fraunhofer IISB - have decided, almost simultaneously, to launch SiC foundry services or contract manufacturing services. This business model establishment addresses the demand of future SiC fabless and design houses that may look for specific manufacturing partners. It will also probably act as a possible second source for IDMs in cases of production overshoot. Power device integrators generally rely on two, or even three sources to lower supply-chain risks. In SiC, it is now easy operating multisourcing for diodes, though not yet for transistors.

Yole Développement now sees the SiC industry reshaping, starting from a discrete device business and now mutating into a power module business. Originally, this was initiated by Powerex, MicroSemi, Vincotech or GeneSiC and recently Toshiba with hybrid Si/SiC products, then other players such as Mitsubishi, GPE, Rohm and more recently Cree have reached the market with full-SiC modules. This trend will become dominant in the coming years as integrators require power modules in most of their mid and high power systems (generally starting from >3kW). Yole Développement forecasts that SiC-based power module demand could exceed $100 million by 2015 and top ~$800 million in 2020 depending on whether or not the automotive industry will adopt SiC.

In Asia, Panasonic and Toshiba are now clearly identified as credible contenders, along with Mitsubishi Electric, now developing SiC power modules. Fuji Electric's new SiC line is now running within the Japanese national program. No Chinese device maker has emerged yet, however, according to the huge investment plan in R&D, Yole Développement suspects new IDMs will soon enter the business. In the US, Global Power Device and USCi have now exited stealth mode and have strongly affirmed their intentions to take market share.

www.yole.fr

SiC MOSFETs in Power Supplies

CREE announced that its expanded portfolio of 1200 V SiC MOSFETs are being incorporated into the latest power supplies from Delta Elektronika BV. Since 1959, the Netherlands-based company has been a leader in producing highly reliable, high-quality power supplies for a range of industrial applications, such as specialized equipment used in factories, automation and industrial power conversion. Its power supplies typically provide high efficiency with low noise levels and are well known for their long operating lifespan.

By using SiC MOSFETs Delta Elektronika demonstrated a 21 % decrease in overall power supply losses and a reduction in component count by up to 45 % when compared to power supply products using traditional Silicon technology. "The new SiC transistor improves both the efficiency and power density of our products. The switching behavior is outstanding and controlling the SiC MOSFET is simple and straightforward", said Job Koopmann, director of Delta Elektronika BV. Introduced in March 2013, Cree's second-generation SiC MOSFETs have been well received throughout the power industry and are experiencing an increasing rate of adoption in several key applications, including a design-in at a major manufactureris next-generation, highly efficient PV inverters.

www.cree.com/power

Cree Licenses GaN Device Patents to Transphorm

Cree has licensed its extensive family of patents related to GaN high electron mobility transistor (HEMT) and GaN Schottky diode devices to Transphorm for use in the field of power conversion devices. The licensed family of patents addresses various aspects of making GaN power devices including nitride materials, HEMT and Schottky diode designs and processing technology. While GaN HEMTs are already used extensively in RF markets by Cree and others, their use in power conversion markets has been targeted by Transphorm and a number of other companies. "Over the last 17 years, Cree has invented technology that enabled the successful introduction of reliable GaN HEMT devices in the RF market. Many of these inventions can and are expected to be used by others to manufacture devices in the burgeoning area of GaN power management systems", stated John Palmour, Cree CTO, Power & RF and one of Cree's co-founders.

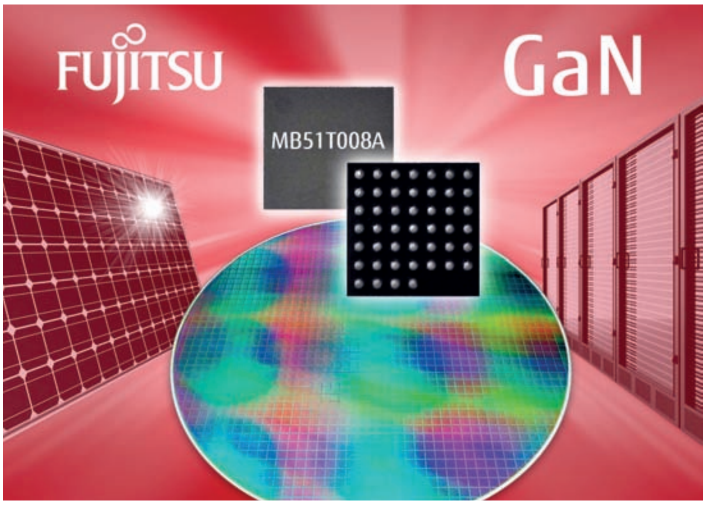
www.cree.com, www.transphormusa.com

"Our RF GaN HEMT technology can be used by others in power", Cree's John Palmour expects Photo: AS

Fujitsu Samples 150V GaN Power Devices

Fujitsu Semiconductor Europe (FSEU) announced the release of MB51T008A, a Silicon substrate-based GaN power device that features a breakdown voltage of 150 V. The new device, which enables normally-off operations, is capable of achieving roughly one half the figure of merit (FOM) of silicon-based power devices with an equivalent breakdown voltage.These GaN power devices are based on the High Electron Mobility Transistor (HEMT) technology, which Fujitsu Laboratories has led the development since the 1980s.

The MB51T008A has a number of advantages, including on-state resistance of 13 mΩ and total gate charge of 16 nC, which enables roughly half the FOM of Silicon-based power devices with an equivalent breakdown voltage. It is characterised by minimal parasitic inductance and high-frequency operations through the use of WLCSP packaging; and a proprietary gate design that enables normally-off operations. The new device is ideal for high-side switches and low-side switches in DC-DC converters employed in power supplies for data communications equipment, industrial products, and automobiles. In addition, because it supports a higher switching frequency in power supply circuits, power supplies can achieve improvements in overall size and efficiency.



Fujitsu Semiconductor is also developing models with breakdown voltages of 600 V and 30 V, thereby helping to enable enhanced power efficiency in a wide range of product areas.

http://emea.fujitsu.com/semiconductor

LTspice IV Simulator Application Handbook

LTspice IV is an outstanding software application for its power, its calculation speed and the universality of its applications. This software can be used to produce high performance electronics where demand for quality must go hand in hand with fast development.

Unfortunately, the electronic Help file is the only documentation available. It is incomplete and far behind the development of the software. This book was designed to fill this gap. The work, with a preface from Mike Engelhardt, is both a learning manual and a collection of applications detailing numerous procedures. With more than 470 illustrations and many examples, it is a efficient tool for mastering the power and richness of LTspcie IV. The author Gilles Brocard has written this work providing detailed responses to the questions he has been asked the most frequently during the training sessions he presents. Advanced users can start reading from Chapter 4 (Schematic editor); the beginner should start with Chapter 2, which explores the many files supplied during the installation of LTspice IV. The novice user can then focus on the application developed in Chapter 3. It demonstrates the main operation principles of LTspice IV. The five main editors of LTspice IV are explained in Chapters 4 to 8. This is where the explanation of the running of the software begins.

This work is intended for all electronics engineers who need to train themselves or deepen their mastery of LTsipce IV, regardless of whether they are professionals in engineering firms or industry, teachers, students or engineering students. Order form, free extracts and index are available on **www.we-online.com/ltspice-book**

Maxim Acquires Volterra

Maxim Integrated Products announced it will acquire Volterra Semiconductor Corp., the transaction value is approximately $450 million net of Volterra's cash position of approximately $155 million.

Volterra is an industry leader in high-current, high-performance, and high-density power management solutions. The company develops highly integrated solutions primarily for the enterprise, cloud computing, communications, and networking markets.

"With Volterra, we will strengthen our position in the enterprise and communications markets," said Tunç Doluca, Maxim's CEO. "We add a very talented team and leading-edge proprietary technology in high-current power management solutions, which further diversifies our business model." At $9 billion, power management is currently the largest and fastest-growing product segment in the analog market, according to Databeans. Maxim offers a broad portfolio of products for power conversion: switching regulators, linear regulators, charge pumps, digital Point-of-Load (POL) converters, and Power Management Integrated Circuits (PMICs), primarily in medium-to-low current applications. Volterra's high-current technology shall expands Maxim's position in this growing segment of the analog market.

www.maximintegrated.com

Simulation Tool for Power Designers

Intersil introduced the version 7.0 of its popular iSIM™ personal edition circuit simulation design tool, adding time saving features and further simplifying part selection for power and analog IC designers.

Intersil's iSim:PE v7.0 speeds the design cycle by identifying parts that can be used in current as well as next-generation designs. The tool selects devices to support increasing power densities, wide input-voltage and temperature ranges, maximum efficiency, fast transient response and other

specifications. Simulated designs are displayed in an online schematic and can be verified immediately. After verification, iSim generates a Bill of Materials (BOM) and a comprehensive design report. New to this release is a tool to quickly search, review and select MOSFETS or diodes based on design requirements, letting users filter and sort from all available devices. A new feature allows designers to add jumpers, enabling easily switching between different circuit configurations. Jumpers are electrically modeled as opens or shorts and are compatible with SIMPLIS® for power management parts and SIMetrix™ for analog ICs. The new iSim:PEv7.0 is available free-of-charge from Intersil at **www.intersil.com/iSim**

New Management at SEMIKRON

The SEMIKRON group has taken a further step in the realignment of its top management, as part of which Peter Sontheimer has been appointed as a new member of the SEMIKRON Management Board starting November 2013.

The 45-year-old has held various management positions at Vincotech over the last 16 years and his many years of industrial experience have made him an expert in power electronics. Along with Harald Jaeger (Operations and R&D) and Thomas Dippold (Finance and Central Functions) he will be responsible for Sales, Product Management and Marketing. Peter Frey has resigned from the SEMIKRON Management Board and will be leaving the company at the end of the year to pursue new opportunities. As a graduate electrical engineer, he has held various leadership positions at SEMIKRON over the course of his 22 years with the group and has been Managing Director of SEMIKRON International GmbH in Nuremberg since 2005.

www.semikron.com

Third Conference/Expo on Electric Drives Production

Increasing power consumption, CO2 reduction, growing mobility or progressing automation – none of these future megatrends are possible without powerful electric drives. The electrification of the automobile powertrain is considered crucial, as the whole sector is facing difficulties resulting from the substitution of the conventional combustion engine. Besides advancing ideas on the design of powerful electric drives, the organization of the manufacturing processes and systems is of great importance.

The third International Electric Drives Production Conference (E|DPC) from October 28 – 30 at Nuremberg Fairgrounds offers an outstanding platform for the exchange of experiences for developers, researchers and potential users.

The conference offers on two days more than 80 technical papers in total of eight tracks: four of them concentrate on the core topics of electric drives production technologies, materials and systems. The focus of the globally accompanying conference on Energy Transfer in Electric Vehicles (E|TEV) is set on the technology of wireless power transmission. For the first time the Energy Storage Production Conference (E|SPC) opens up new ideas and synergies at the same occasion. And the conference is hosting the well established VDMA (German Association of Machine Tool Maker) symposium e-motiv.

The focus of the conference is set on the presentation of highly innovative products from various industries as well as manufacturing processes and strategies. Following the conference, there will be an industrial exhibition, tutorials, a poster presentation, technical tours and an accompanying program. The exhibition covers the entire process chain right through to the production of electric drives. It showcases all components and materials as well as production processes and systems. The event will appeal to engine manufacturers, looking to strengthen their market position whether based on cost, quality or innovation, as well as to car manufacturers and suppliers, who want to systematically plan their entry into electromobility. Producers of electric machines and electro-mechanic products receive comprehensive information regarding the production of electric drives.

www.edpc.eu

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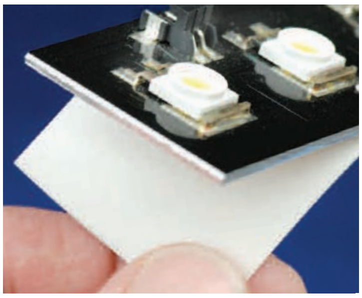

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IEGT Plus SiC - A Hybrid Approach to Inverter Efficiency and Performance Improvement

Silicon Carbide devices have the potential to unlock significant performance and efficiency improvements in applications ranging from rail traction to renewable energy generation. Now, the introduction of hybrid technologies that combine these performance and efficiency advantages with the high-power handling capabilities of Silicon Injection-Enhanced Gate Transistors (IEGTs) is providing engineers with an effective way of significantly reducing losses while minimizing equipment size.

Dr. Georges Tchouangue, Chief Engineer Power Semiconductors, Toshiba Electronics Europe, Düsseldorf, Germany

Improving the efficiency of large motor drives used for applications such as rail traction or heavy industries like steel rolling, even by only a small percentage, can save a significant quantity of energy normally wasted as heat. This can translate into positive benefits for business operating costs, equipment design and performance, and carbon footprint. High-power semiconductors have made tremendous advances in recent years, as new device architectures, fabrication processes and technologies have helped to improve both switching and conduction efficiency.

In order to meet wider system requirements such as reliability and overall cost, designers of high-power drives such as choppers and inverters are typically faced with a choice of a thyristor or Insulated Gate Bipolar Transistor (IGBT) as the main switching element. Both device types have strengths and weaknesses, which force designers to make a selection that will deliver the best compromise in relation to a given application.

Power switch performance

Generally, thyristors have a low forward voltage, resulting in low conduction losses, but can require more complicated commutation circuitry to turn the device off. The Gate Turn Off (GTO) thyristor overcomes this reliance on commutation circuitry, although switching efficiency remains lower than that of an IGBT.

The IGBT combines the advantage of a voltage-controlled Metal-Oxide Semiconductor (MOS) gate, which allows relatively simple gate-drive circuitry, with the low saturation voltage of a bipolar transistor. Its ability to support high switching frequencies allows the use of smaller capacitive and inductive components. The IGBT also has a large Safe Operating Area (SOA), which helps enhance safety and reliability. The one drawback of the IGBT is its relatively high saturation voltage, compared to the thyristor's low forward voltage, resulting in higher conduction losses which can impair overall energy efficiency.

Injection Enhancement Gate Transistors

In recent years we have seen the development of the Injection Enhancement Gate Transistor (IEGT). These combine the ease of use, support for high switching speeds, and large SOA of the IGBT with high conduction efficiency normally associated with a thyristor–based design.

The IEGT is a high-power trench MOS gate device that behaves in the same way as an IGBT, yet has a low saturation voltage comparable to the forward voltage of a thyristor. The thyristor's low forward voltage is the product of high carrier concentration resulting from the injection of electrons at both the anode and the cathode. In contrast, the conduction performance of a conventional IGBT is governed by the movement of holes from the collector to the emitter resulting in a relatively low carrier concentration at the emitter side.

The IEGT process, combined with an optimized gate structure and distance between electrodes, overcomes this limitation of the IGBT by creating a high

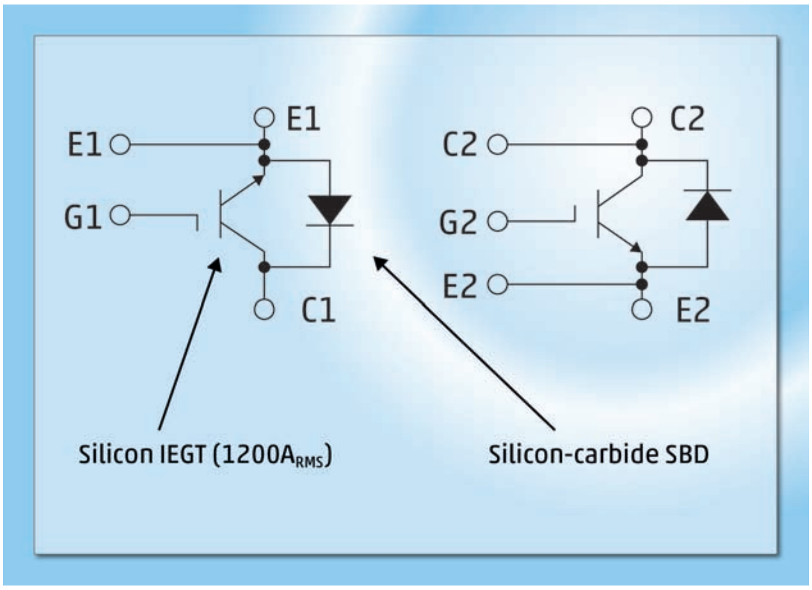


Figure 1: Latest-generation hybrid Silicon-IEGT/SiC-SBD half-bridge module

carrier concentration similar to that of a thyristor, allowing the saturation voltage to be much lower than a conventional IGBT and comparable to the forward voltage of the thyristor. The blocking voltage is also higher than that of an IGBT, and similar to that of a thyristor.

Diode reverse recovery

In half-bridge motor drivers and other power-conversion applications where anti-parallel diodes are connected to conduct freewheeling currents, the reverse-recovery characteristic of the diode has an important effect on the operating efficiency of the circuit. When conducting freewheeling current, the diode stores charge as minority carriers that contribute to minimizing the diode forward voltage. When the diode is commutated, this stored charge must be neutralized by recombination and reverse-current flow before the diode can behave as if turned off. This process of reverse recovery contributes a proportion of system energy losses. To minimize these losses, equipment designers have typically used ultrafast or hyperfast silicon Fast-Recovery Diodes (FRDs) that have the shortest possible recovery time. In many cases these FRDs are integrated within the power module – Toshiba, for example, has introduced a variety of IEGT modules with integrated FRDs. These cover voltage and current ratings up to 3.3 kV and 400 A, 800 A or 1200 A and are available in 140 mm x 130 mm or 140 mm x 190 mm packages.

Next-generation IEGT/SiC power module

To further enhance the efficiency of high-power IEGT modules, Toshiba has introduced its latest-generation IEGT modules with integrated Silicon carbide (SiC) Schottky Barrier Diodes (SBDs). Figure 1 shows the connections and internal circuit of the module.

As a wide bandgap semiconductor technology, SiC allows greater efficiency and reliability than conventional Silicon devices such as fast-recovery diodes. So far, a relatively small number of manufacturers have successfully brought SiC products to market. SiC-SBDs are effective replacements for Silicon diodes for power conversion and switching across a wide range of power ratings and commercial applications. They can offer as much as 50 % greater efficiency than conventional Silicon diodes, and also offer improved stability up to high voltages and currents owing to reduced heat generation. Toshiba has introduced a number of discrete high-voltage SiC-SBDs, such as the 650 V TRS12E65C launched in March 2013.

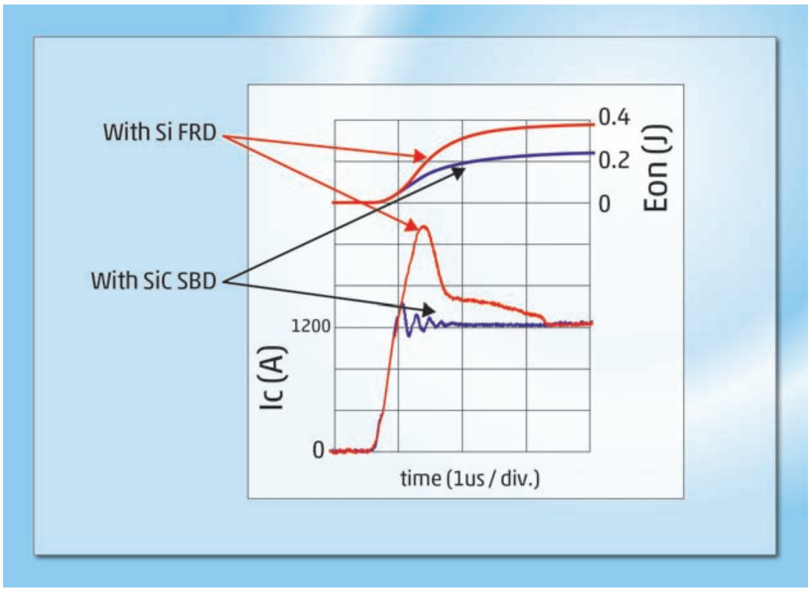


Figure 2: Module turn-on energy and reverse-recovery current with Si-FRD and SiC-SBD

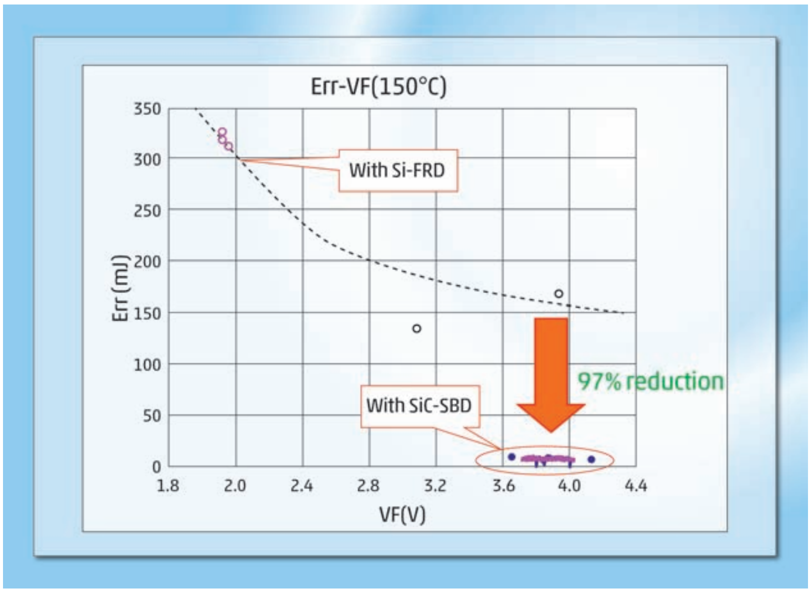


Figure 3: Comparison of module reverse-recovery losses with Silicon and Silicon Carbide diodes

Offering a valuable increase in efficiency as well as superior thermal management, SiC technology is desirable in applications such as solar inverters, in addition to very high-power industrial traction drives. High-power string inverters are currently the most attractive target for SiC diodes and transistors, while cost-sensitive microinverters are expected to combine Silicon transistors with SiC diodes to increase performance at a lower price premium.

Toshiba's latest IEGT/SiC-SBD hybrid module combines 1700 V/1200 A Silicon IEGTs in a half-bridge connection, with anti-parallel SiC SBDs, in the 130 mm x 140 mm x 38 mm module size. The IEGT has been shown to have saturation voltage of less than 3.0 V when conducting 1200 A. It can turn off a high current quickly and has low switching losses, since the turn-off energy (E_{off}) can be as much as 30 % less than that of a conventional device at an applied voltage of 850 V. In addition, the module provides guaranteed operation up to 150°C.

The co-packaged SiC-SBD has forward current rating of 600 A with low forward voltage of 2.8 V, and is highly suited to traction inverter applications. The leakage current of the SiC-SBD is less than 10 μA. In addition, the internal structure of the SiC-SBD is optimized to provide high surge-current capability and also to minimize the forward voltage at high currents.

With its improved reverse-recovery characteristic the SiC-SBD effectively reduces both turn-on loss and reverse-recovery loss. In fact, the reverse recovery

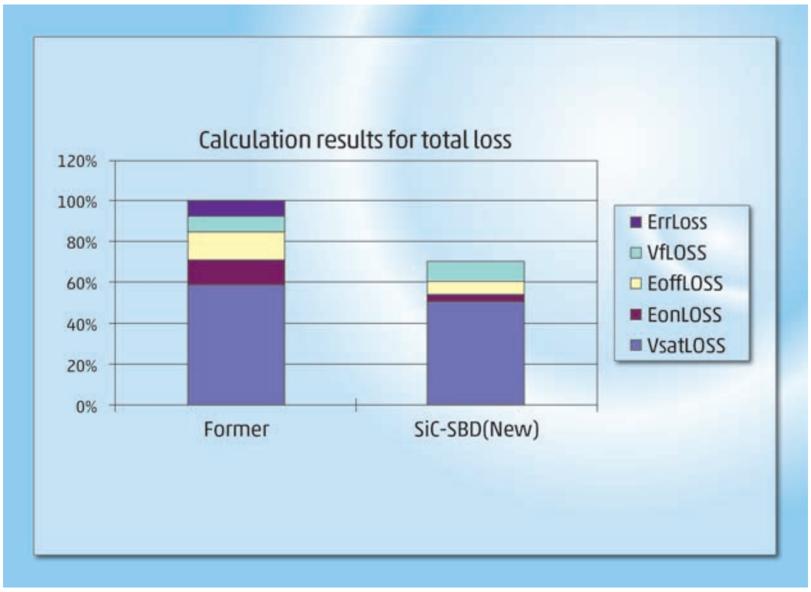


Figure 4: **The hybrid IEGT/SiC-SBD module has lower energy losses compared to the previous generation**

loss is less than one tenth of the loss when using a conventional silicon diode. Figures 2 and 3 illustrate the influence of the SiC diode in reducing module reverse-recovery losses and turn-on losses. The lower waveforms shown in Figure 2 illustrate the significant reduction of reverse-recovery current leading to the 97 % saving in reverse-recovery energy losses illustrated in Figure 3. The upper waveform of Figure 2 shows how using a SiC-SBD also yields a valuable saving in turn-on energy.

The plastic module package is designed to provide high reliability and low thermal resistance. Internally the module features an Aluminum Silicon Carbide (Al-SiC) Metal Matrix Composite (MMC) baseplate material, which has extremely low thermal resistance and a low coefficient of thermal expansion (CTE) allowing the internal structure to be optimized for excellent lifetime characteristics with low thermal fatigue and the ability to withstand a high number of thermal cycles. The construction of the module features materials displaying high comparative tracking index (CTI), and allows a high insulation-withstand voltage.

Module performance analysis

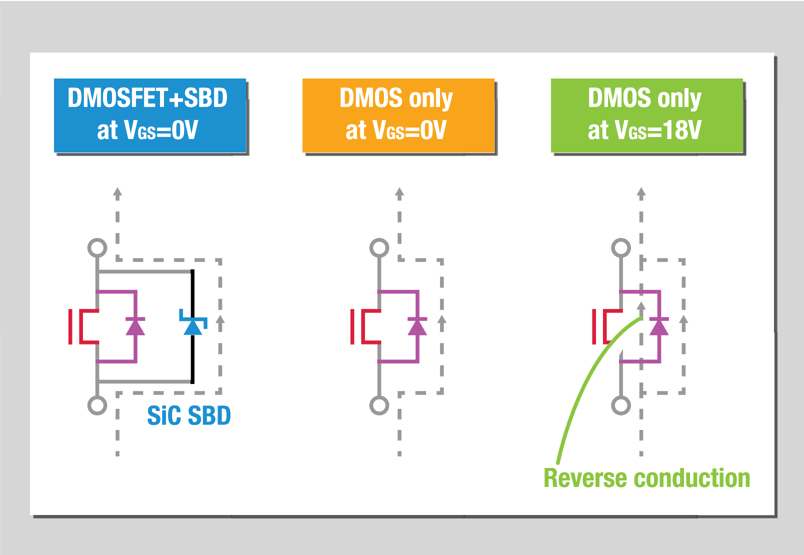
Figure 4 compares the loss performance of a half-bridge inverter using the latest 1700 V/1200 A hybrid IEGT/SiC-SBD module and a previous-generation device featuring conventional Silicon Fast-Recovery Diodes (FRDs). The diagram shows that the total hybrid module energy loss is as much as 30 % lower than the losses of the earlier module.

The significant improvement in efficiency delivers further advantages by allowing the size of any cooling systems and other motor-control components to be reduced. Overall, this can allow the size of the inverter to be reduced by as much as 40 %.

SiC MOSFET-Only Module Increases Current at Reduced On-Resistance

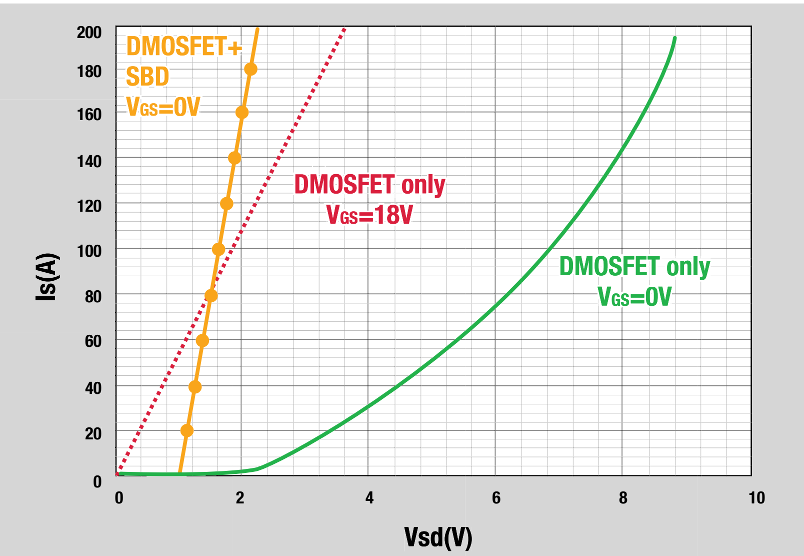
ROHM introduced last year a 1200 V / 120 A full Silicon Carbide power module composed of SiC Schottky barrier diodes (SBDs) and SiC MOSFETs. When compared with conventional IGBT modules, this module can reduce switching loss by 85 %. However, this module is not capable of supplying high currents demanded for industrial applications. Now a methodology to raise rated current has been presented on the example of the newly developed 1200 V / 180 A SiC module using the same package size. **M. Hayashiguchi, M. Miura, K. Hayashi, N. Hase and K. Ino, ROHM Co., Kyoto, Japan**

Several companies have started commercial production of SiC switching devices such as MOSFETs and JFETs. As industrial applications tend to require higher current levels of 100 A or more, ROHM started commercial production of full SiC modules in March 2012. However, its application is rather limited because of its rated current. Expanding the chip size is a straightforward way to achieve higher currents but this may not be the best way today because lowered manufacturing yield due to crystal defects will bring cost up. By making full use of the SiC characteristics two key technologies were employed to increase current rating, 1) eliminating anti-paralleled SBDs by turning on the MOSFETs to allow reverse current flow, and 2) parallel use of multiple MOSFET chips without current miss-sharing.



ABOVE Figure 1: **Current flow in reverse direction**

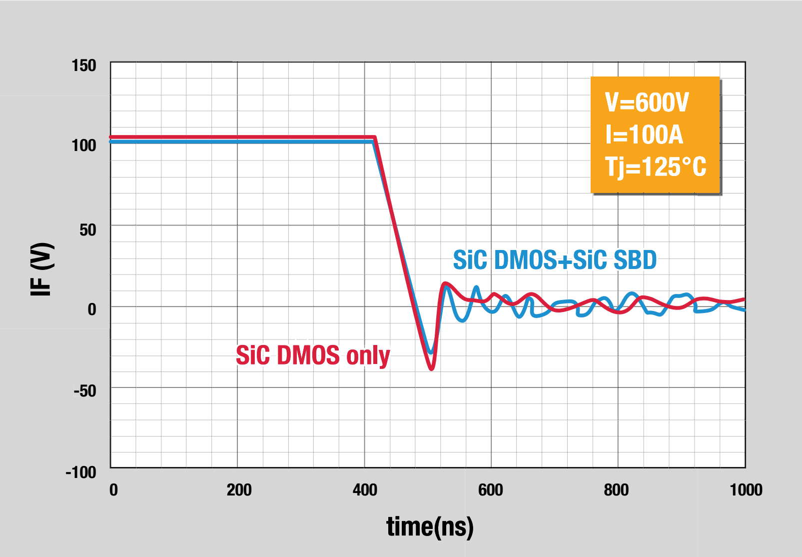
BELOW Figure 2: **Body diode and reverse conduction characteristics of 100 A SiC module**



Reverse conduction of SiC MOSFETs

The offset voltage of SiC PN diode is relatively high because SiC is a wide bandgap material and this may cause high conduction loss during commutation under Vgs=0 V condition. In many cases of inverter/converter drive, the turn-on signal is applied to the FETs at commutation-side after dead time is finished while it is impossible to operate IGBTs at third-quadrant – thus this turn-on signal does not produce any effect in IGBT-based power electronics. However, things are distinctly different in the case of MOSFETs – the relatively high Vf (forward voltage) of the body-diode can be reduced by turning on the MOS channel to allow reverse conduction as shown in Figures 1 and 2.

In MOSFET-only configuration utilizing



LEFT Figure 3: **Reverse recovery characteristics of body diode at 25°C**

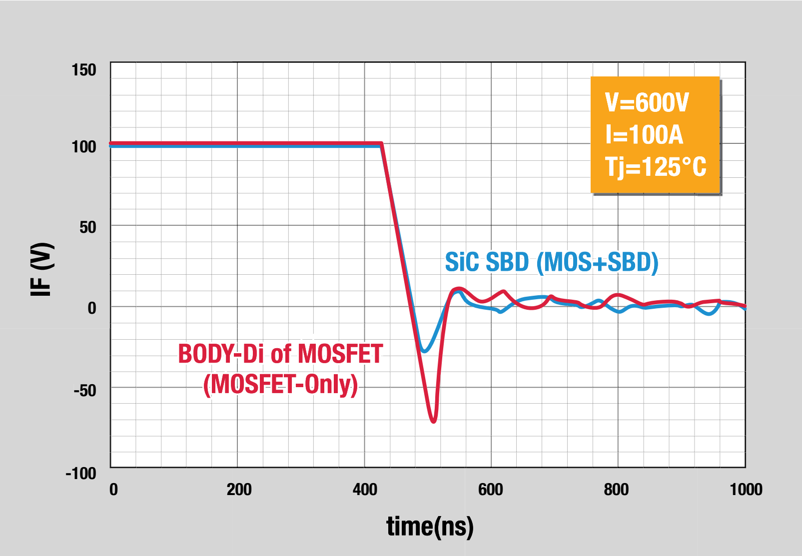


Figure 4: **Reverse recovery characteristics of body diode at 125°C**

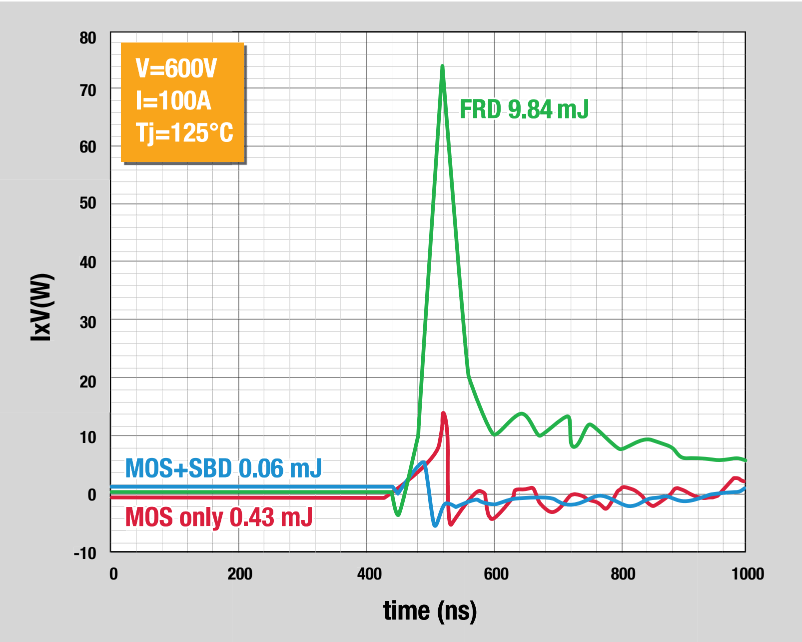


Figure 5: **Reverse recovery energy**

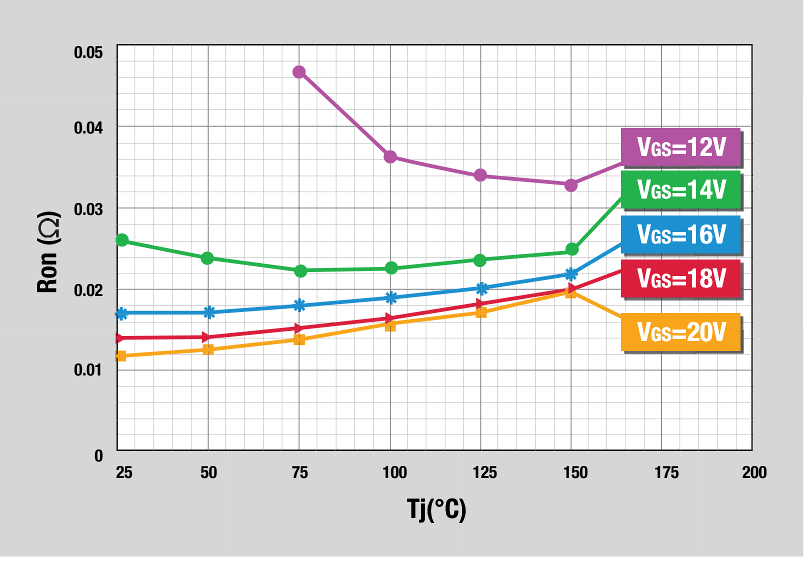
reverse conduction, the body diode is conducted only during dead time. Despite very short period of dead time to prevent shoot-through current, bipolar degradation of SiC devices can be still serious problem. SiC PN diode has been suffering defect expansion after forward conduction that results in increases in both on-resistance and leakage current. ROHM succeeded in suppressing defect expansion as reported in PCIM 2012 and confirmed the reliability of body-diode for 1000 h without any change in characteristics.

As for reverse recovery characteristics, body diode of SiC MOSFETs shows as fast recovery time as SBDs (Figures 3, 4), which leads to lower EMI noise and loss level not achieved by Si MOSFETs or even by Si-FRD. Recovery current of the body diode slightly increases at 125°C while that of SBDs is the same as RT, but reverse recovery energy is very small compared with Si-FRD (Figure 5). All of these facts contributed to realization of a SiC power module without additional free-wheeling diodes.

Paralleling SiC MOSFETs

If devices with negative temperature coefficient of on-resistance are connected in parallel, current might concentrate on a chip with the lowest R_{on} and cause thermal runaway in the worst case. However such risk is lower in the case of SiC MOSFETs as its temperature coefficient of on-resistance is positive (Figure 6) when its recommended on-state V_{gs} is applied (i.e. V_{gs}=18V) – the characteristics make parallel connection of the switching devices much easier.

Figure 7 shows the temperature change at chip surfaces observed by a pyrometer along with time. Four MOSFET chips are mounted and connected in parallel in one module, one chip out of the four chips has lower R_{on} and the rest has higher R_{on}. These chips were intentionally prepared to analyze the current crowding effect due to such R_{on} variation. The normal variation of



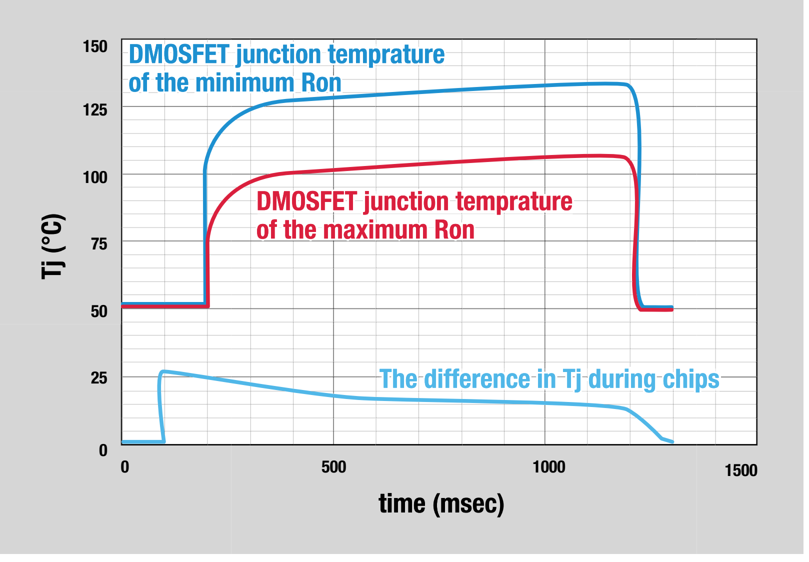


Figure 7: Temperature change during current conduction of the intentionally prepared module which consist of 3 MOSFET chips with higher on-resistance and 1 MOSFET chip with lower on-resistance in parallel

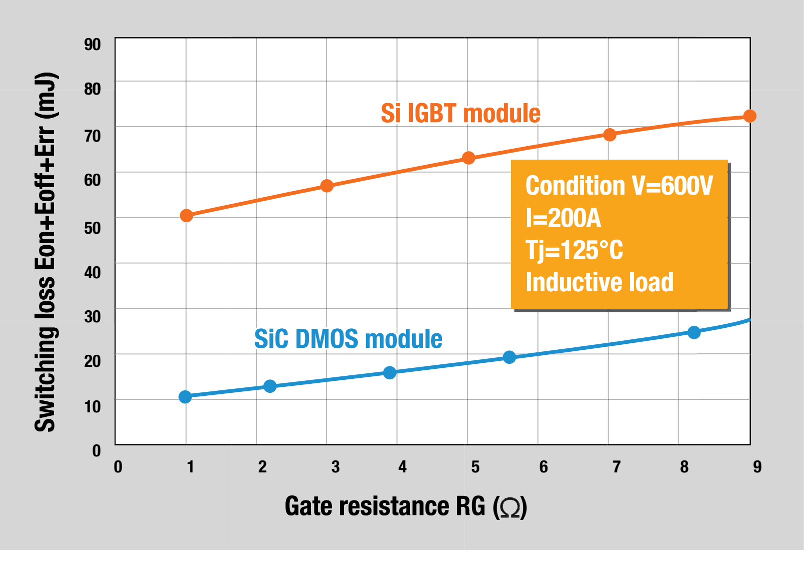


Figure 8: Comparison of total switching loss between Si IGBT module and 180 A SiC DMOS module

LEFT Figure 6: On-resistance vs junction temperature characteristics

Ron, in the mass produced module, is less than half of that for this experiment.

As shown in Figure 7, temperature difference among chips is larger at the very beginning of conduction but it becomes smaller with time (12°C difference at 1 s) because of self-balancing effect due to positive temperature coefficient of R_{on}.

The other concern regarding parallel use is miss-sharing of gate current at turn-on. As for paralleled Si IGBT chips, due to its low internal gate resistance, the balance between each gate currents is easily influenced by the difference in stray inductance. Then the devices may be broken by rush current and resonant oscillation triggered by this.

Contrary to Si IGBTs, thanks to relatively high internal gate-resistance of SiC MOSFETs (several Ω), distribution of gate current among paralleled chips is well balanced without additional gate resistance put individually. These characteristics make multiple connections of SiC MOSFET chips in parallel much easier without miss-sharing of both drain and gate current, which helps to prevent thermal runaway or resonant oscillation.

Properties of 180 A SiC MOSFET module

By replacing SBDs with MOSFETs, rated current was increased from 120 A to 180 A in the same package size. Drain-source on-state voltage at drain current of 180 A is 2.3 V (R_{on}=12.8 mΩ: about 40 % less than 120A module). Due to no-tail current and fast recovery characteristics of SiC devices, total switching loss is reduced by 75 % against IGBT module if a small external gate resistor is used (see Figure 8). The module is reliable for body-diode conduction and will not show bipolar degradation because high reliability is confirmed in our SiC-MOSFETs.

Conclusion

Based on existing devices a new half-bridge power module containing only SiC MOSFETs rating 1200 V was developed. Maximum drain current increases from 120 A to 180 A while on-resistance decreases by 40 % within same package size by replacing external SiC Schottky Barrier Diodes by the improved internal MOSFET body diode.

Literature

"Low loss, High Current SiC MOSFET Module", Proceedings PCIM 2013 Europe, pages 325 - 332

Microcontroller Simplifies PFC Design

In Europe, all equipment connected to the public utility grid needs to comply with European Standard EN 61000-3-2. This standard sets the maximum permissible harmonic current that is injected by equipment back onto the public utility grid. The standard affects any electronic and electrical equipment with a power rating greater than 75 W. A microcontroller based active PFC operating in Critical Conduction Mode is a suitable solution for cost sensitive application. This PFC can be easily integrated into a XMC1300 design without incurring much effort or extra cost. **Eugene Yuen, Senior Application Engineer, Infineon Technologies, Singapore**

The main contributor of the harmonic current is the equipment rectification circuit that converts the input alternating current (AC) to direct current (DC). A typical circuit consists of standard full bridge rectifier feeding a bulk capacitor. Current is drawn from the mains when the input voltage exceeds that of the bulk capacitor. The current is limited by the resistance of the diode and capacitor; as a consequence the input current waveform is non-sinusoidal and contains many harmonics.

One technique to comply with the standard is by shaping the input current of an equipment to be proportional to the applied line voltage thus giving an input current that is in phase with the line voltage. The purpose is to make the load circuitry appear purely resistive to the utility grid thus generating less current harmonic. This is known as active Power Factor Correction (PFC).

This also means additional cost as extra circuitry is needed to implement the active PFC. This is unavoidable but for microcontroller (MCU) based design, the MCU can be used to implement the PFC function in addition of the main application e.g. driving a motor. This will save the cost of purchasing an additional PFC controller chip at the price of complexity.

But the addition of a PFC to a motor control application increases the complexity of the design. The XMC1300 from Infineon Technologies is a microcontroller capable of handling this level of complexity at a low cost.

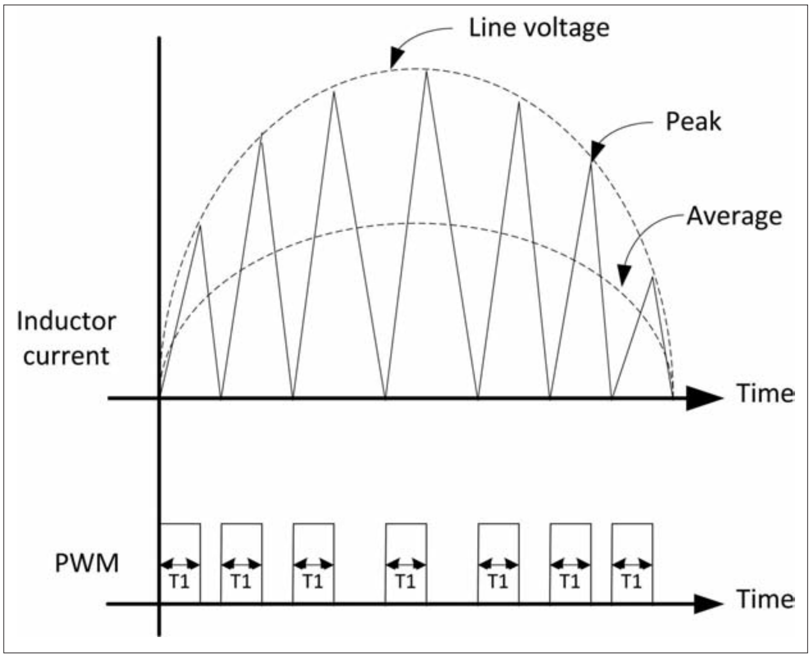


Figure 2: **PFC in Critical Conduction Mode**

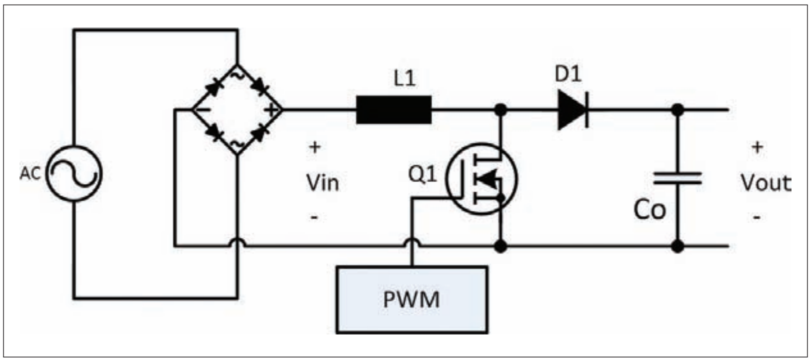


Figure 1: **Boost PFC schematic**

Boost PFC in Critical Conduction Mode

There are several ways to implement an active PFC. The most popular method is to use a boost converter (Figure 1). The boost converter input current is "shaped" to be proportional to the input voltage by modulating boost MOSFET. The rectified source voltage wave shape is used as a reference, the inductor current which is the input current will be "shaped" to be sinusoidal and in phase with the source voltage.

For low output power level (<300W) a boost circuit operating in Critical Conduction Mode (CrCM) is a simple solution for active PFC (Figure 2). In CrCM the inductor current is operating in the "critical" section between Continuous Conduction Mode and Discontinuous Conduction Mode.

In each switching cycle, the boost inductor is charged from zero current. The PWM on-time is held constant for each switching cycle during the whole line cycle. A new switching cycle is only started when inductor current falls to zero. As a result the inductor current is triangular in each switching cycle.

For a single switching cycle, the voltage across the inductor is given

$$Vin = L\frac{di}{dt}$$

Given inductor, L is fixed and constant "on" time, T1

$$Ipeak = \frac{T1}{L}Vin$$

Based on the inductor current shape, the average current is half of the peak current

$$Iaverage = \frac{1}{2}Ipeak = \frac{1}{2}\frac{T1}{L}Vin$$

With a fixed inductance and constant on-time, the peak switch current is automatically forced to track the input voltage. This also mean that the input current ($I_{average}$) will track the input voltage (V_{in}). This PFC can be realized automatically without current sensing. However, for load regulation there is still a need for a compensation loop.

PFC with XMC1300

The boost PFC operating in CrCM can easily implemented using Infineon XMC1300 MCU. The MCU only needs to run the voltage compensation loop. A Proportional-Integral (PI) control loop can be used for the voltage compensation. Additionally the control loop need not be run on every switching cycle. Infineon XMC1300 standard ARM Cortex M0 central processing unit(CPU) running at 32MHz is more than capable to run the PFC

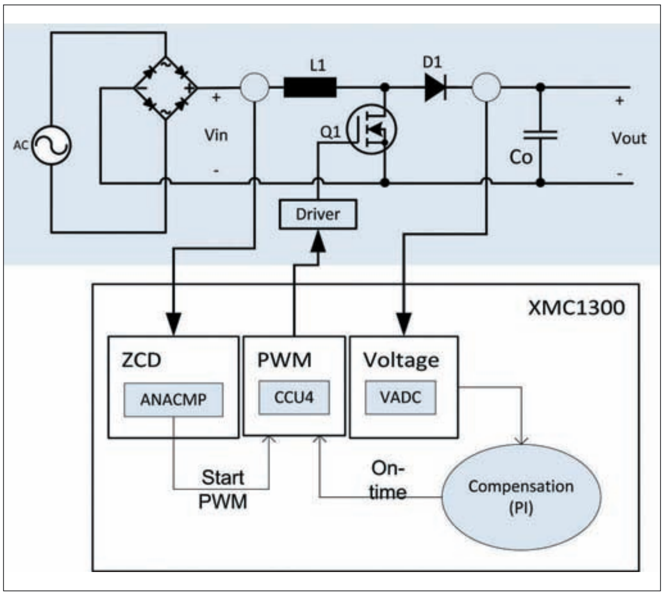


Figure 3: **XMC1300 PFC implementation**

compensation loop with enough CPU time left for other task.

The XMC1300 powerful capture and compare timers (CCU4) can be configured to generate complex PWM output with minimal CPU load. Once configured the PWM are automatically generated without further CPU intervention.

The CCU4 shadow transfer mechanism, allows the PWM duty cycle to be updated without introducing any glitch in the PWM. This also allows the voltage compensation loop to update the PWM on-time independently from the generation of PWM.

The CCU4 also support external event to trigger the start of PWM generation. This can be used by the zero crossing detection (ZCD) circuit to start the PWM upon detecting inductor current has reached zero. A typical ZCD circuit will consists of a comparator that compares the inductor current with a reference zero. The on-chip comparator (ANACMP) can be used as part of the ZCD circuit to trigger the CCU4. This will save the cost of an external comparator.

The PFC output voltage can be measured with the 12-bit versatile analog to digital converter (VADC). If desired the voltage measurement can also be synchronized with the PWM output by using the CCU4 output to trigger the VADC conversion.

Other considerations

The XMC1300 is designed to be able to handle a wide variety of applications, e.g. motor control and power supply with ease. A good example is the design of a field oriented control of a 3-phase motor which can make use of another advanced PWM peripheral, the CCU8 and the MATH co processor. Communication is usually a major reason that a microcontroller is considered for a design. The communication peripheral of the XMC1300, the USIC, is configurable to be able to handle a variety of protocols.

Digital systems are not just about hardware as software plays a very crucial part. Software performance can make or break a project. Software design is aided with the free CMSIS library from ARM and the completely free software tool set DAVE that includes IDE, compiler, debugger and code generator.

High Frequency Oscillations due to Driver Coupling

The coupling between the driver and the power module is usually given too little attention. Yet, many problems can be tracked back to this very interface, such as when IGBTs are switched very rapidly, or when desaturation takes place during short circuits. This article outlines some of the considerations with regard to potential causes. **Stefan Schuler, Development Engineer, SEMIKRON, Nuremberg, Germany**

A driver's primary task is to provide the power required for switching the IGBTs, and to establish a galvanic insulation between the input signals.

The underlying principle of a driver which provides galvanic insulation to the TOP and BOT sides, e.g. by means of two transformers, is shown in Figure 1. The downstream circuits are the signal processing and the actual driver stage. Besides the typical activation voltage of +15V and a negative shutoff voltage, the power supply may provide additional voltage for logic circuits or microcontrollers. The connection to the power module is often implemented by empirically defined gate resistors. A series of complex test procedures makes sure the module switches safely and correctly under all and any circumstances.

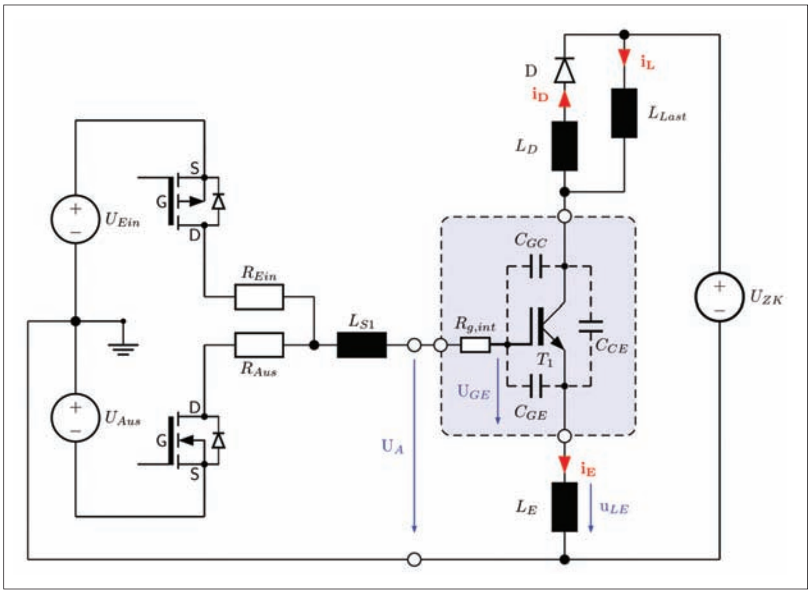


Figure 2: Equivalent circuit diagram with driver connection

Focus on parasitics

The electric coupling allows for generating a greatly simplified equivalent circuit diagram (Figure 2). It shows the switching lower IGBT (BOT), its parasitic capacitances and the integrated series resistor, a load L_{LOAD}, and the free-wheeling diode D in the TOP branch. The parasitic inductances L_D and L_E (also called leakage inductances) represent the conductor tracks and bonding wires of the diode and the IGBT. On the driver side, the schematic shows a push-pull output with power supply, gate series resistors and the parasitic conductor track inductance L_{S1}.

The driver's output voltage U_A is parallel to the actual gate-emitter voltage u_{GE} and the voltage drop u_{LE} of the parasitic inductance in the emitter branch. A current change in the IGBTs generates an induced voltage uLE that equals L_E multiplied by di_E/dt. Quickly, the bonding wires on the emitter side are identified as the main causes of the parasitic inductance. As a rule of thumb, calculations are made with one nanohenry (nH) per millimeter of bonding wire length. Major current changes easily induce several volts of voltage. However, the ohmic resistance can easily be neglected, as it is only approximately 5…10 mΩ per bonding wire, so in a 75 A chip, for instance, it would clearly stay below 100 mV.

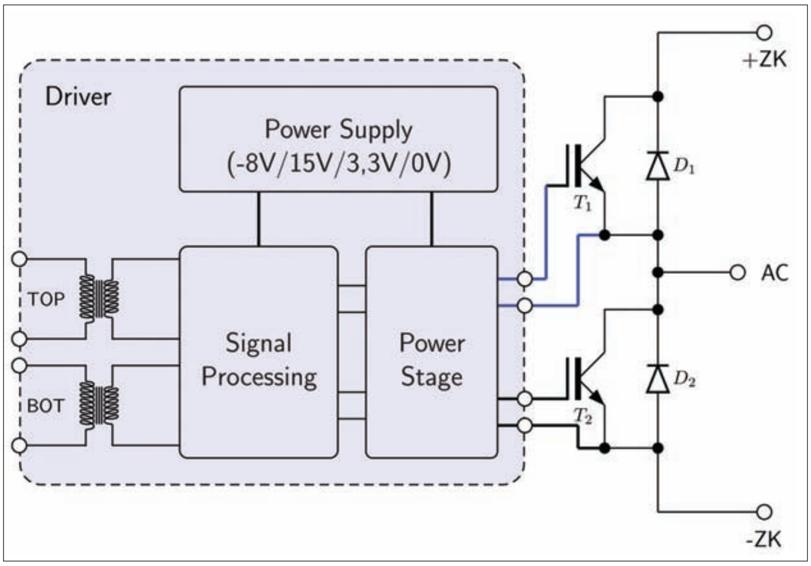


Figure 1: Half-bridge circuit with driver principle

Coupled LC circuits

A closer look at Figure 2 shows a first LC circuit which consists of the components L_{S1}, L_E (summarized into L_S) and the gate-emitter capacitance C_{GE}. The gate series resistors $R_{g,int}$ and $R_{On/Off,}$ summarized into R_g, dampen this LC circuit. On the one hand, this causes a shift of the angular resonance frequency towards smaller values for ω, on the other hand, the resonance spectrum becomes greater while at the same time, the amplitude is dampened. In short - the quality is diminished. A second LC circuit is formed by the parasitic components of the intermediate circuit, the IGBT that is being looked into, and the parasitic inductance L_E, which is the link towards the driver circuit.

Finally, there is a third LC circuit, consisting of the Miller capacitance C_{GC} and the finite, yet frequency-defining switching time of the IGBT. Therefore, repercussions on the driver are possible via two different mechanisms: on the one hand, via the emitter's inductance L_E, and, on the other hand, via the Miller capacitance as mentioned above. The following chapters shall look into more details of which one of the two effects stated will be the dominant one in each individual case, causing a tendency towards oscillation in the whole system.

Emitter inductance influence

The measurable influence of the emitter's parasitic inductance is limited to large current changes, which primarily occur when switching takes place. Analyzing the switch-on process (Figures 3 and 4), one initially recognizes a negative feedback phase that turns into a positive feedback phase. This circumstance is owed to the diode's reverse recovery charge which causes a positive feedback while it discharges because the emitter's current decreases, making di/dt negative for a short period of time. The switch-off process, however, is characterized by an exclusive negative feedback phase. In both cases, the proportion of the coupling level is determined by the current intensity to be switched within a time window, while during the switch-on process, said recovery charge of the free-wheeling diode needs to be taken into account. Generally, the negative emitter coupling is a desirable circumstance, as it contributes to a certain stabilization of the whole system by causing the effective current slopes of the individual IGBTs to assimilate.

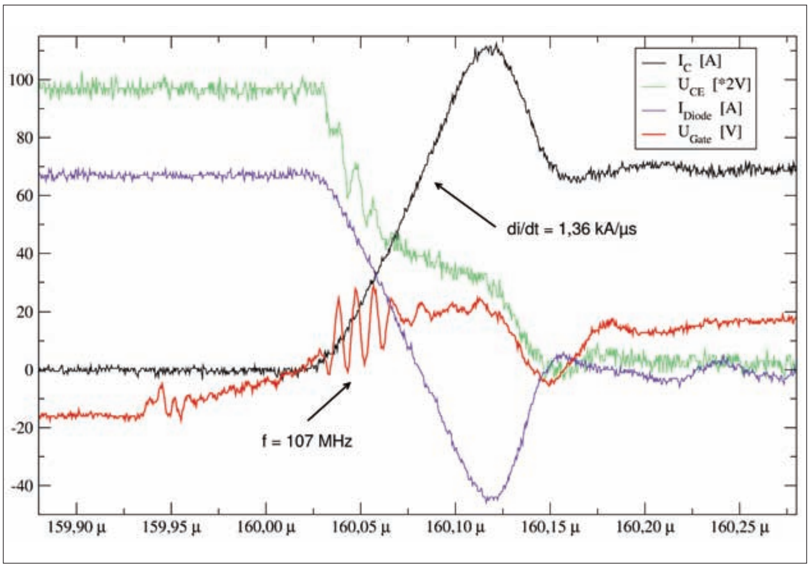


Figure 3: Switch-on process with 100 ns slope time of the collector current (10-90 %)

Source: Dominic Malane

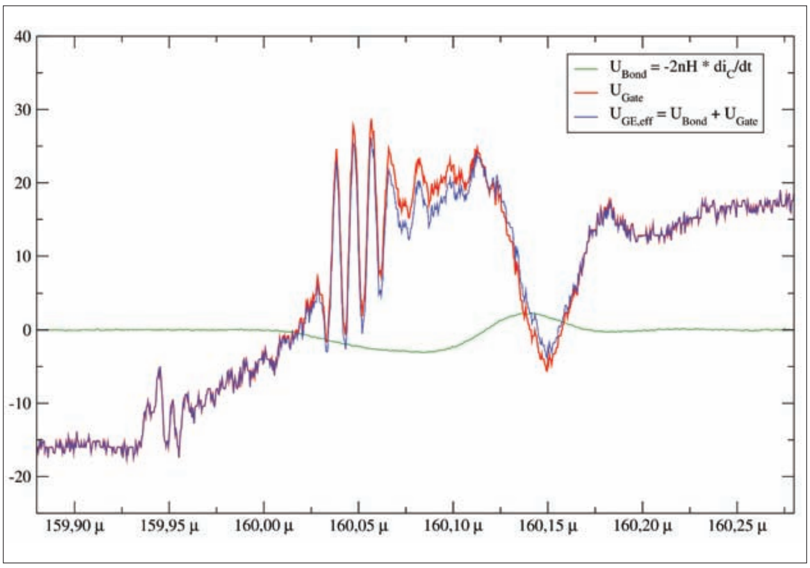


Figure 4: Gate voltage curve during switch-on (excerpt from Fig. 3). Green shows the curve of the voltage induced at the eight parallel emitter bonding wires (2 nH total). The blue line is the calculated effective gate voltage

Miller capacitance influence

Basically, the Miller effect is a negative coupling, because a rapidly declining emitter-collector voltage (switch-on) will cause a displacement current to flow from the gate to the collector. The IGBT will then be a little less conductive until an equilibrium is established between the gate current and the displacement current, which becomes visible in the oscillogram as a Miller Plateau with its charateristic flat shape. The displacement current is proportional to the Miller capacitance and the collector-emitter voltage change du_{CE}/dt. However, the Miller capacitance itself strongly depends on the voltage: it reaches a minimum when uCE equals the DC link voltage, and peaks when u_{CE} is lower than the gate voltage u_{GE}. This can be monitored very well when comparing the plateau curve against the collector-emitter voltage curve.

Now, while the switching time determined by the driver is significantly longer than the switch-on delay of the IGBT, the displacement current will be moderate, the Miller Plateau will be nicely articulated and the system only contains a non-critical discrepancy between the actual and target conditions. When the switching is too aggressive, however, it is not possible to establish a stable equilibrium, as the high du_{CE}/dt caused by this circumstance will cause a high displacement current and, hence, a rapidly changing gate potential which the IGBT is unable to compensate quickly enough due to its latency. The consequence is a strong resonance at the gate and the collector. In tests, it was easily possible to produce a frequency amplitude of 28 V at the gate with an DC link voltage of 200 V.

Switch on

When the active gate-emitter uGE reaches the threshold voltage, the current slowly begins to commutate from the free-wheeling diode to the IGBT. This current change is the reason for the voltage induced at the emitter's inductance that counteracts the driver voltage U_A and reduces the effective gate-emitter voltage u_{GE} – a classic case of negative feedback.

According to general assumption, the consequence would be for di/dt to be reduced, and along with this, also the negative feedback, due to the IGBT's reduced conductivity, so the current is able to increase, which in turn causes a high-frequency oscillation (of the current). This assumption is not perfectly correct, because as a matter of fact, it's not the current that is being modulated, but the collector-emitter voltage. The current curve itself is very inert, its velocity of change is low, so the induced voltage of the emitter's inductance remains almost constant across a wide range. However, a distinction must be made at this point between different cases, namely 1) driver switching speed higher than IGBT and 2) driver switching speed lower than IGBT.

In the first case, the current is modulated by the IGBT's switching behavior, resulting in the familiar curves where the collector-emitter voltage only drops steeply after the entire current has commuted to the IGBT. In the second case, the maximum current increase is determined by the environment, i.e. the effective inductances during the commutation. This specific case allows the IGBT to go to early partial saturation, which shows in the fact of the collector-emitter voltage already dropping significantly during the current increase (Figure 3).

The reduction of the collector-emitter voltage that occurs during the commutation process can mostly be tracked down to parasitic inductances along the path which can be calculated from the ratio of the voltage difference between U_{ZK} and u_{CE} and the current slope. In case of high switching speeds, this characteristic flat spot in the u_{CE} curve will disappear.

Across a wide range, the increase rate of the current is determined by the gate series resistor. When, during a later switching cycle, higher currents commute to the IGBT, the time window will enlarge accordingly. The conditions for di_E/dt will therefore stabilize, which causes a negative feedback that changes only slowly, and which might be the reason for higher switching losses but does not cause any tendency towards oscillation.

However, the situation is dramatic for the Miller effect, particularly for steep voltage slopes (9.8 kV/µs in Figure 3). By nature, it's a negative feedback, but it is phase-shifted by the IGBT's response time. When excited with a certain frequency, the negative feedback might turn into a positive feedback – resonance scenario! This shows in a clear tendency towards oscillation with high displacement currents (more than 2 A in this example). The oscillation will only end after a few cycles, usually at the time when the effective emitter-side negative feedback peaks.

Energy transfer

The emitter's inductance feeds energy into the driver circuit during a high diE/dt. The curve of the energy feed is continuous and rather slow, so no excitation of the driver's LC circuit might occur.

The elements of the coupled driver that determine the frequency are the parasitic inductances and the gate-emitter capacitance C_{GE} (approx. 4 nF in the example). In the test described, the gate achieved a frequency of approx. 100 MHz, with the time behavior of this primary, feed-providing LC circuit is mostly determined by the switching delay of the IGBT. The coupling element to the secondary driver LC circuit is the gate-collector capacitance.

Approaches

So, which measures need to be taken in order to suppress the undesirable oscillation behavior?

In most cases, the first means of choice will be to try to increase the gate series resistor. Firstly, this will increase the IGBT's switching times, secondly, this provides a classic way of damping the whole system. The slower switching times will effectively reduce the displacement current and the excitation energy, the disadvantage lies in the higher switching losses.

Another common alternative is the purposeful tuning of the secondary LC circuit by means of a capacitance that is parallel to the gate-emitter capacitance. This measure also dampens the Miller effect due to the better capacitance ratio. In some cases, one would also install an upstream R-C element, so effectively, together with an integrated gate resistor and gate capacitance, this would translate into an R-C-R-C element constellation, more widely known as a two-stage low pass. When the cut-off frequencies of both filter parts match, the total cut-off frequency will be reduced to half the value of each individual low pass. In many cases, this is a pretty useful compromise, yet, at the sacrifice of slower switching times and higher losses.

So, what to do? It's desirable to have an advantageous impedance curve of the driver, also for high frequencies. Twisted wires that are as short as possible leading to the module constitute an effective and mostly cost-efficient measure. What's more, smart routing of the conductor tracks will reduce the inductance, i.e. at least parallel routing of the auxiliary emitter and gate tracks, or even better, in two adjacent layers. What's very important is to provide impulse-resistant capacitors at the supply connectors of the push-pull output. These will reduce the inductive influence of the two supply wires to the output transistors. Last but not least, the focus should be on fast and low-resistive output transistors. When these measures are implemented stringently, artificially slowed down switching can be omitted just the same as complex and expensive filters.

Conclusion

In power modules, parasitic inductances and capacitances prohibit fast switching with low losses. The design of the new driver needs to be matched to the module, i.e. in the switching process, the feedback of the IGBT on the driver must not induce oscillation. Classic damping approaches do not always produce satisfactory results; oftentimes, these measures are put in place only later. It is much more efficient to focus on the interface already during the design of the driver, and to ensure low-impedance adjustment across the entire frequency range by design.

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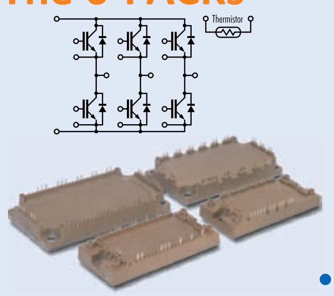
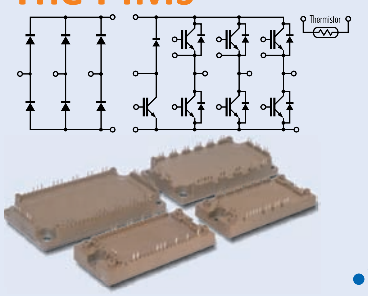


Package	I_C	600V	1200V	1700V
45x107.5 mm	50A	● ■	● ■	
	75A	● ■	● ■	
	100A	● ■	● ■	
62 x 122 mm	100A		● ■	●
	150A	● ■	● ■	●
	180A		● ■	
	200A		● ■	

● With solder pins ■ With PressFit contacts

The PIMs



Package	I_C	600V	1200V
45x107.5 mm	25A		● ■
	35A		● ■
	50A	● ■	● ■
	75A	● ■	
	100A	● ■	
62 x 122 mm	50A		● ■
	75A	●	● ■
	100A	● ■	● ■
	150A	● ■	● ■

● With solder pins ■ With PressFit contacts

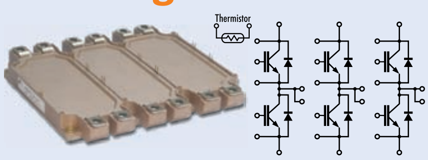
The 2-PACKs

● With Solder Pins

● With Spring Contacts

Package	I_C	1200V	1700V
62 x150 mm	225A	● ●	●
	300A	● ●	●
	450A	● ●	●
	550A		● ●
	600A	● ●	

The High Power 6-PACKs



Package	I_C	1200V	1700V
150 x 162 mm	225A	●	
	300A	●	●
	450A	●	●
	550A	●	

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For High Power LEDs, Solar Cells, and Batteries

The best LED drivers accurately regulate LED current for consistent color reproduction and modulate it rapidly for high contrast dimming. They also recognize and survive short and open circuits, monitor and report current levels, guard against overheating, and protect weak power supplies from excessive load currents. A standard switching converter would require a number of additional expensive amplifiers, references and passive components to fulfill these responsibilities. In contrast, the LT3763 LED driver-controller has these functions built in. **Luke Milner, Design Engineer, Linear Technology Corp., Milpitas, USA**

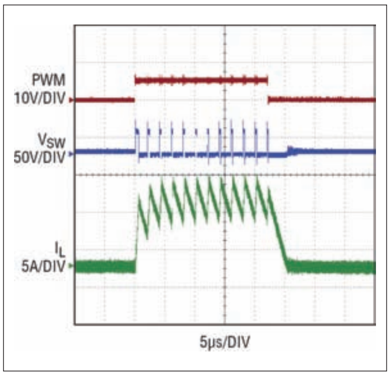
The LT3763 is more than just a high performance LED driver. Its rich feature set simplifies the design of other demanding applications, such as safe charging of a sealed lead-acid batteries, or maximum power point regulation for a solar panel, or a combination of both. The LT3763 performs these tasks with high efficiency, even at input voltages reaching 60 V.

Driving LEDs

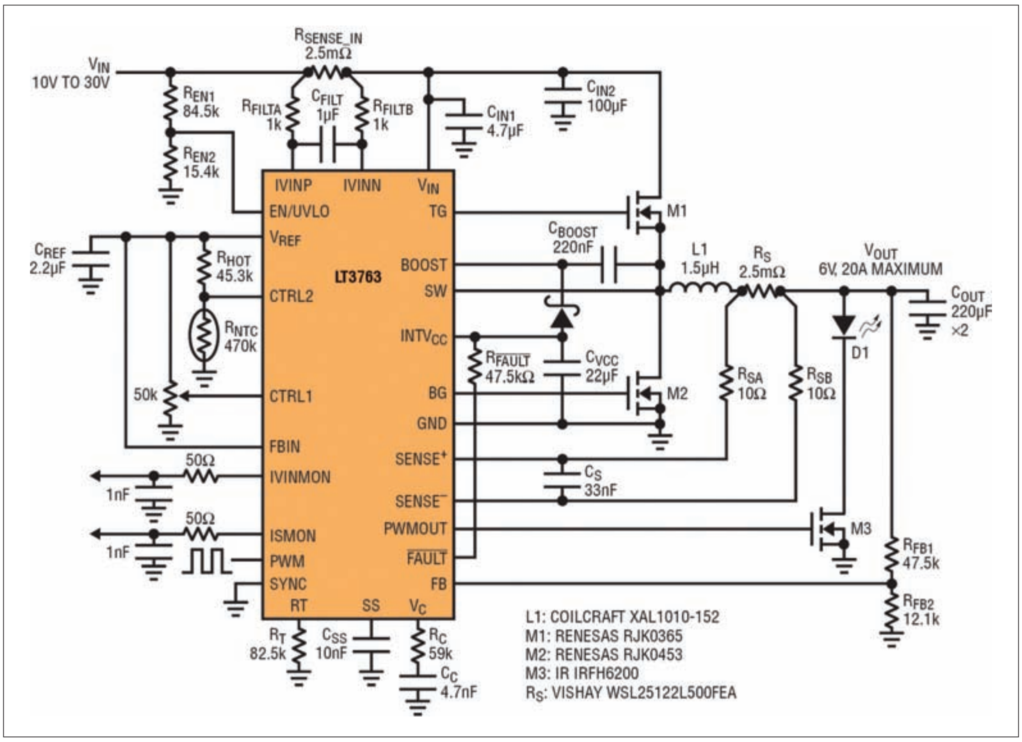
Figure 1 shows the LT3763 configured as a high power LED driver. A potentiometer at the CTRL1 pin permits manual adjustment of the regulated LED current from 0 to 20 A. For thermal regulation of the LED current, a resistor with a negative temperature coefficient is mounted near the LED and connected from the CTRL2 pin to GND.

The resistor network at the EN/UVLO pin programs the LT3763 to shut down if the input voltage falls to less than 10V. The resistor network at the FB pin defines an open-circuit condition as when the output reaches 6V, and should that ever happen, the LT3763 automatically reduces the inductor current to prevent overshoot and pulls down the /FAULT pin to mark the occasion.

The LT3763 is designed to provide flicker-free LED dimming as shown in Figure 2. This is achieved by pulling PWMOUT low whenever PWM is low and thereby disconnecting the LED, by similarly disconnecting the compensation network at V_C, and resynchronizing internal switching clocks to the PWM pulse. These maneuvers ensure that subsequent pulses are identical, that the inductor current rises as fast as possible to satisfy the



ABOVE Figure 2: PWM dimming performance of the circuit in Figure 1



LEFT Figure 1: A single high power LED (20 A) driver with analog and PWM dimming

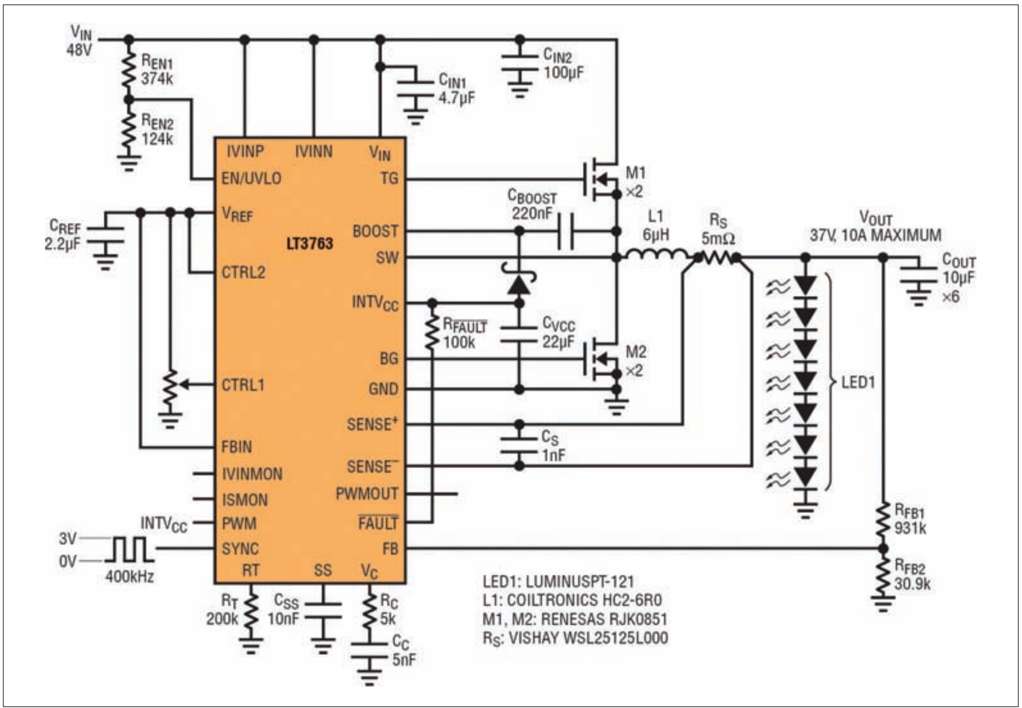


Figure 3: **350 W white LED driver**

programmed LED current level, and that the LED light never flickers.

The LT3763 can be configured as in Figure 3 to deliver 350 W with 98 % efficiency from a 48 V input. An internal regulator supplies the drivers of the TG and BG pins with enough power for each to drive two of the external NMOS power switches. Higher power applications can be built by connecting LT3763s in parallel, so that current is shared equally between the two controllers. This configuration also illustrates how the SYNC pin can be used to synchronize the parallel connected LT3763s to an external clock.

The high output voltage rating of the LT3763 enables 35 V at the output with the simplicity of a standard buck converter. The output voltage can be as high as 1.5 V less than input voltage, and the configuration in Figure 4 makes use of this feature to charge three sealed lead-acid batteries in series (up to 45 V) from a 48 V supply.

Charging batteries

The battery charger shown in Figure 4, like all chargers, must be able to precisely regulate the batteries' rated charging current (constant current mode) until the battery voltages reach the limit set by their chemistry. The charger must maintain that voltage (constant voltage mode) without overshoot until the current drawn by the trickle-charging batteries becomes very small. Once the trickle charge phase is complete, the charger should allow the batteries' voltages to decay to a relaxed level before finally settling at and holding that final voltage indefinitely.

The combined current and voltage regulation loops on the LT3763, and its LED fault handling circuitry, nearly make it a complete battery charger. Only a single additional transistor is required to form a

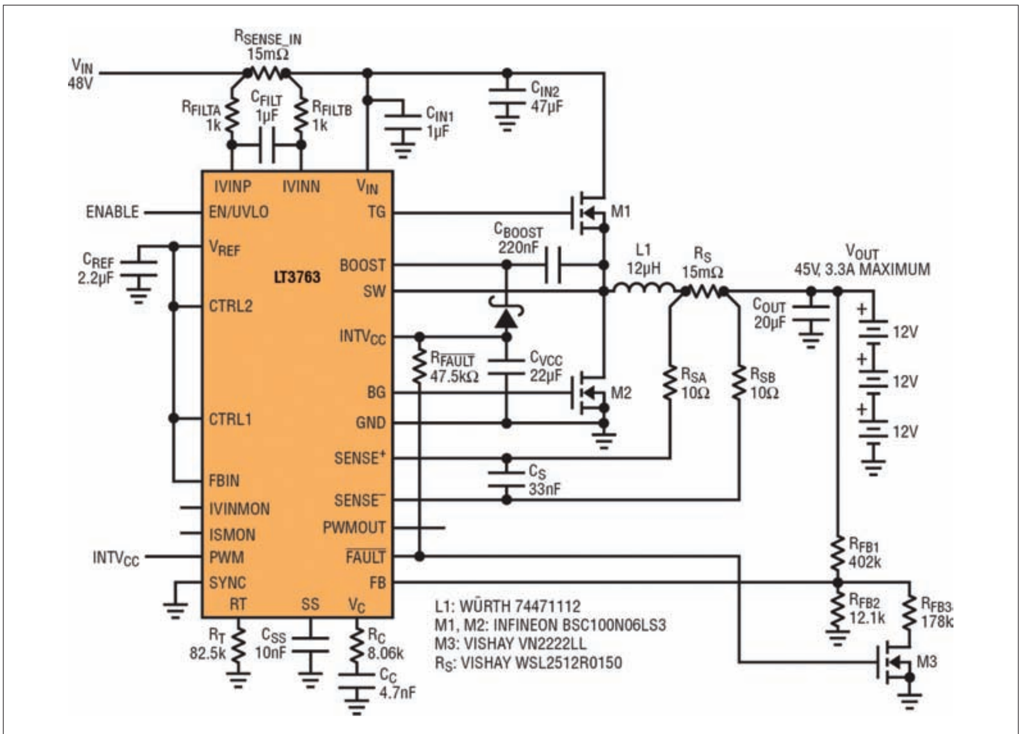


Figure 4: **3. 3A, six-cell (36 V) SLA battery charger**

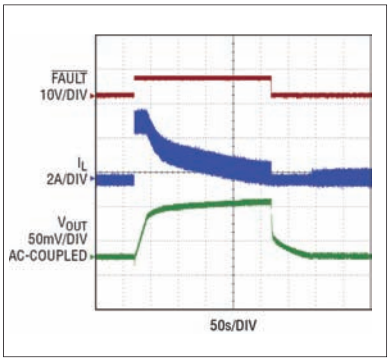


Figure 5: 36 V SLA battery charging cycle

complete battery charging system.

The resistor divider at the FB pin has been designed to program the charging voltage to 45 V. As in the case of an open-circuit, when the voltage reaches 45 V, the LT3763 automatically reduces the current to prevent overshoot as shown in Figure 5.

Subsequently, during trickle charging, the battery draws less current over time. When the charging current reduces to 10 % of the regulated current (C/10 battery specification), the LT3763's open-circuit fault condition is triggered. The resulting high-to-low transition at the /FAULT pin is used to turn off the gate of the added transistor M3 and remove the resistor RFB3 from the feedback network. The programmed output voltage is thereby lowered, and the LT3763 stops switching to allow the batteries to relax on their own.

When their combined voltage decays to the newly programmed value, the LT3763 begins switching again and provides a sustaining current necessary to maintain the output voltage indefinitely. As an added benefit, the /FAULT pin transition serves as a signal that the trickle charging has begun.

Regulating solar panels

A well-designed solar panel power supply requires an intelligent combination of current and voltage regulation. In an optimum design, a converter must sense the voltage on the panel and adjust the current it draws to maintain the input voltage at the panel's maximum power point. If it draws too much current, the voltage of the high impedance panel will collapse. If it draws too little current, available light energy is essentially wasted.

In many common solutions, a solar panel controller designer would use an amplifier to sense the input voltage and adjust the voltage on the current control pin. The LT3763 includes this function at the FBIN pin. Simply tie CTRL1 high, to the 2V reference available at V_{REF}, and add a voltage divider from V_{IN} to FBIN. When the voltage at FBIN falls to nearly 1.205 V, the internal amplifier automatically overrides the CTRL1 voltage and reduces the load current. This regulates the input voltage (the voltage of the solar panel) at the maximum power point for the panel. The resistor divider on the FBIN pin is shown in Figure 6 and can be customized to fit the requirements of any solar panel.

In the configuration shown in Figure 6, the converter can generate whatever inductor current, up to 5 A, is required to hold the panel voltage at 37 V. Input voltage feedback is via the voltage divider at the FBIN pin, which in turn regulates the inductor current to what is actually necessary to hold the panel at peak power in any given light condition.

As shown in Figure 7, the process of charging a battery with a solar panel looks very similar to charging with a low impedance supply as before. The difference is that the regulated inductor current (charge current) is not preset by the designer, but is instead adjusted on the fly via the feedback loop regulating input voltage. This effectively minimizes charge time, since input power is maximized at all times, regardless of panel illumination.

Since the LT3763 has the capability of regulating input voltage and current, as well as output voltage and current, and provides a fault flag with C/10, it can easily be used with a wide variety of solar panels to charge many different types of batteries.

Monitoring current levels

In each of the applications presented here, the LT3763 provides an additional service by monitoring the input and output current levels. Voltages across the IVINP and IVINN pins ranging from 0 to 50 mV are amplified with a gain of 20, and the resulting voltage appears at the IVINMON pin. The voltage at the ISMON pin is an identical amplification of the voltage across the SENSE+ and SENSE– pins, as shown

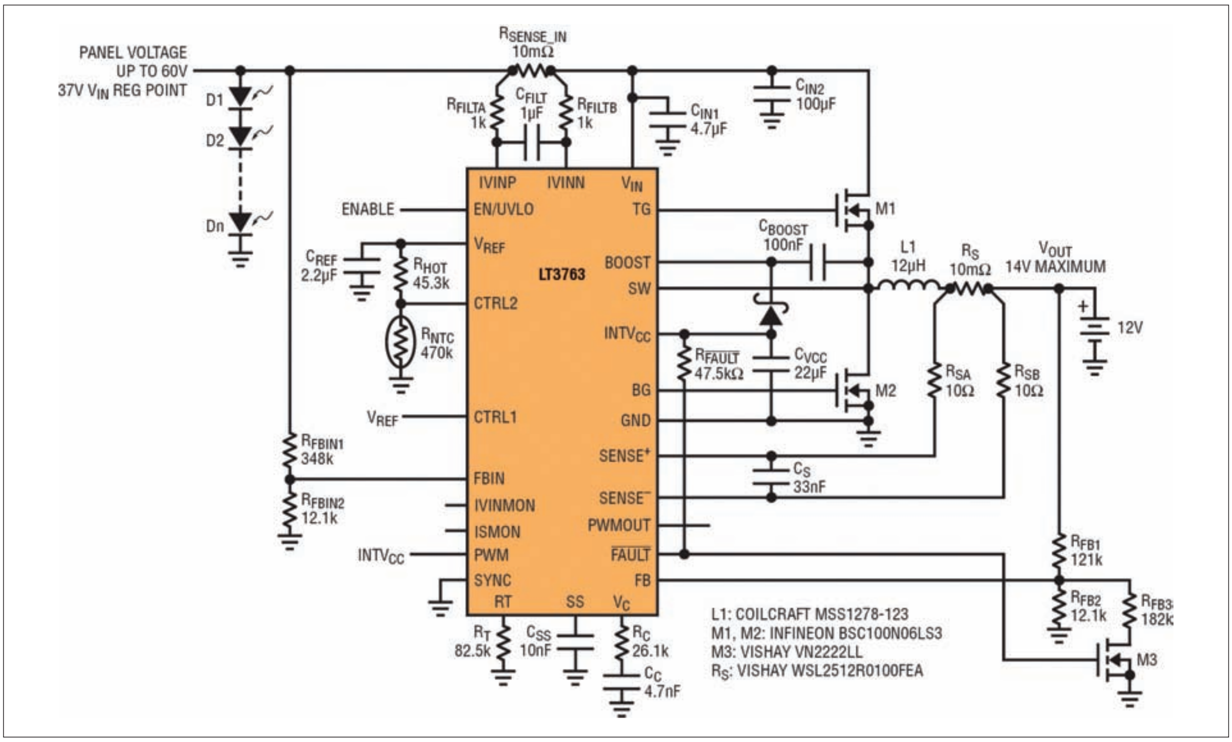


Figure 6: 70 W solar energy harvester with maximum power point regulation

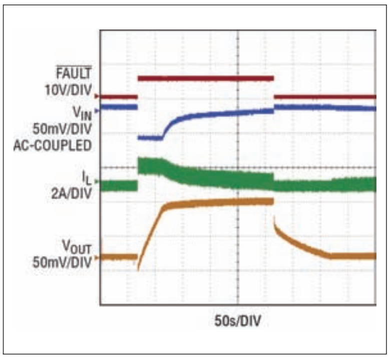


Figure 7: Solar powered SLA battery charging

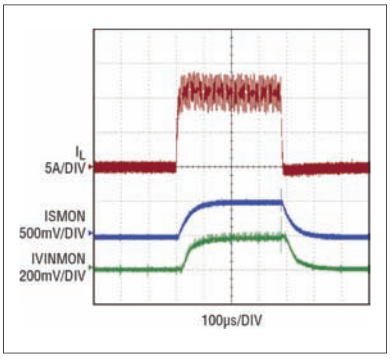


Figure 8: Current monitor outputs in an LED driver application with PWM dimming

in Figure 8.

These signals are helpful in systems that must verify the current provided to LEDs or measure the efficiency of voltage conversion. They can also help to estimate the power provided by a solar panel or to monitor the current trickling into a charging battery as it decays to zero.

Due to the discontinuous input current of a step-down buck converter, a low-pass filter is typically necessary at the IVINP and IVINN pins as shown in Figure 1 and Figure 4. A much smaller filter at the SENSE+ and SENSE– pins may also be useful in filtering high frequency noise, but it is not necessary. Even with these filters, the monitors are fast enough to track reasonably short PWM pulses as shown in Figure 8. Nevertheless, if a designer is more concerned with average current levels than instantaneous current levels, then additional low-pass filters can be easily added to the ISMON and IVINMON pins.

Conclusion

The LT3763 is a versatile step-down buck converter that integrates many complex features essential for not only LED drivers, but solar harvesters and battery chargers as well. A PWM driver and current monitors are included with fault detection, current limiting, input and output voltage regulation. Due to its high voltage rating, all of these features can be utilized to illuminate long strings of LEDs or charge stacks of batteries. Available in a 28-lead TSSOP package, the LT3763 is a compact, complete, and efficient power system.

Magnetic Replacement Ballast IC

International Rectifier now offers a control IC for magnetic ballasts used in fluorescent lamps. The IRS2538DS emulates the behavior of a magnetic ballast control to offer an one-chip magnetic replacement ballast solution. As traditional magnetic ballasts continue to be phased-out of the marketplace due to their low efficiency, manufacturers are looking for an electronic replacement with equivalent reliability and low-cost. The IRS2538D IC delivers all of the benefits of an electronic ballast solution such as high efficiency, small size, light weight, and no lamp flicker while additionally offering an affordable, greener alternative to existing approaches, Available in a compact SO8 package, the device utilizes a novel control method to achieve high power factor with ultra-low THD to eliminate the need for a PFC stage and electrolytic capacitor at the input. The new IC integrates a 600 V half-bridge control circuit, bootstrap MOSFET and comprehensive set of protection features to further reduce component count and PCB area. The IRS2538DS also features preheat, ignition and running lamp modes, closed-loop lamp current control, fixed preheat time (2 s typical), adaptive deadtime (0.5 µs to 1.5 µs typical), lamp insert auto-restart, micropower start-up (125 µA) and an internal 15.6 V Zener diode clamp. Pricing begins at $0.94 each in quantities of 10,000-units.

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Highly efficient, three-phase motor control expertise, once only obtainable to a niche market of motor designers, is now available to a wider audience of developers. Texas Instruments brings its InstaSPIN-FOC™ (field-oriented-control) sensorless motor control technology to its real-time-control F2802x MCUs. Engineers can use this FOC technology, embedded in the ROM to accelerate motor control development while improving efficiency for cost-sensitive BLDC (brushless DC), PMSM (permanent magnet), and AC Induction motor based applications. With the ability to identify, tune and control any type of three-phase, synchronous or asynchronous motor in just minutes, MCUs with InstaSPIN-FOC are ideal for a variety of applications, such as washing machines, compressors, pumps, fans, electric bicycles, tools, treadmills, compact drives, sewing and textile machines, lifts and hobby motors.

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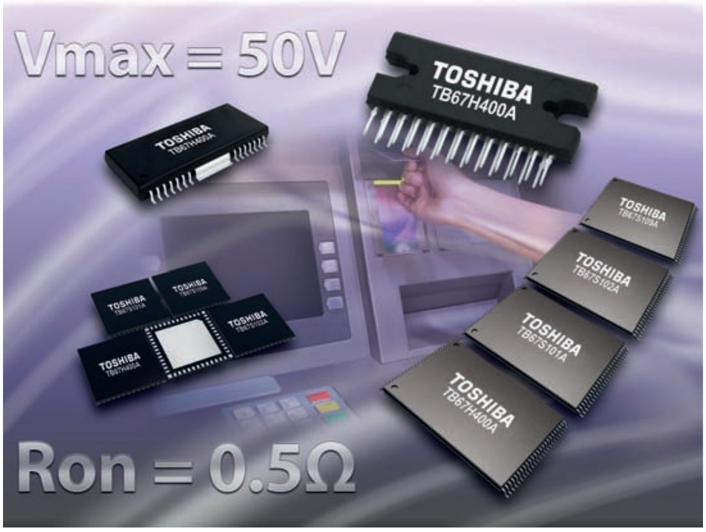
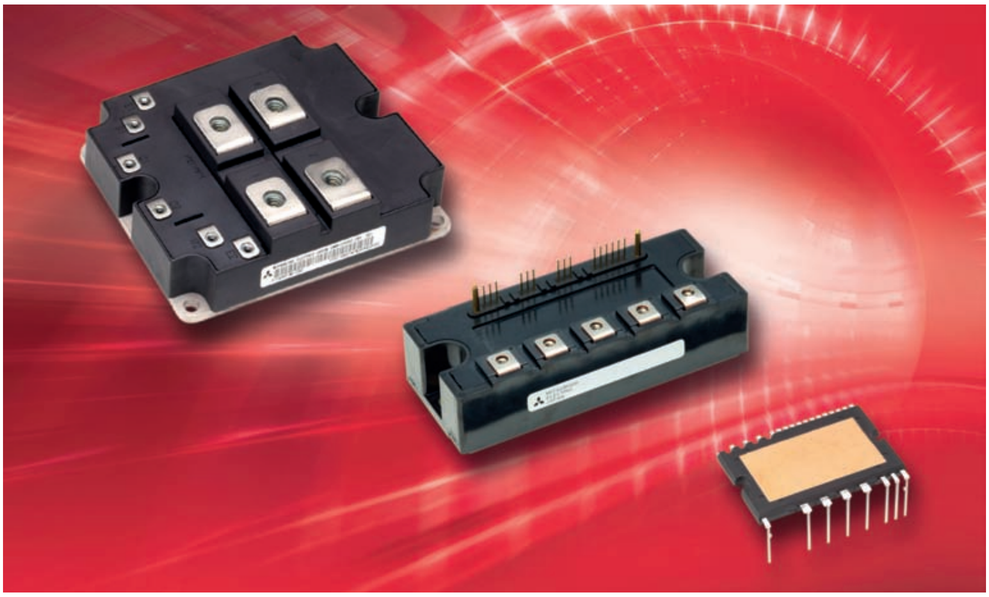
Brush Motor and Stepper Motor Drivers



Toshiba Electronics Europe has announced the availability of several new high-speed motor driver ICs that support high voltages and currents. The TB67H400A 2-channel DC brush motor driver and the TB67S10xA series of stepper motor drivers deliver the high speed, voltage and currents demanded by applications such industrial automation, CNC machines, home appliances, ATMs and banknote counters. All of the new drivers have a maximum 50 V rating and a low on resistance of 0.5 Ω (maximum, sum of the upper and lower side). The HTSSOP48 can be used for system downsizing, while continuous operation at high current is addressed by using a high-power dissipation package such as HZIP25. The HSOP package allows flow soldering on a paper phenolic board, which helps to reduce the cost of printed circuit board development. The TB67S10xA series of stepping motor driver ICs offers low heat-generation at high voltage and high current. Fabricated using the latest high voltage analogue process, the TB67S10xA series incorporates ADMD technology which automatically optimizes the drive current, improving switching speed and contributing to lower heat generation and higher drive efficiency.

The TB67H400A is a 2-channel motor driver IC for brush motors that supports a maximum operating current of 3.0 A (4.0 A rated) per channel for a 2-channel drive. A parallel channel control function also allows the device to operate as a single-channel driver delivering up to 6.0 A (8.0 A rated). It is available in four different package types to meet a number of specific customer requirements. Small packages, such as the QFN48 and HTSSOP48 can be used for system downsizing, while continuous operation at high current is addressed by using a high-power dissipation package such as HZIP25. The HSOP package allows flow soldering on a paper phenolic board, which helps to reduce the cost of printed circuit board development.

www.toshiba-components.com



Hybrid SiC Power Modules

Mitsubishi Electric Corporation has launched three different hybrid SiC power modules for use in home appliances, industrial equipment and railway traction applications. Depending on the target application three different versions in three different packages are available equipped with Si-IGBTs and SiC Schottky-barrier diodes (SBDs). Model PSH20L91B6-A, which is a Hybrid SiC DIPPFC™ (Transfer-molded-type IPM with integrated PFC), is designed for use in home appliances. PMH200CS1D060 – a Hybrid SiC-IPM – is intended for industrial applications, and the Hybrid SiC Module CMH1200DC-34S is designed specifically to fulfill the needs of railway traction applications.

In the Hybrid SiC DIPPFC™ for home appliances the SiC SBDs eliminate the recovery current of the free-wheel diodes and decrease EMI noise. The device is rated for 600 V/20 A. Switching frequencies up to 30 kHz enable designers to use smaller inductive components resulting in smaller form factors of the overall system. The integrated PFC circuit as well as the driver part further reduce the footprint and simplify the wiring patterns. In terms of package dimensions (24 mm x 38 mm) the PSH20L91B6-A devices are compatible with Mitsubishi Electric's Super Mini DIPIPM products. In the Hybrid SiC IPMs for industrial applications power losses are reduced by about 20 % compared to PM200CS1D060 (S1-IPM), therefore enabling smaller, more efficient equipment. The device is rated for 600 V/200 A. Both package (measuring 50 mm x 120 mm) and control terminals are compatible with Mitsubishi Electric's PM200CS1D060 (S1-IPM). The short circuit protection is integrated in the module. PSH20L91B6-A and the PMH200CS1D060 are equipped with a built-in drive circuit as well as with protection against undervoltage, overcurrent and overtemperature. The Hybrid SiC modules for railway traction systems reduce power losses by about 30 % compared to Mitsubishi Electric's CM1200DC-34N (N-series IGBT). The device is rated for 1700 V/1200 A. Package (140 mm x 130 mm) and terminals are compatible with Mitsubishi Electric's CM1200DC-34N (N-series IGBT).

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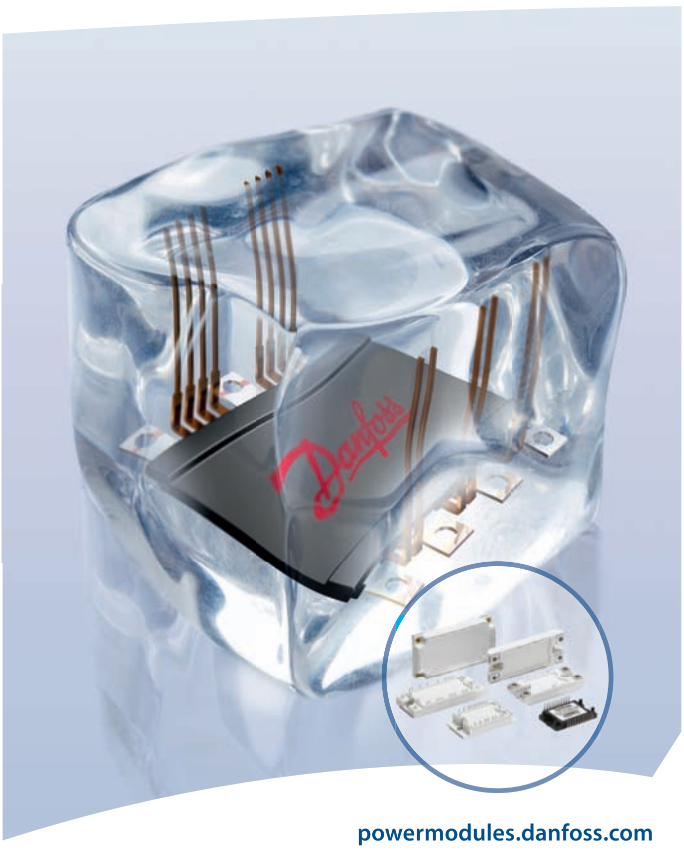

High-Power SiC Diodes

IXYS Corp. announced the introduction of the SS150 and SS275 Series High Power SiC Diodes by its Colorado division. Three configurations provide designers with flexible connection and layout options. Packaged in low inductance, surface mount DE Series package, these products are both available in 600 V/10 A and 1200 V/5 A ratings. Standard internal configurations include Triple Independent – no common connections, Triple Anode – anodes are tied together, and Triple Cathode – cathodes are tied together. The use of Silicon Carbide allows extremely fast switching, high frequency operation with zero recovery and temperature independent behavior. Coupled with low inductance RF package, these diodes can be utilized in any number of fast switching circuits or high frequency converter applications.

www.ixyscolorado.com

IGBT 4.5 kV Power Module

Infineon's new 4.5kV IHV module features highly insulating 6.5 kV housing offering enhanced protection by means of greater creepage and clearance distance and can be used in demanding environments. The module is based on IGBT 3 with trench field stop technology and a field stop diode. In combination with AlSiC base plate it guarantees low conduction and switching losses and thus high energy efficiency combined with robustness. The module is designed for currents between 400 A and 1,200 A and features enhanced DC stability. It can be used in an extended temperature range from -50 to 125°C. It retains its blocking capability completely even below 0°C. The new IHV module complements the existing product family, which currently consists of 3.3 kV, 4.5 kV and 6.5 kV classes, each in single-switch and dual-diode configurations. An extension of the 4.5 kV module class with a chopper and another diode configuration is planned for the beginning of 2014. For the first half of 2014 Infineon plans the launch of housing type B for applications in the area of medium voltage drives, power transmission including HVDC, and distribution and inverters for wind power stations.

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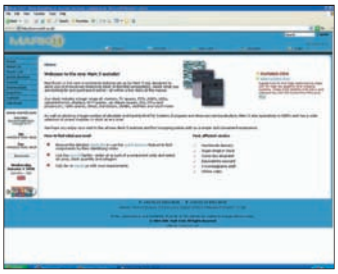

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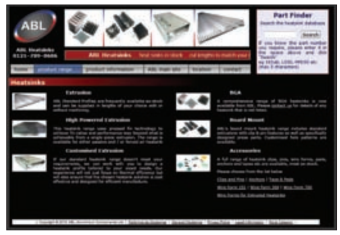

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Ultra-Low $R_{DS(ON)}$ Automotive COOLiRFET®

Package	$R_{DS(on)}$ Max@ 10Vgs (mΩ)	Q_G Typ (nc)	I_D Max (A)	RthjC Max	Part Number
	0.75	305	240	0.40°C/W	AUIRFS8409-7P
D²PAK-7P	1.0	210	240	0.51°C/W	AUIRFS8408-7P
	1.3	150	240	0.65°C/W	AUIRFS8407-7P
	1.2	300	195	0.40°C/W	AUIRFS8409
	1.6	216	195	0.51°C/W	AUIRFS8408
D²PAK	1.8	150	195	0.65°C/W	AUIRFS8407
	2.3	107	120	0.92°C/W	AUIRFS8405
	3.3	62	120	1.52°C/W	AUIRFS8403
	1.2	300	195	0.40°C/W	AUIRFSL8409
	1.6	216	195	0.51°C/W	AUIRFSL8408
TO-262	1.8	150	195	0.65°C/W	AUIRFSL8407
	2.3	107	120	0.92°C/W	AUIRFSL8405
	3.3	62	120	1.52°C/W	AUIRFSL8403
	1.3	300	195	0.40 °C/W	AUIRFB8409
TO-220	2.0	150	195	0.65 °C/W	AUIRFB8407
	2.5	107	120	0.92 °C/W	AUIRFB8405
	1.98	103	100	0.92 °C/W	AUIRFR8405
DPAK	3.1	66	100	1.52 °C/W	AUIRFR8403
	4.25	42	100	1.90 °C/W	AUIRFR8401
	1.98	103	100	0.92 °C/W	AUIRFU8405
IPAK	3.1	66	100	1.52 °C/W	AUIRFU8403
	4.25	42	100	1.90 °C/W	AUIRFU8401

The new International Rectifier AEC-Q101 qualified COOLiRFET® technology sets a new benchmark with its ultra-low $R_{DS(on)}$. The advanced silicon trench technology has been developed specifically for the needs of automotive heavy load applications offering system level benefits as a result of superior $R_{DS(on)}$, robust avalanche performance and a wide range of packaging options.

The COOLiRFET® Advantage:

- Benchmark $R_{DS(on)}$
- AEC Q101 qualified
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