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POWER MODULES

Novel Low Inductive Phase-Leg IGBT Module Eases Paralleling

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COVER STORY

Novel Low Inductive Phase-Leg IGBT Module Eases Paralleling

At PCIM 2015 ABB has introduced the LinPak, a new open standard phase-leg type IGBT module with a rating of 1700 V and 2 x1000 A and a footprint of 100 mm x 140 mm. This type of module will set a new standard in power density. We designed the LinPak to accommodate chipsets from 1200 V up to 3300 V. The LinPak IGBT module features an exceptionally low stray inductance enabling the full utilization of advanced low switching loss IGBT chipsets and even future full Silicon Carbide switch solutions. In addition the LinPak is ideally suited for parallel connection with negligible derating, thus a large range of inverter power can be realized with just one module type. Together with the open standard concept this module fulfills a long wish of the industry in nearly all high power segments such as traction & CAV (commercial, construction and agricultural vehicles), wind-power & solar and industrial drives to name a few.
Full story on page 15.

Cover supplied by ABB Switzerland Semiconductors.

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The Vital Role of Power Semiconductors

Growing population and economy of this planet require us to build up a sustainable society. In electric power conversion, more energy-saving and more resource-saving, efficient systems must be developed. Power devices are the key to develop more efficient electric systems. The advancement of power semiconductor devices has been and continues to be the key to more efficient power electronics to develop more energy-saving and more natural-resource-saving electric equipment and systems and to accelerate the shift from fossil to renewable energy resources for decelerating global climate change. Those activities of power semiconductor devices and power electronics will help the establishment of a sustainable society system. IGBT and power MOSFET are mainstreams of power semiconductor devices in the 30 to 40 years repeatedly improved by counting a number of their design-renewed generations. One important trend is recent and todays entrance to the market of new types of power semiconductor devices, such as RB- IGBT, RC-IGBT, and SJ MOSFET, to enhance the power density and to reduce the losses. Another important trend is starting of Wide Bandgap era in the market. The impact of WBG devices, such as SiC and GaN, are dramatic to enhance the power density and to reduce the losses greatly. Especially the effects of SiC devices are dramatic, expressed Tatsuhiko Fujihira, CTO Fuji Electric in his keynote at PCIM Europe 2015.

ABB introduced the LinPak IGBT module architecture (see our cover story), which features an exceptionally low stray inductance enabling the full utilization of low switching loss IGBT chipsets and even future full Silicon Carbide switch solutions. In addition the LinPak is ideally suited for parallel connection with negligible derating, thus a large range of inverter power can be realized with just one module type, according to the manufacturer. Also at PCIM Mitsubishi Electric announced the design of new 3.3/6.5 kV power modules designated Platform 1 together with a major European manufacturer – since Mitsubishi's fellow Gourab Majumdar denied that Infineon or Semikron will partner in this effort it could be ABB. Additionally the company will expand its SiC module offerings up to 1.2 kA in the 1200/1700 V range. And a Japanese consortium works on 3.5/10 kV SiC power modules. At PCIM 2014 Toshiba introduced a hybrid SiC power mododule and for this year we expected to see a full-SiC solution, but Chief Engineer Georges Tchouangue just announced plans to work on SiC MOSFETs rated 1200 V/47 A. On the other hand, Cree announced a 900 V SiC MOSFET device. Following its 1200 V MOSFETs, which exhibit superior performance to high voltage IGBTs, the new devices can outperform lower voltage superjunction Silicon MOSFETs. According to Cree, this platform delivers vastly superior characteristics, thereby providing power designers with the potential to innovate smaller, faster, cooler, and more efficient power solutions. Without question, it is beyond the reach of anything currently achievable with Silicon. Existing 900 V Silicon MOSFETs have severe limitations for high frequency switching circuits due to extremely high switching losses and poor internal body diodes. Further limiting the use of silicon MOSFETs is the on-resistance that increases 3 x over temperature, which causes thermal issues and significant derating. SiC is already in use in automotive power applications such as hybrid inverters (Toyota). And GaN certainly will find its way into these applications, Fujihira pointed out.

There are clear incentives for the automotive industry to consider GaN power devices. The possibility of obtaining a reduction of electrical power conversion losses leads to consideration of the value of increasing the number of EV/HEV units within the automotive manufacturers product mix. Clearly imposed fleet emission limits are the prime incentives; however range anxiety, battery and cooling system cost, also relate to power conversion efficiency. GaN devices built upon Silicon substrates will meet the needs of the automotive industry in terms of voltage and current rating. The suggested ratings for a GaN power transistor are a voltage blocking capability 600 V and minimum single-die current rating of 100 A. To directly compete with Silicon, and allowing no premium for higher performance (efficiency), the GaN transistor would have to be priced at less than $10/cm?. The future use of 8-inch (200 mm) wafers, on-chip drivers, and redundancy schemes to increase yields plus the removal of the need for anti-parallel reverse conduction diodes and the absence of massive heat removal systems and powerful drivers will help towards achieving the overall system cost target. The device cost target will become far less problematic. Cost is however very closely related to production volume. The EV/HEV penetration of the total automotive market is currently very small. The battery cost is the primary factor that determines the EV/HEV manufacturing cost. The growth potential for EV/HEV cars will be greatly improved as battery costs fall below $400/kWh. This close relationship has been recognized and an intense effort is being made to reduce battery costs even further. The EV/HEV combined sales are forecast to reach 30 million units annually by 2025.

All these subjects have been discussed in PEE's Special Conference Session "Power GaN for Automotive Applications" and PEE's Panel Discussion "Quo Vadis Power GaN". Already in our May issue we have published some related articles, more on that in this issue.

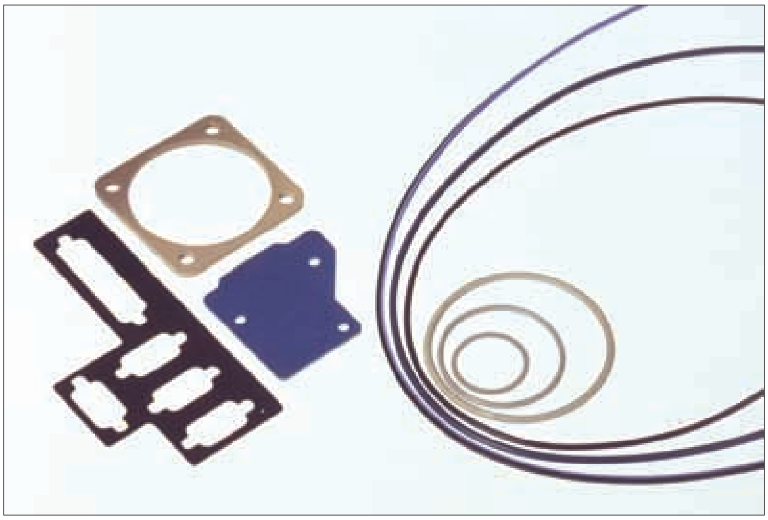
Enjoy reading!

Achim Scharf
PEE Editor

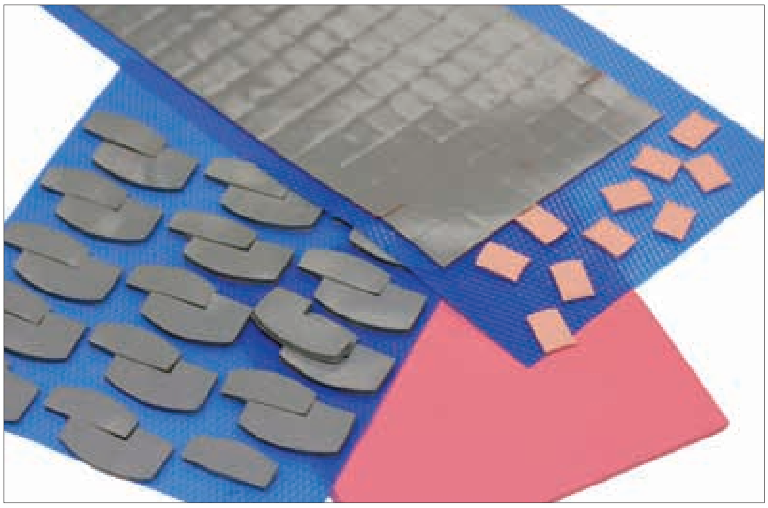
Thermal Interface and EMI Shielding for Automotive

The rapid development and evolution of both automotive electronics and vehicle electric drive systems has created EMI and thermal issues previously only encountered in military and aerospace systems. The upshot is an automotive community that today demands ever increasing standards of performance, longevity and reliability, while at the same time requiring significant reductions in cost over solutions delivered to the military and aerospace sectors.

Put simply, the high proliferation of electronic devices in vehicles has resulted in an increase in power consumption and power density. As a consequence, more efficient and more thermally conductive interface materials are required. However, in order to restrict weight and minimize costs, the automotive industry is pursuing more compliant materials that fill air gaps with wider tolerances and can be compressed under relatively low loads.



Chomerics automotive elastomers offer EMI shielding



Automotive gap filler and pad

Heat and EMI

Of course, any technical solution has to bear quality regulations in mind. Unfortunately, the close proximity of multiple electronic devices that have to operate in vehicles without causing interference has resulted in increasingly stringent standards. Furthermore, the advent of radars, higher frequency electronics and third party devices such as mobile telephones and navigational aids, means that shielding materials must prove effective in demanding operating conditions.

Depending on where the thermal or shielding materials are installed they may be subject to very different fluids, vibration and temperature cycling. With this in mind, an EMI gasket solution for use in the passenger cabin may not be suitable for the engine compartment, where elevated temperatures come into play. Similarly, it's unlikely to be the optimum solution on the braking system, where it may be exposed to salt and moisture from the road.

More extreme under-bonnet or external applications require the material to withstand the rigours of the road while simultaneously being compatible (from a galvanic perspective) with the conductive surfaces, which are usually aluminium. Typically this is done using either fluorosilicone or EPDM seals along with aluminium friendly conductive filler technology such as Ni/C, Ag/Al or Ni/Al. Alternatively, these sealing solutions can be deployed in conjunction with an environmental non-conductive seal.

Regarding electric drive and electronic controls systems on vehicles, these are also potential sources of electrical noise, as well as possible victims of interference. What's more, the heat generated in these devices will have to be dissipated, thus demanding the use of thermal solutions.

Nickel-plated conductive elastomers tend to deliver sufficient levels of EMI shielding for most applications and offer galvanic compatibility with aluminium structures under typical conditions, although in some instances extra precautions need to be taken to avoid corrosion issues. In the case of thermal interface materials, recent developments of one-component silicone gel technology has enabled the use of lighter structures with wider tolerances on electronic housings.

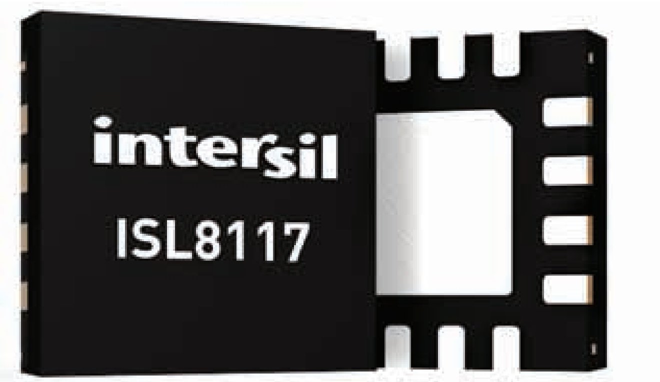
Ultimately, the advent of more electronics in vehicles and the drive for lower emissions will result in higher specification requirements for thermal interface materials and EMI shielding products. Some of this will be offset by integrating what is currently several electronic systems into fewer units, but there will undoubtedly be an ever increasing number of sensors and camera systems. In addition, the extensive use of radars are likely to result in increased requirements for microwave absorber type materials.

www.parker.com/chomerics

60V Synchronous Buck Controller Simplifies Power Supply Design

The ISL8117 is a synchronous buck controller to generate POL voltage rails and bias voltage rails for a wide variety of applications in industrial and general purpose segments. Its wide input and output voltage range makes it suitable for telecommunication and after-market automotive applications.

The ISL8117 uses the valley current modulation technique to bring hassle free power supply design with minimal number of components and complete protection from unwanted events. It offers programmable soft-start and enable functions along with a power-good indicator for ease of supply rail sequencing and other housekeeping requirements. In ideal situations, a complete power supply circuit can be designed with 13 external components and provide OV/OC/OT protections in a space conscious 16 Ld 4 mm x 4 mm QFN or easy to assemble 6.4 mm x 5 mm 16 Ld HTSSOP packages. Both package use an EPAD to improve thermal dissipation and noise immunity.

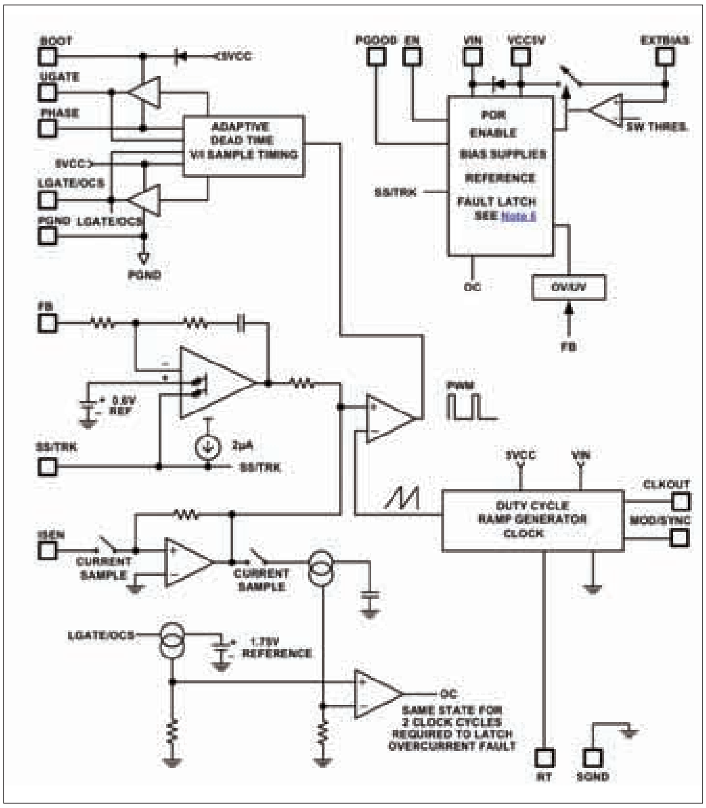


ISL8117 Buck controller chip

The ISL8117 utilizes internal loop compensation and single resistor settings for other functions such as operating frequency and overcurrent protection. Its current mode control with input-voltage feed-forward enables it to cover various applications even with fixed internal compensations. The unique DEM/Skipping Mode at light load lowers standby power consumption with consistent output ripple over different load levels.

The ISL8117 integrates control circuits for a synchronous buck converter. The driver and protection circuits are also integrated to simplify the end design. The part has an independent enable/disable control line EN, which provide a flexible power-up sequencing and a simple VIN UVP implementation. The soft-start time is programmable by adjusting the soft-start capacitor connected from SS/TRK. The valley current mode control scheme with input voltage feed-forward ramp simplifies loop compensation and provides excellent rejection to input voltage variation.

All the ISL8117 functions can be internally powered from an on-chip, low dropout 5V regulator or an external 5V bias voltage via the EXTBIAS pin. Bypass the linear regulator's output (VCC5V) with a 4.7μF capacitor to the power ground. The ISL8117 also employs an undervoltage lockout circuit, which disables all regulators when VCC5V falls below 3.5V. The internal LDO can source over 75 mA to supply the IC, power the low-side gate driver and



ISL8117 block diagram

charge the boot capacitor. Whendriving large FETs at high switching frequency, little or no regulator current may be available for external loads. For example, a single large FET with 15 nC total gate charge requires 15 nC x 300 kHz = 4.5 mA (15 nC x 600 kHz = 9 mA). Also, at higher input voltages with larger FETs, the power dissipation across the internal 5 V will increase. Excessive dissipation across this regulator must be avoided to prevent junction temperature rise. Thermal protection may be triggered if die temperature increases above +150°C due to excessive power dissipation.

Gate driver

The low-side gate driver is supplied from VCC5V and provide a 2 A peak sink and source current. The high-side gate driver is also capable of delivering the same currents as the low-side gate driver.

Gate-drive voltage for the upper N-Channel MOSFET is generated by a flying capacitor boot circuit. A boot capacitor connected from the BOOT pin to the PHASE node provides power to the high-side MOSFET driver. To limit the peak current in the IC, an external resistor may be placed between the BOOT pin and the boot capacitor. This small series resistor also damps any oscillations caused by the resonant tank of the parasitic inductances in the traces of the board and the FET's input capacitance.

At start-up, the low-side MOSFET turns on first and forces PHASE to ground in order to charge the BOOT capacitor to 5 V. After the low-side MOSFET turns off, the high-side MOSFET is turned on by closing an internal switch between BOOT and UGATE. This provides the necessary gate-to-source voltage to turn on the upper MOSFET, an action that boosts the 5 V gate drive signal above VIN . The current required to drive the upper MOSFET is drawn from the internal 5 V regulator.

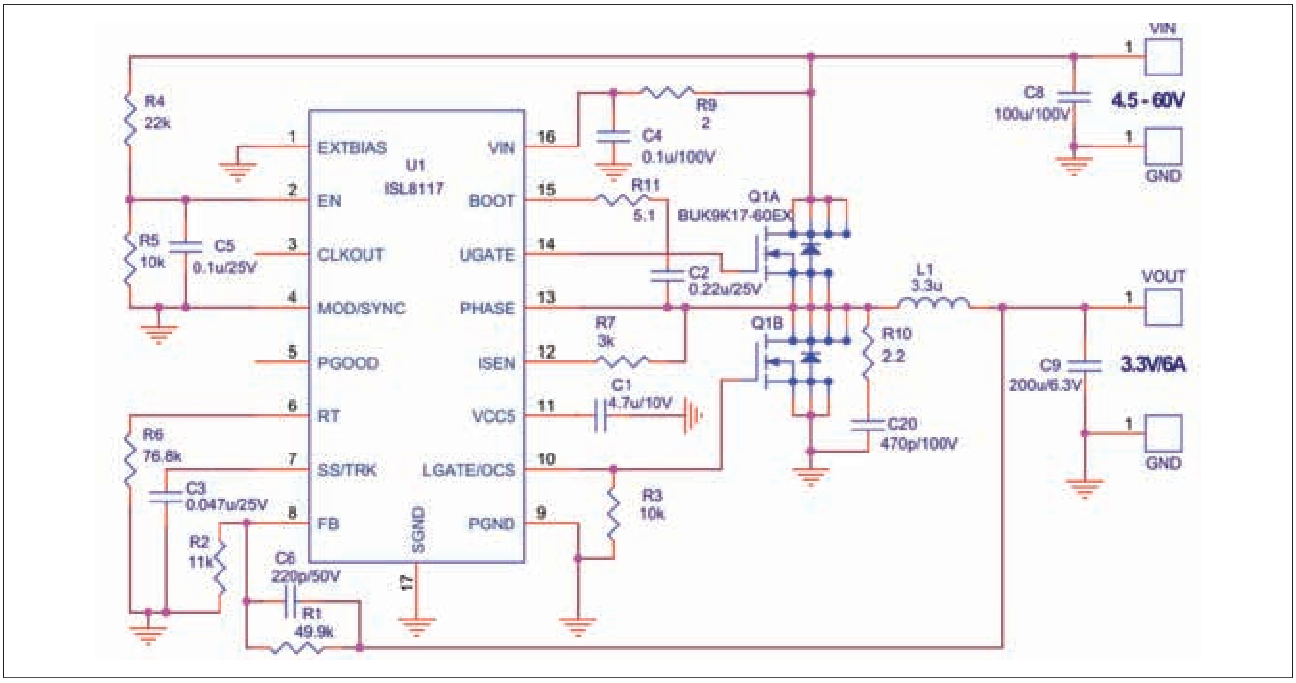
External power MOSFETs

The logic level MOSFETs are chosen for optimum efficiency given the potentially wide input voltage range and output power requirement. Two N-Channel MOSFETs are used in the synchronous-rectified buck converters. These MOSFETs should be selected based upon on-resistance, gate supply requirements and thermal management considerations.

When large MOSFETs are used, an external 5 V bias voltage can be applied to the EXTBIAS pin to alleviate excessive power dissipation. Voltage at the EXTBIAS pin must always be lower than the voltage at the VIN pin to prevent biasing of the power stage through EXTBIAS and VCC5V. An external UVLO circuit might be necessary to guarantee smooth soft starting.

The ISL8117 incorporates an adaptive dead time algorithm on the synchronous buck PWM controller that optimizes operation with varying MOSFET conditions. This algorithm provides approximately 16 ns dead time between the switching of the upper and lower MOSFETs. This dead time is adaptive and allows operation with different MOSFETs without having to externally adjust the dead time using a resistor or capacitor. During turn-off of the lower MOSFET, the LGATE voltage is monitored until it reaches a threshold of 1V, at which time the UGATE is released to rise. Adaptive dead time circuitry monitors the upper MOSFET gate voltage during UGATE turn-off. Once the upper MOSFET gate-to-source voltage has dropped below a threshold of 1V, the LGATE is allowed to rise. It is recommended to not use a resistor between UGATE and LGATE and the respective MOSFET gates as it may interfere with the dead time circuitry.

www.intersil.com/products/isl8117



ISL8117 typical application

Capacitors for Power Electronics

IGBT Snubbers

RF Mica Capacitors

DC Link Capacitors

-High Current, High Voltage Film

-High Capacitance Aluminum Electrolytic

AC Output Harmonic Filter Capacitors

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Electrification Spurs Automotive Powertrain Semiconductor Market Growth

The automotive powertrain semiconductor market grew 8.3 % in 2014, according to recent analysis from IHS. Increasing volumes of new vehicles and the need for fuel efficient vehicle technologies were the main drivers contributing to this growth.

IHS forecasts that revenues related to powertrain semiconductors will increase with a compound annual growth rate (CAGR) of nearly 6 % in the next five years from $7.2 billion in 2014 to $9.5 billion in 2019. Electrification is propelling the powertrain semiconductor market on a global scale. As an example, start-stop systems are forecast to grow at a CAGR of 21 %, while plug-in hybrid vehicles are expected to have a strong annual growth of 37 % for the next five years. In addition, for internal combustion engines, there is an increasing trend away from traditional incumbent multi-port fuel injection systems towards gasoline direct injection systems. Direct injection systems are more efficient and require higher semiconductor content than their multi-port counterparts.

"Propulsion systems for electric and hybrid vehicles demand, on average, 10 times more semiconductor content than a conventional engine, said Ahad Buksh, analyst, automotive semiconductors at IHS. "Without electrification, the powertrain semiconductor market would have only grown 3.1 % annually for the next five years, whereas electrification is now accelerating the market at 6 % growth rate annually."

Electrification is a major revenue generator for powertrain in the coming years. Some key components include the motor inverter, DC/DC converter, battery management system and plug-in charger, all of which require power management by analog ICs and discrete components. Growth rates are expected to be high, as the market is currently relatively small. These applications saw growth of 24 % in 2014 and another 22 % increase is forecast in 2015, the highest of any automotive semiconductor application. From a revenue perspective, semiconductor content in electric and hybrid vehicles are expected to generate more than $1 billion in total revenue growth from 2014 to 2019, by which time IHS forecasts that $1.6 billion will be generated in this segment.

Emissions legislation efforts in most regions around the world are the main drivers for semiconductor sales in powertrain applications, while current concepts in engines and exhaust after-treatment systems for ICEs, together with a requirement for on-board diagnostics, require sensors for their operation. As a result, the market for semiconductors in internal combustion engines was $4.3 billion in 2014, growing to $5.4 billion in 2019. The engine control unit (ECU) consumes most of the semiconductor content in these applications, in addition to a growing trend toward electrification of various components – including fans, water pumps and oil pumps that will further contribute to powertrain semiconductor revenues in the future. Leading the path for growth, however, is the stop-start system.

www.ihs.com

Infineon Leads Several EV/HEV Research Project

The research project "HV-ModAL" aims to make the drive train of electric vehicles even more powerful than the current ones. Within the next three years, HV-ModAL wants to create an electric drive train modular system toolbox, which is suitable for a wide range of electric cars from various manufacturers. Thus, the ten partners from the whole automotive value chain and the sciences intend to further expand the global market position of the German automotive industry in the field of electric vehicles – purely electric, plug-in hybrids and small transport vehicles. The power bandwidth should be between 50 and 250 kW with the range of the vehicles further extended. Today, 125 kW and a range of 150 km are typical. HV-ModAL is a German acronym that translates as "Modular drivetrain topologies for electric vehicles with high power".

During the first project stage, the HV-ModAL research partners intend to come to an understanding of electric drive platforms that is shared throughout the automotive value creation chain. Then they will conduct extensive concept and component research to determine the individual components that can be best coordinated with each other for such electric drive platforms. Among other things, research will address IGBT power modules for high-power drives up to 250 kW and high voltages of up to 900 V, modular multi-level DC/DC converters, batteries with integrated DC/DC converters, and system components for batteries over 600 V. To describe and define these components, then best tune them to one another, the partners are constructing a common, flexible system simulation model for different vehicle platforms. To verify the theoretical results, optimized components and architectures will be built as demonstration models, and tested. The results will be the basis for the HV-ModAL system designs, and ultimately the modular system toolbox for the broadest possible range of electric drives. Over the duration of the project, about Euro 7.5 million will be invested. About 50 % of that amount will be funded by the German Federal Ministry of Education and Research (BMBF). The project will run until December 31, 2017. Infineon Technologies has the project lead. Others include the automobile manufacturers BMW AG and Daimler AG, the automobile system supplier Robert Bosch GmbH, the drive system developer AVL with its subsidiaries in Stuttgart and Regensburg, the Fraunhofer Institute for Integrated Systems and Device Technology (IISB) in Erlangen, the Leibnitz Universität Hannover, the Universität der Bundeswehr München and RWTH Aachen University.

Additionally the "Luftstrom" research project investigates how batteries in electric vehicles can be charged more efficiently. Luftstrom (Airstream) will help accelerate the conversion to climate-friendly mobility. Twelve partners in the German automotive sector, its supply industry and the sciences are collaborating on this project for the next three years. The use of new power semiconductors is expected to reduce losses during charging and, ultimately, make charging almost noiseless.

Electric vehicles are mainly charged overnight. However, charging in the charging device and voltage regulators creates heat that fans of water-cooled aggregates have to dissipate, for example. This can be quite noisy. As a result of the Luftstrom research, the electronic power components will lower the losses during charging by 30 %. This means lower waste heat – and with less cooling effort the cooling units become more compact and operate more quietly. Components that already cause very few losses, such as auxiliary power supplies, might even be able to do without the previously required water cooling – which means that the loud fans would be eliminated. The key to low-loss power electronics lies in state-of-the-art power semiconductors based on GaN)or SiC. The Luftstrom project will therefore also determine how such power semiconductors can be used reliably in charging devices, voltage regulators and inverters for auxiliary power units. Its research results will accelerate the transition to air-cooled and fan-less systems for future generations of electric vehicles.

The German Federal Ministry of Education and Research (BMBF) is contributing funding in the amount of about Euro 3.9 million to the Luftstrom research. Infineon Technologies has the project lead. The other project partners include AVL Software and Functions GmbH, BMW AG, Daimler AG, Fraunhofer Institute for Integrated Systems and Component Technology IISB, the University of Applied Sciences Ostwestfalen-Lippe, Lenze Drives GmbH, Robert Bosch GmbH, RWTH Aachen University, Siemens AG, Leibniz University Hannover, and Volkswagen AG.

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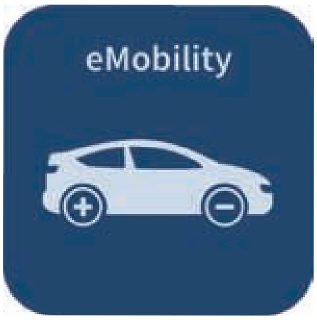


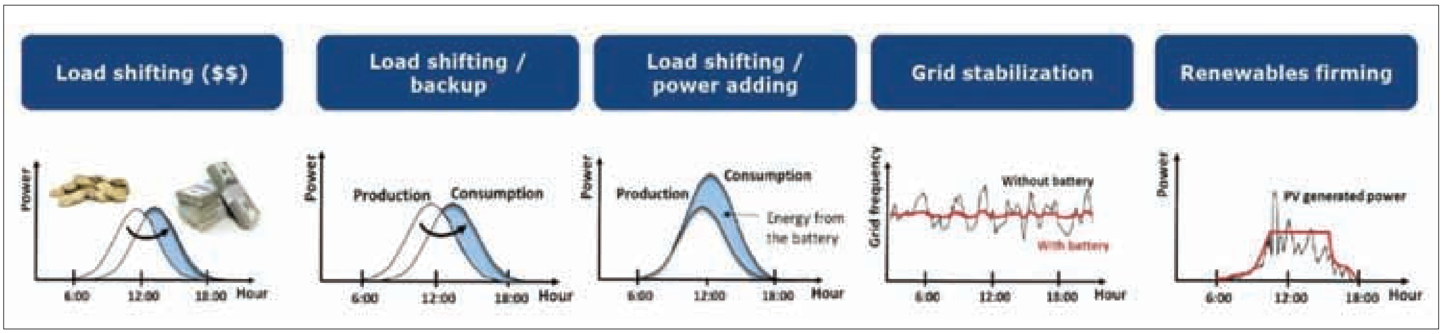
EV/HEV Players Drive Stationary Battery Energy Storage Business

The recent announcement of Tesla battery storage solution called Powerwall, confirms the trends towards massive deployment of distributed stationary storage systems. Automated, compact and simple to install, it offers independence from the utility grid and the security of an emergency backup.

"Rechargeable batteries are particularly suitable for distributed energy storage. Although using a battery as an energy storage solution is decades old, new battery technologies are still maturing and their future cost decrease is expected to significantly speed up the development and deployment of existing and new technologies and applications, thus leading to new business opportunities. The growing electric vehicle/hybrid electric vehicle (EV/HEV) market is a game changer driving battery performance improvement and cost decrease. The new Tesla positioning on both EV/HEV and stationary batteries helps it to increase the market volume and to reduce the production costs", explains Yole's Senior Analyst, Energy Conversion & Emerging Materials, Dr Milan Rosina. "The growing of electric vehicle/hybrid electric vehicle market is currently reshaping for the stationary battery market".

The modular characteristic of battery systems means their size and features can be optimized for very different requirements in a multitude of applications. In particular, their fast demand response capability widens the scope of services (frequency regulation, etc.) that could be provided by batteries, compared to other energy storage technologies. Different battery technologies are commercially available, safe, proven, and used in daily life. The same battery technology can be used in many different applications (stationary/portable/transport) enabling lower production cost because of higher cumulated production volume, common battery technology development, and simpler logistics. Decreasing battery cost allows broader deployment in both existing and new applications. There is still great potential for further cost reduction and performance enhancement of battery systems. "The development and cost decrease of lithium-ion batteries, very suitable for applications in transport, will largely be driven by the growing EV/HEV market", details Rosina. This strong driving force will result in a battery technology consolidation associated with decreasing market share for more mature battery technologies (lead acid, NiMH…). All energy storage technologies currently under development or already being commercially deployed have to face strong competition from Li-ion batteries that have the advantage of high energy density, high power density, high modularity, and decreasing costs.

www.yole.fr



Some benefits of using stationary battery systems **(Source: Yole)**

Transphorm Announces New $70 million GaN Investment

Transphorm Inc. announced a $70 million investment round led by global investment firm KKR. This investment follows initial rounds of funding from funds affiliated with Kleiner Perkins Caufield and Byers, Foundation Capital, Google Ventures, Soros Quantum Strategic Partners, INCJ, Fujitsu. Transphorm will use this funding to support its growth, product innovation and expansion.

"Gallium Nitride is the most important new semiconductor in the world today," said Dr. Shuji Nakamura, 2014 Nobel Laureate in Physics and Director of the Solid State Lighting and Energy Electronics Center (SSLEEC) at UC Santa Barbara. "My invention of the GaN-based LED and Solid State Lighting has changed the world in illumination. Gallium Nitride is also the best material for power conversion and is essential to eliminate the enormous amount of energy wasted in these processes. GaN-based power conversion products will have the same positive impact on energy we saw with LED-based lighting." GaN power devices provide a power efficiency of up to 98 % in data centers and telecom applications, resulting in energy savings of over 10 GWh annually in a typical datacenter, or the equivalent of the annual electricity usage of 1,000 typical U.S. homes. In addition to PV inverters and datacenters, other applications for GaN technology include power supplies, motor drives and automotive systems. Transphorm has established strategic partnerships with industry-leading customers and suppliers. Yaskawa Electric Corporation, launched the first GaN-based commercially produced solar photovoltaic (PV) inverter, powered by Transphorm GaN, in the Japan market earlier this year. GaN products enable approximately 50 % smaller PV inverters in residential and small commercial installations up to 5 kW, resulting in lower system, installation, and service costs while at the same time delivering more energy per solar panel to the grid. Tata Power Solar has also teamed with Transphorm to develop leading edge PV inverters. In order to provide customers with high quality volume production, Transphorm partnered with Fujitsu Semiconductor, to produce its products in Fujitsu's automotive-class wafer fabrication facility in Aizu-Wakamatsu, Japan. "In the long term, we believe GaN has the potential to replace all of the existing Silicon-based technology used in high voltage products, and wide adoption of this technology will dramatically reduce the amount of energy that is wasted by electric devices," David Kerko, Senior Advisor of KKR, added.

www.transphormusa.com

Amantys acquired by Maschinenfabrik Reinhausen

Amantys, an IGBT-driver specialist based in Cambridge (UK) announced in March to close its operations after burning around €15 million funding in its 4-years existence. Amantys was founded by former ARM executives and Cambridge University. Regensburg-based Maschinenfabrik Reinhausen recently acquired all industrial property rights, including patents and brands, of Amantys Ltd., along with the bulk of the company's technical facilities and equipment.

Maschinenfabrik Reinhausen, a traditional family-run company headquartered inRregensburg/Germany, is a leader in the regulation of power transformers with on-load tap-changers. This acquisition marks the completion of another important stage in the implementation of its long-term technology strategy. The technologies acquired are an important element as the Reinhausen group expands its skills and expertise for application in power electronics. The acquisition opens up a wide variety of new technological possibilities for expansion and optimization of the future product and application portfolio. In May Reinhausen decided to found a wholly-owned subsidiary in Cambridge called Amantys Power Electronics Ltd. The company's areas of activity will include research and development as well as the manufacture, marketing, and sales of products and services for power electronics and the regulation and control of electrical networks. The team will include a number of employees who previously held important positions at amantys ltd. One of the first steps will be to reactivate and optimize the existing product portfolio. At the same time, innovative technologies will be further developed as a collaborative effort between development partners and customers. "Reinhausen's involvement will safeguard the continued development of established IGBT driver technologies. But we will focus on more customer-specific solutions", underlined Uwe Kaltenborn, Head of Corporate Technology.

www.reinhausen.com

"Maschinenfabrik Reinhausen continue Amantys' IGBT driver business in a more customer-specific manner" stated Uwe Kaltenborn at

StarPower Builds R&D Center in Nuremberg

Starpower's power semiconductor module production in Jiaxing/China

StarPower Europe AG, the European subsidiary of the Chinese power semiconductor manufacturer StarPower Semiconductor Ltd, is building a European development center in Nuremberg, Germany. The company will invest close to a million Euros in the laboratory. The goal is to test new technologies and materials for power modules, and ransfer the gained know-how to the production in China.

Christian Kroneder, formerly employed at Semikron, is responsible for building the R&D Centre and is simultaneously heading the development team in the headquarters. "We are testing prototypes and acquiring the respective production and testing equipment in Germany, from the bonder to the sintering press, in order to build and test modules'" Kroneder stated. "New technologies, packages and materials are being tested, such as the sintering of semiconductor chips to substrates. All these technologies lead to greater power cycling and reliability of the modules. This in turn plays a major role in specific applications, such as the automotive area and wind energy. The R&D Centre ensures that innovations and trends within Europe are integrated into the development of future products". A 240 m? space was leased and remodelled to accommodate the offices and laboratories. The process engineers and developers from the headquarters are involved from the beginning and are trained in Nuremberg, so that the know-how can be easily transferred into the series production of semiconductor modules. "Nuremberg is with its scientific and industrial power electronics activities ideally suited for R&D. We expect to add new employees to our existing staff of four people", Kroneder underlined. In fiscal year 2014 StarPower, with 350 employees, achieved a record turnover of $70 million.

www.starpowereurope.com

Novel Low Inductive Phase-Leg IGBT Module Eases Paralleling

ABB has introduced the LinPak, a new open standard phase-leg type IGBT power module with a rating of 1700 V and 2 x 1000 A and a footprint of 100 mm x 140 mm. This type of module will set a new standard in power density. LinPak is designed to accommodate chipsets from 1200 V up to 3300 V. A 3300 V module version will follow early next year. **Raffael Schnell, Samuel Hartmann, Dominik Trüssel, Fabian Fischer, Andreas Baschnagel and Munaf Rahimo, ABB Switzerland Semiconductors**

The LinPak IGBT module features an exceptionally low stray inductance enabling the full utilization of advanced low switching loss IGBT chipsets and even future full Silicon Carbide switch solutions. In addition the LinPak is ideally suited for parallel connection with negligible derating, thus a large range of inverter power can be realized with just one module type. Together with the open standard concept this module fulfills a long wish of the industry in nearly all high power segments such as traction and CAV (commercial, construction and agricultural vehicles), wind-power and solar and industrial drives to name a few.

Figure 1: ABB's low inductive LinPak IGBT module for reliable high-power converters

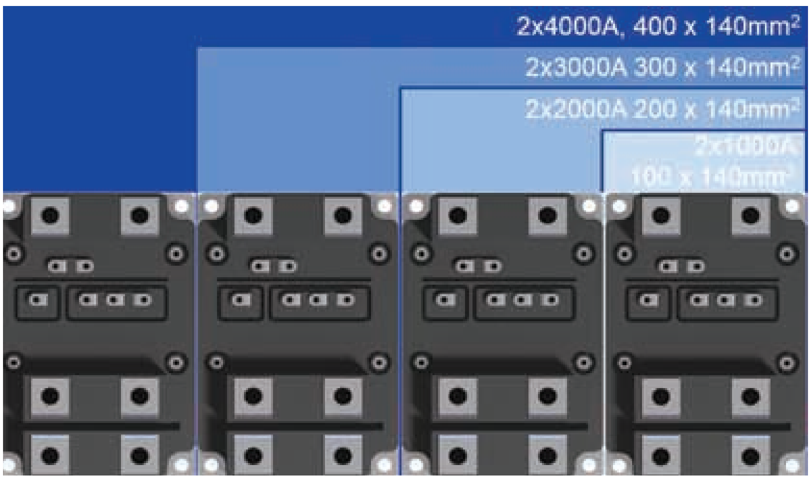


Figure 2: LinPak scalability

Open standard approach

Present IGBT module solutions are at its limit when it comes to advanced and faster IGBT/diode chipsets since the overall stray inductance per switched ampere is too large and high over-voltage will occur. In addition, the available electrical contact area of today's modules is limited and dates back to times when the packages were rated with 50 % less current than now. Due to today's modules' lack of scalability, a large variation of outlines exist to match various inverter ratings. The presented LinPak module concept (Figure 1) addresses all these issues and is published as an open standard, meaning module manufacturers can freely adopt the outline and customers benefit from a standard solution provided by more than one supplier making inverter designs easier.

The LinPak offers as well exceptional low stray inductance of 10 nH and an easy customer interface enabling the construction of a very low inductive DC connection with sufficient contact area for the high current densities. This is the ideal fit for the full utilization of the advanced fast IGBT/diode chipsets such as the latest 1700V SPT+ technology. It also makes the package fit for future hybrid and full SIC solutions that come with much higher switching speeds.

Besides the very advanced and novel package concept, the LinPak features

Module Type	Current Rating	Foot-print	Current / Area
LinPak	2 x 1000A	100 x 140mm²	14.3Acm^{-2}
HiPak	3600A	140 x 190mm²	13.5Acm^{-2}

Table 1: Current density of LinPak compared to other module types

Module Type	Nominal current	Phase current	Amp / M8 screw (phase terminals)	Amp / M8 screw (DC terminals)
LinPak	1000A	707A	354A	250A
HiPak	3600A	2546A	600A	600A

Table 2: Current per M8 screw connection

ultra-sonic welded terminals and an advanced high reliability solder joint between the AIN substrate and AlSiC baseplate material combination. In addition, the well-established high temperature cycling capable bonding technique and the gate-print to substrate aluminum bond interconnect from the improved HiPak are incorporated in the new LinPak design.

Module scalability and record current density

The LinPak module type offers the benefit that just one module type is needed per voltage rating. Thanks to a homogenous current path concept, the module enables parallel connection of more than four modules without any significant derating (Figure 2). The current density offers a solid improvement of more than 10 % compared to older module types on the market as shown in Table 1.

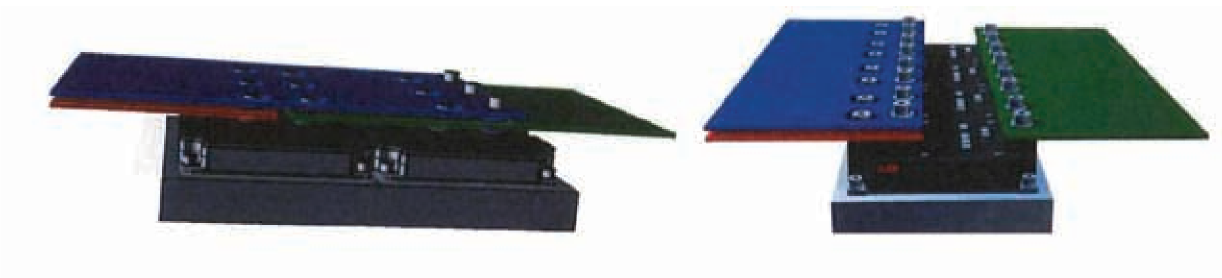
Mechanical concept and connections

The gate-unit connection is realized with a simple adapter-board (PCB) directly mounted onto the module between AC and DC terminals. The connection to the auxiliary terminals for gate, emitter, collector and thermistor are realized with M3 screws. In addition, four molded M3 nuts are positioned in the corners to mechanically fix the adapter board in harsh environmental applications like traction or CAV. The adapter-board connects the modules' gates and aux emitters in parallel. Thus, many modules can be connected in parallel with just one gate-unit.

The power connections are designed to enable an absolute symmetrical DC connection, which is crucial for excellent current sharing. The creepage and clearance distances are designed according to IEC 60664-1 and EN 50124-1 for functional insulation up to a device rating of 3300 V.

The LinPak offers the highest contact area per rated current. Table 2 compares the current per M8 screw for various packages. To compare the various package types, the phase current is calculated with the device nominal current divided by 1.414. Because of the high contact area heating of the contact interface and the terminal itself is much reduced compared to HiPak or PrimePack modules.

Present module designs have rather high stray inductance values causing high over-voltages. This makes the use of advanced fast chipsets – such as the ABB 1700V SPT++ chipset – difficult and the



	HiPak (1.7kv / 3600A)	4 LinPak (1.7kV / 4000A)
Module inductance	16nH	2.5nH (10nH for a single module)
Bus-bar inductance	10nH	1.5nH
Capacitor inductance	1.5nH	1.5nH
Total (module including DC-link)	27.5nH	5.5nH (22nH for a single module)
$L_\sigma \cdot I_{nom}$ (3600A)	99µVs	19.8µVs
Over-voltage @ t_f = 0.12µs (1700V SPT^{++})	**825V** ***100%***	**165V** ***20%***

Figure 3: Stray inductance including bus bar LinPak vs HiPak

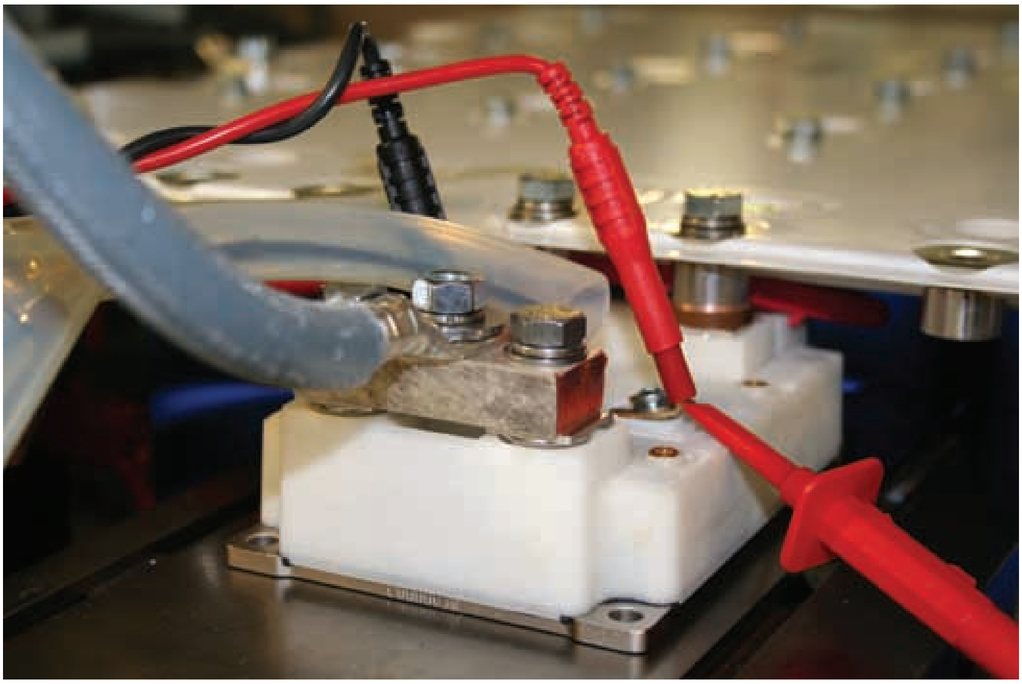


Figure 4: Double pulse test setup

use very fast future SiC solutions close to impossible.

The LinPak is designed to offer the lowest internal stray inductance current thus enabling low inductive bus bars. Figure 3 compares the LinPak with a HiPak including a bus bar and an assumed DC-capacitor inductance of 1.5 nH. Still when including the bus bar and capacitor, the over-voltage is below critical levels compared to the HiPak solution – even with fast chipsets. This allows for parallel

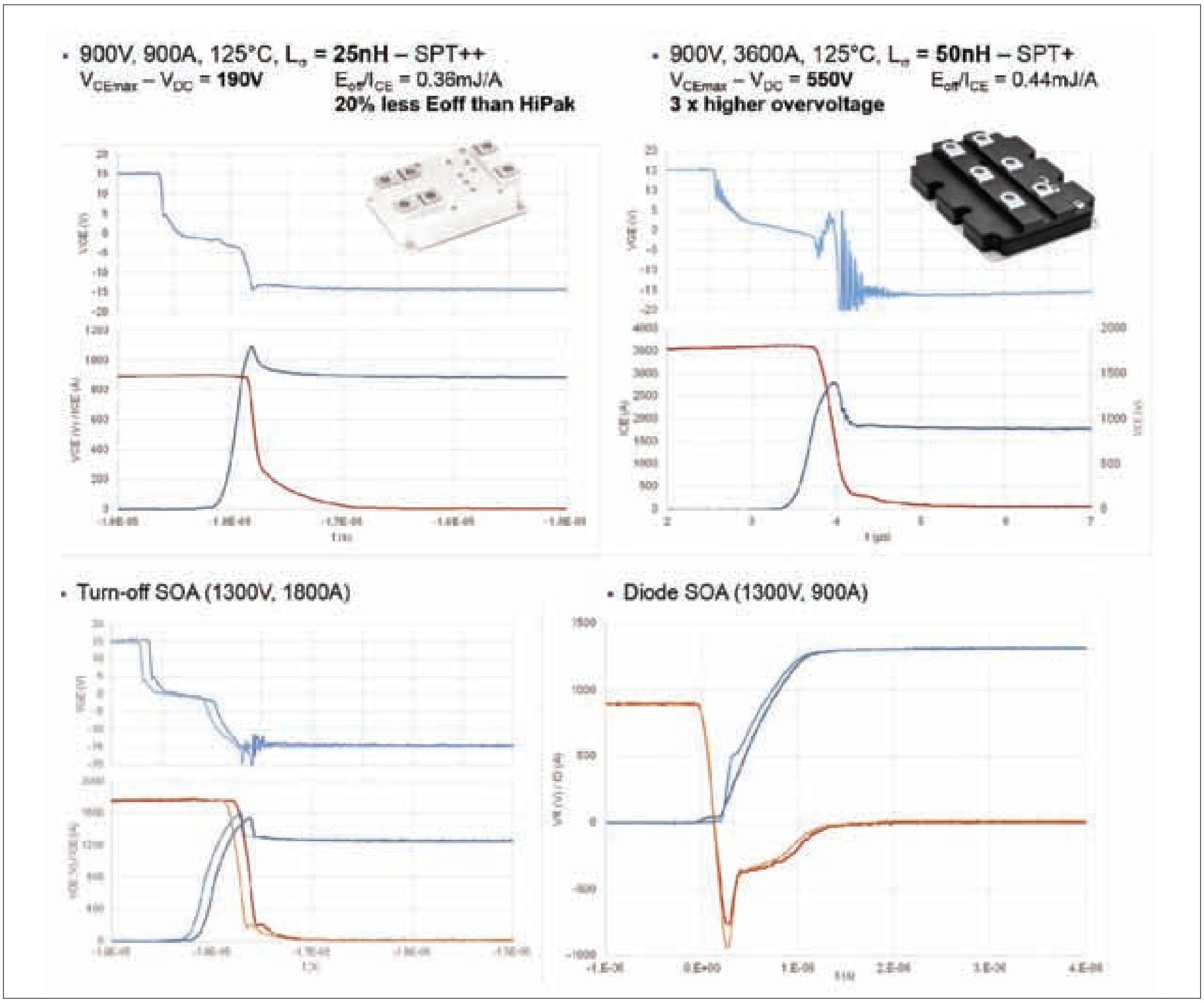


Figure 5: LinPak nominal turn-off switching compared to HiPak (top), LinPak and diode SOA at 125°C (bottom)

connection up to high current applications without compromising the switching losses.

Electrical measurements of prototype modules

Prototype modules with a current rating of 2 x 900 A have been tested in a double pulse test setup at a realistic customer DC-link with laminated bus bars specifically designed for the new LinPak (Figure 4).

The measurements fully confirmed what was expected from the LinPak concept. The tests revealed that an overall DC-link stray inductance including module, bus bar and capacitors of about 25 nH can be achieved already with the prototype module. As a result, the over-voltage from the switching stays well within the maximum device rating and snappy diode recovery can be considered as a term of the past.

Figures 5 (top) shows the LinPak and HiPak IGBT module switching waveforms at nominal conditions. The LinPak shows very smooth switching characteristics with three times lower over-voltage and 20 % less switching losses compared to an equivalent HiPak module. The modules have also been tested up to the specified SOA (Safe Operating Area). Thanks to the low stray inductance no active clamp was needed to limit the IGBT over-voltage and both, IGBT and Diode SOA show very clean waveforms (bottom).

Conclusions and outlook

The LinPak is a new open standard module that satisfies the requirements posed by both new advanced fast and high current density chipsets as well as customer wishes for a flexible and scalable IGBT module that is, in addition, ready for future technologies such as SiC devices. The benefits of the novel low stray inductance LinPak IGBT module are clearly demonstrated and measurements confirmed the expectations into the new module.

Today, the benefits of the new package enable the customer to profit from the latest chip technologies with low inductance for achieving the highest current density. Furthermore, particle free ultrasonic welding of the main terminals, advanced wire bonding including the well-established AlN / AlSiC substrate / baseplate material combination for high temperature cycling capability are incorporated.

Looking ahead, the new module also allows a smooth phase-in of future technologies both on chip level with respect to Silicon and SiC based devices as well as on advanced material joining techniques as they become available for cost efficient mass production without major changes in the converter design.

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Automotive Opportunities for Power GaN

This article includes studies of the market opportunity, current performance and projected performance of very large area GaN devices that have applicability to the automotive market. Comparisons are made regarding the performance differences between SiC, GaN, and IGBT devices. A yieldable large area 650 V/100 A GaN device is described. **Girvan Patterson, GaN Systems Inc, Ottava, Canada**

Large GaN power devices are currently at the introduction phase. Very rapid market growth is expected within the next five years leading to sales exceeding $500 million by 2020. Yole has published a market research report (June 2014) that identifies EV/HEV applications as being a key element of the market opportunity. Ramp-up will be quite impressive starting in 2016, at an estimated 80% CAGR (see Figure 1).

There are clear incentives for the automotive industry to consider GaN power devices [1, 2, 3, 4, 5, 6]. The possibility of obtaining a reduction of electrical power conversion losses leads to consideration of the value of increasing the number of EV/HEV units within the automotive manufacturers product mix. Clearly imposed fleet emission limits are the prime incentives; however range anxiety, battery and cooling system cost, also relate to power conversion efficiency (see Figure 2).

GaN devices built upon Silicon substrates will meet the needs of the automotive industry in terms of voltage and current rating. The suggested ratings [1] for a GaN e-Mode power transistor are a voltage blocking capability 600 V and minimum single-die current rating of 100 A. To directly compete with Silicon, and allowing no premium for higher performance (efficiency), the GaN transistor would have to be priced at less than $10/cm^2$ [1]. The future use of 8-inch (200 mm) wafers, on-chip drivers, and redundancy schemes to increase yields plus the removal of the need for anti-parallel reverse conduction diodes and the absence of massive heat removal systems and powerful drivers will help towards achieving the overall system cost target. The device cost target will become far less problematic.

Cost is however very closely related to production volume. The EV/HEV penetration of the total automotive market is currently very small. The battery cost is the primary factor that determines the EV/HEV manufacturing cost. The growth potential for EV/HEV cars will be greatly improved as battery costs fall below $400/kWh. This close relationship has been recognized and an intense effort, as shown in Figure 3, is being made to reduce battery costs even further. As shown, the EV/HEV combined sales are forecast to reach 30 million units annually by 2025.

While light EV/HEVs constitute the dominant the potential market area for GaN power switch devices there are other related applications. Figure 4 shows the forecast for the relative value for various sectors of the Electrically Powered Vehicle market. By 2025 it is expected that the light EV/HEV will make up 33 % of the market, while Buses, Military and Forklift vehicles will each hold approximately 13 to 16 % of the market. Diversity will ensure that there will be a large variety of power semiconductor types required.

The automotive market opportunity is possibly the largest that can be addressed by GaN devices. The current market is being served by IGBTs, which are low cost and well understood

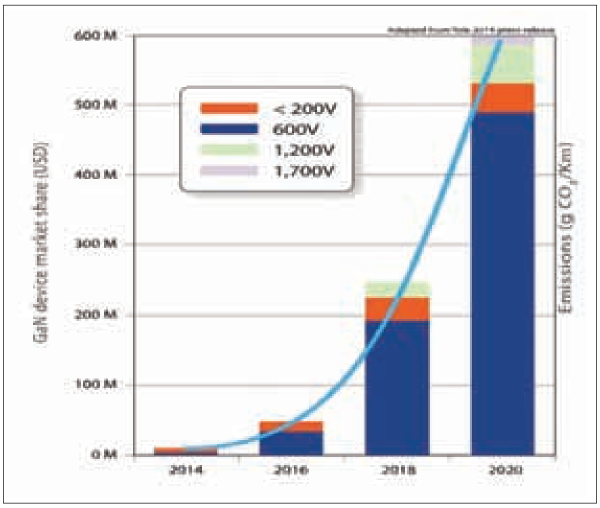

Figure 1: Market opportunities for GaN power transistors

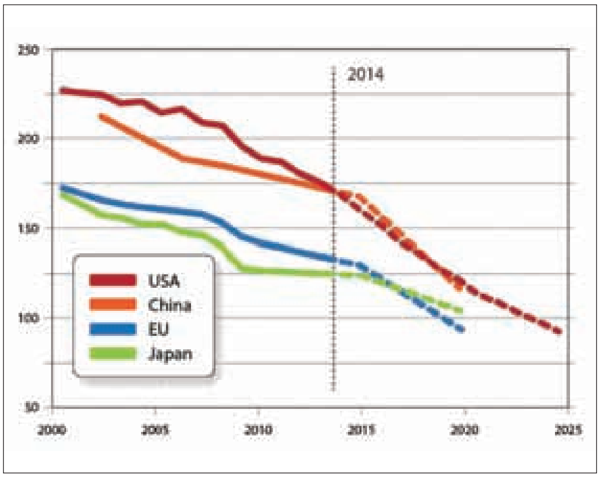

Figure 2: Fleet emission limits by region

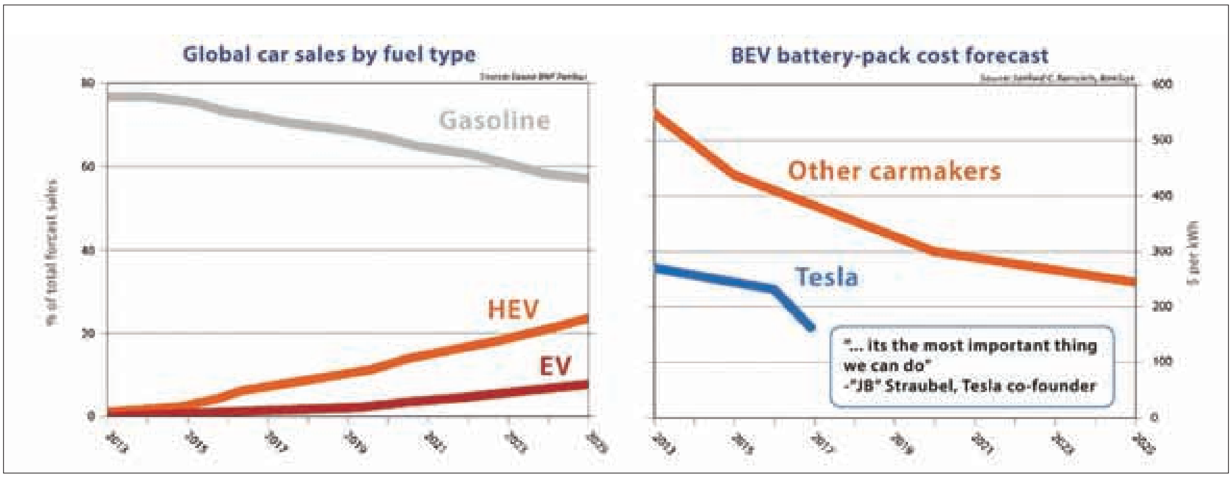

Figure 3: **Global car sales by fuel type and BEV battery-pack cost forecast**

devices. Displacement of IGBTs will be achieved only when the efficiency improvements and reliability of GaN are well established.

EV/HEV power and operating voltage

Figure 5 shows the power and blocking voltage requirement of the various types of EV/HEVs introduced in the 2010/12 time period [7]. It is expected that future EV/HEVs will have wider range of requirements. Already SiC devices are expected to be introduced that are optimized for 900 V operation and GaN devices will also follow this path.

The potential competitive threat offered by SiC is real because the SiC devices offer excellent thermal performance in terms the variation of on-resistance with temperature. It is however the Device Value in terms of Performance versus System Cost that is critical. The 6-inch starting wafer cost for a GaN on Si device is $25 - 50 while a SiC wafer cost can be $5,000. Even under extremely adverse thermal conditions, 175°C junction temperature, large area GaN devices can have lower on-resistance than a SiC device, smaller chip area, and far smaller switching losses. The lateral nature of current GaN devices allows for the inclusion of on-chip drivers, the achievement of very low capacitance - lower gate charge, and the use of yield enhancing schemes.

Battery voltage levels for hybrid and electric cars range from 100 V to 450 V. A boost converter is normally used where a higher fixed voltage is required. Over voltage provisions dictate that GaN devices rated for a blocking voltage of 650 V will need to safely withstand 850 V and a 900 V device will need to safely withstand 1200 V. Figure 6 shows the leakage current and incipient breakdown characteristics of a GaN e-Mode transistor that has a 6 micron epitaxial layer deposited upon a silicon substrate. Figure 6 shows that this 650 V rated device is able to withstand 1000 V. At 650 V the leakage current is 0.1 μA/mm of gate width. This means that a 1000 mm device that is suitable for use at 100 A could potentially has a total leakage current of just 0.1 mA.

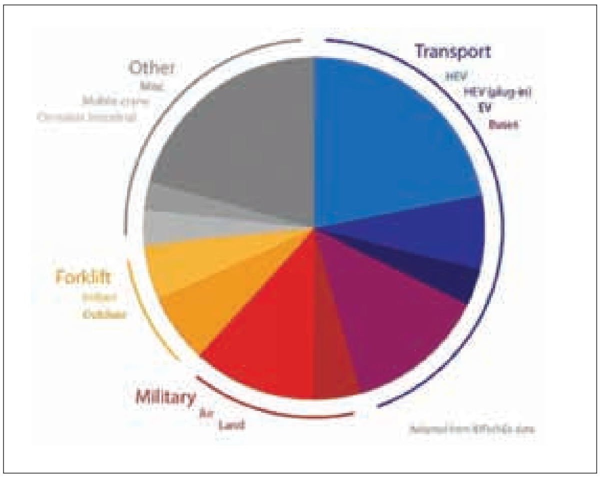

Figure 4: **Relative value of electrically powered vehicles in 2025 by application**

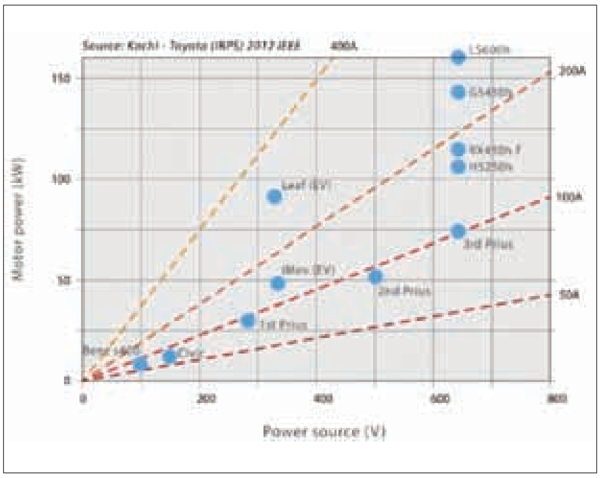

Figure 5: **Motor power and operating voltage of EV/HEVs**

Specific on-resistance and figure of merit

Figure 7 compares the specific on-resistance of all the common power devices. The GaN device starred is a 1.6 mΩ·cm², 1900 V transistor resulting from the research work of Prof. Medjdoub and his team at IEMN (France) [4]. If this work results in practical devices it is possible to show an estimated performance which is better than 1 mΩ·cm² at 1200 V leading to a safe blocking voltage of 900 V.

Charts, such as that shown in Figure 7, can be misleading because only the active device area is usually used to

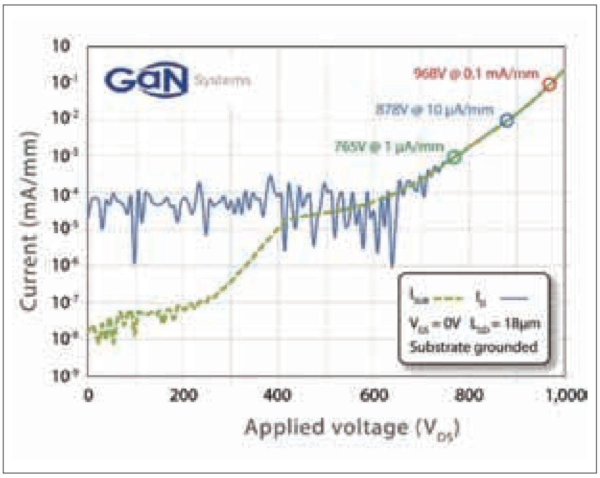

Figure 6: Leakage current of a 650 V GaN device

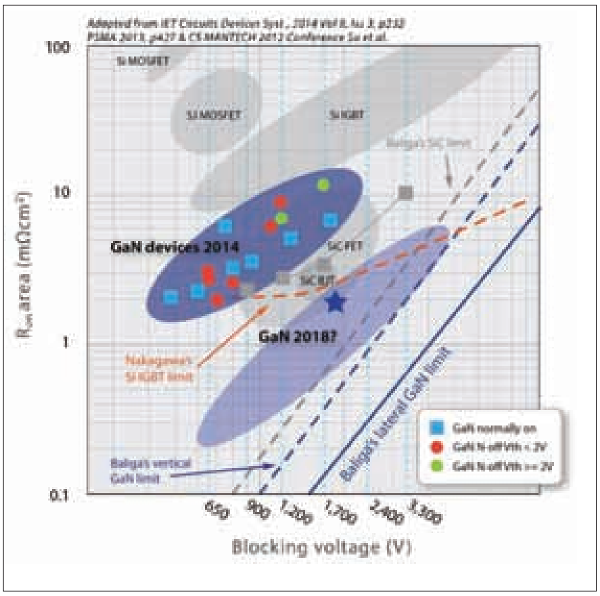

Figure 7: Specific on-resistance

provide the basis of calculating the specific on-resistance. Real devices have an overhead interconnect area additional to the active area. Also, fabrication cost is, of course, not simply related to device area.

Another method of assessing the potential performance of the very large devices needed for automotive power switches is to examine the datasheets of smaller parts currently in the market. Large area devices are simply made up of the same structural blocks as smaller devices within the family type. The Figure of Merit (FOM) is then constant across the family while other key loss parameters such as Q_{RR} simply scale with current. Table 1 shows the conventional FOM and the FOM Hard Switching (FOM_{HS}) [8]. The QRR is related to the diode loss that is present in bipolar structures. The data shown is based upon calculations made using the following datasheets: GaN e-Mode GS660506, GaN Cascode TPH3006PS, Si MOSFET FCP190N60E, and Si IGBT STGB20V60DF [8].

The devices, presently being used in EV/HEVs, are IGBTs. These are low cost well established, well understood devices. Freescale Semiconductor has examined the possibility of using GaN devices as replacements for IGBTs [9]. Using the assumption that a 1m? GaN device is achievable it is possible to construct Table 2.

This table was developed using IGBT data and a GaN device model, based upon experimental devices that correspond to the 2018 projected performance of GaN transistors shown in Figure 7. The losses shown greatly favor the GaN transistors. In this simulation four 4 m^2 650 V/100 A GaN transistors are connected in parallel to achieve the 1 m? performance shown. The power loss reduction is better than 3.5 : 1 at 400 A and 10 : 1 at 100 A.

Large GaN transistors

Transistors capable supplying 100 A and 200 A are shown in Figure 8. These are 650 V (blocking voltage) devices, include an on-chip gate driver, and use redundancy to improve yield, to achieve 1.6 A/mm^2. They have a maximum on-resistance of 16 mΩ and 8 mΩ respectively. The photographs show the dies before they are post processed using an additional copper metal system that greatly increases the current handling capability.

The schematic circuit shows the on-chip drivers of the 100 A device. Two additional small transistors (Q1, Q2) are provided. These provide very secure direct drive to the large device D3. This scheme greatly simplifies the required pre-driver circuitry. The post processing element of the production sequence plays a vital part of the achievement of producing viable, yieldable, very high current, very large area, lateral GaN power devices. GaN devices that are lateral have limited current handling capability because of the limited thickness of the aluminum metal that is deposited in conventional foundries. It is, therefore, vitally important to augment the original metal system with a high conductive copper super-structure metal system as shown in the Figure 8 schematic.

Additionally the yield of very large GaN devices can be seriously affected by the typical foundry defect density. This issue is also remarkably easy to address by using post processing. Using a proprietary isolated island structure

Parameter	GaN e-Mode	GaN Cascode	Si MOSFET	Si/FRD IGBT
FOM: $Q_G \cdot R_{on}$ (pC·Ω)	375	1,400	10,000	17,000
FOM_{HS}: $(Q_{GD}+Q_{GS2}) \cdot R_{on}$ (pC·Ω)	185	550	4,400	7,300
$Q_{RR\ Diode}$ (400 A) (nC)	0	2,000	190,000	6,000

Table 1: 600/650 V device comparison

25 °C, 400 A Typ. values	IGBT	GaN Simul.	
V_{cesat} : V_{on} (V)	1.45	0.4	Voltage drop at full load 400 A
P_{sat} : P_{on} (W)	580	160	Conduction loss at full load
E_{off} (mJ)	13	0.25	Switching off energy
E_{on} (mJ)	2.9	0.42	Switching on energy
V_F : V_{on} (V)	1.55	0.4	Forward voltage drop (reverse current)
P_{VF} : P_{Von} (W)	620	160	Reverse conduction loss
E_{REC} : E_{Roff} (mJ)	3.6	0.9	Reverse recovery loss
V_{cesat} : V_{on} @ 100 A (V)	1.0	0.1	Voltage @ 25 % load
P_{sat} : P_{on} @ 100 A (W)	100	10	Conduction loss @ 25 % load

Table 2: IGBT/GaN power loss

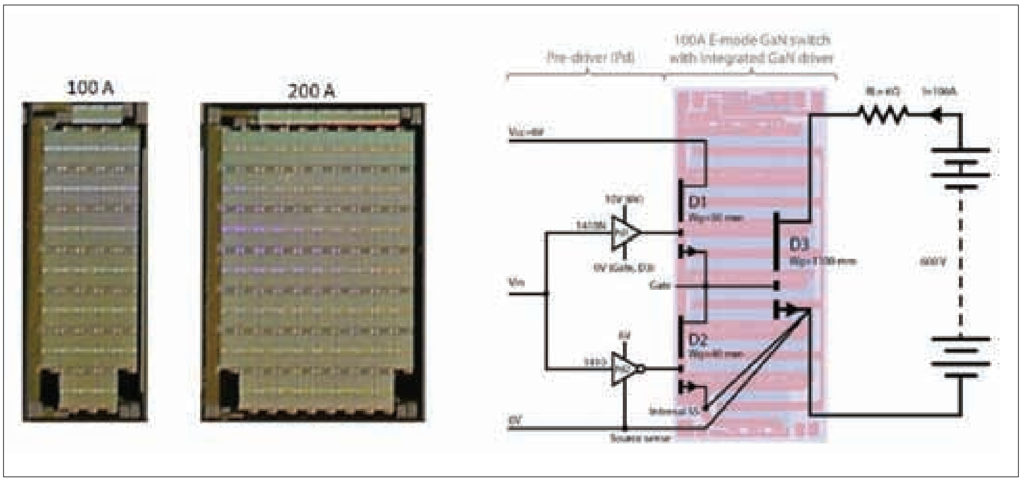

Figure 8: Die photographs and schematic circuits of large area GaN transistors

the defective islands can be totally isolated by providing no interconnect to any islands affected by the defects. It is therefore possible to select only the best performing islands. This greatly improves the overall device performance and yield.

Conclusion

The potential for very high volume use of GaN transistors in automotive applications has been described. The lower losses are attractive but GaN devices that meet the demanding requirements of the automotive industry are at an early stage of development. However the interest of the automotive industry is palpable. The actual acceptance of GaN devices into automotive applications will be determined by the achievement of the high volume production of reliable devices. It is likely that the automobile industry will generally be among the later adopters of the technology. The consumer electronics industry is currently moving very rapidly to develop new products using GaN e-Mode 650 V devices. The clear motivation is simply the desire to achieve an overwhelming performance advantage over their competitors. The early adopters within the automotive industry are also those who are the most innovative and competitive [10].

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Digital Control Limits Inrush Current

AC/DC power supplies and rectifiers employ large bulk capacitors. During power-up, these capacitors require large amount of current to charge up resulting in a large inrush current. This inrush current creates limitations in the operation of power devices and interference of those devices with power line and circuit breakers. It also affects the reliability of power system due to overstress caused by instantaneous but huge surge in initial current at power up. Known solutions to limit inrush current [1, 2] require resistors or conventional NTC thermistors which contribute significant power loss and decrease the efficiency. Our approach has two objectives: first, to illustrate advantages of digital power control that overcomes many of the disadvantages of the existing technology and second, to raise interests in digital control of the high power converters, stimulating development of its next generation. **Anatoliy Tsyrganovich, Leonid Neyman, and Abdus Sattar, IXYS Corporation, USA**

IXYS Digital Inrush Current Controller, a novel design that overcomes many of the disadvantages of the existing technology to limit the inrush current in high power AC/DC power supplies and AC/DC rectifiers, combines IXYS digital power control technology with Zilog's 8-bit Z8F3281 MCU to illustrate a unique approach to limit capacitor pre-charge current to a predetermined value at each half sine-wave cycle. Capacitor charge is spread over a number of cycles until the capacitor is charged proportionally to a peak value of AC voltage source.

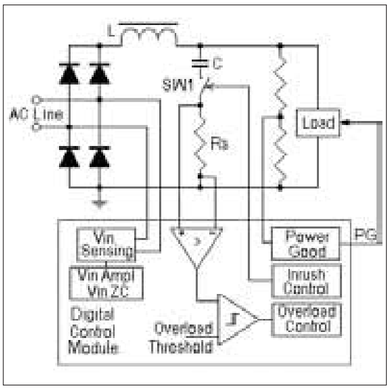


Figure 1: Circuit schematic for digital inrush controller

This controller features programmable overload protection and "Power Good" status signal. It is not sensitive to power outage, brownout and ambient temperature variations. It can operate with input voltage range from 80 to 240 V AC and load current up to 3 A. Entire operation process and essential values are fully programmable. The controller may be programmed to 50 Hz, 60 Hz or any other line input frequency operation.

Time-dependent pulse train

Figure 1 shows a conceptual circuit schematic in which the key idea is to provide charge to bulk capacitor in equal increments. Capacitor is charged according to time-dependent pulse train driving the transistor SW1. The pulses are designed in a way to provide substantially equal voltage increment applied to capacitor to keep peak of charging current about the same value at each cycle. Number of cycles which depends on the capacitor value and the charge current is selected depending on the desired ripples amplitude at the output. The charge current is a function of number of pulses and the timing position with respect to the rectified sine wave.

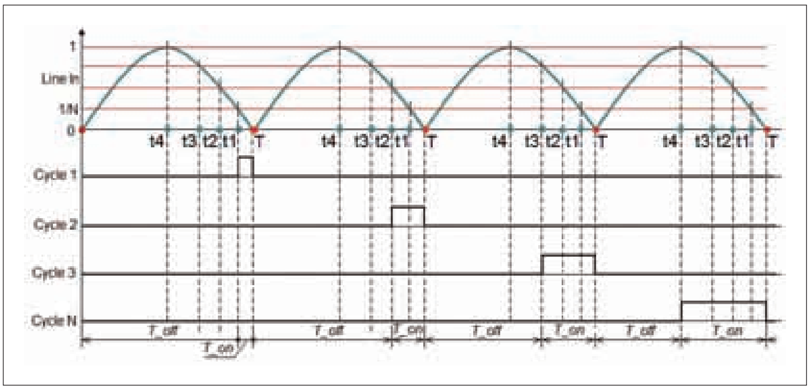


Figure 2: Digital inrush control timing

Figure 2 shows an example of generating the pulse train for SW1. If we can consider N cycles for inrush control then we can split the normalized amplitude of half-rectified sine wave to N segments with increment of 1/N as shown in the Figure 2. During Cycle 1, SW1 is on (conducting) from the time stamp t1 to T thus allowing the capacitor C charge to the voltage proportional to normalized value 1/N. The charging current does not rise instantly because it is a current in serial LC resonant circuit. That shapes the current waveform to the resonant one. The current is rising until capacitor voltage reaches input voltage.

Then current continue its resonant behavior because SW1 is still conducting. No further oscillation occurs because input voltage drops below voltage on capacitor, and then SW1 is off (not conducting). Capacitor remains pre-charged to the voltage proportional to 1/N. In Cycle 2, capacitor C is pre-charged by another voltage increment 1/N in the process similar to Cycle 1. Capacitor C is charged N cycles to the voltage value proportional to the input line voltage.

Principle of operation

Another variable to control inrush current is LC time constant. Capacitor C value depends on desired ripple value. After selecting the capacitor C value, the designer can decrease peak inrush current by increasing inductance L. If there are physical limits to L value, the number of cycles N should be used to set the required peak current. Turn ON time for Switch SW1 should be defined for each active cycle.

For cycle 1 in Figure 2, the delay from the zero crossing point (point 0 in Figure 2) to the beginning of turning SW1 on, t1, is denoted as *T_off*. The time between t1 and T, an active time to keep SW1 on is denoted as *T_on*, and the period or cycle duration is denoted as *T*.

Active time *T_on* for each occurrence i is defined as geometrical transform as shown in equation 1:

$$T_{on(i)} = \frac{T}{\pi/2}\,\mathrm{asin}\,(i/N), \quad where\ i = 1 \ldots N; \quad (1)$$

The period T is measured by MCU at initialization. Values of *T_on* are determined by (1) and stored in memory. Values of *T_off* are derived by firmware according to expression 2:

$$T\_off = T - T\_on; \quad (2)$$

Figure 3 illustrates a conceptual algorithm which is executed in MCU Z8F3281 for the first 4 cycles of inrush control. Timing counter value corresponds to time at any given moment of discrete time base provided by the internal clock. The counter first counts from zero crossing to *T_off* value. When the counter reaches *T_off* value, it initiates a *T_on* pulse (black line on Figure 3) which continues till counter reaches *T_on* value finalizing one charging cycle. The rectified power line voltage (blue line) is shown for reference.

Figure 4 illustrates timing position and amplitude of the capacitor C current (red curve) with respect to *T_on* pulses. It is noted that the inrush controller generates a single current pulse during each cycle. The capacitor C charge is completed, when input voltage drops below capacitor voltage. The input power line is isolated from the rest of the circuitry by the diode bridge circuit, and inductor discharges into C. Then the switch SW1 is turned off (not conducting) up to the end of the cycle. The algorithm is based on reactive power transfer, hence, losses are limited mostly to those on strain resistance.

Figure 4 also shows that capacitor C pre-charge is completed at time stamp 0.066 ms. After that, Power Good (PG) signal is generated and load is activated. Capacitor current shows up as negative beginning at time stamp 0.066 ms, because current is sourced from the capacitor when load is activated. Power Good signal can be delayed in respect to end of pre-charge of C to let load stabilize before some other functions are executed. The overload threshold is programmable as well, and it is set to 3.5 A in the current design.

Overload Protection is a valuable feature to protect a device from damage in case of overload. If overload is detected by a comparator, then the MCU disconnects capacitor C from the load by turning off SW1. Also, the PG signal is set to logic low to disable load if possible. Overload protection can be programmed for two modes of operation: (1) immediately shut down the device and wait for user interference and (2) to allow device restart by predetermined number of times.

After initial pre-charging and connecting the load, the MCU may be reconfigured for other power management tasks. For example, it can perform power factor correction (PFC) control and keep track records on device performance, overload conditions, power outages, power brownouts, etc. Based on collected information, the MCU is able to display on

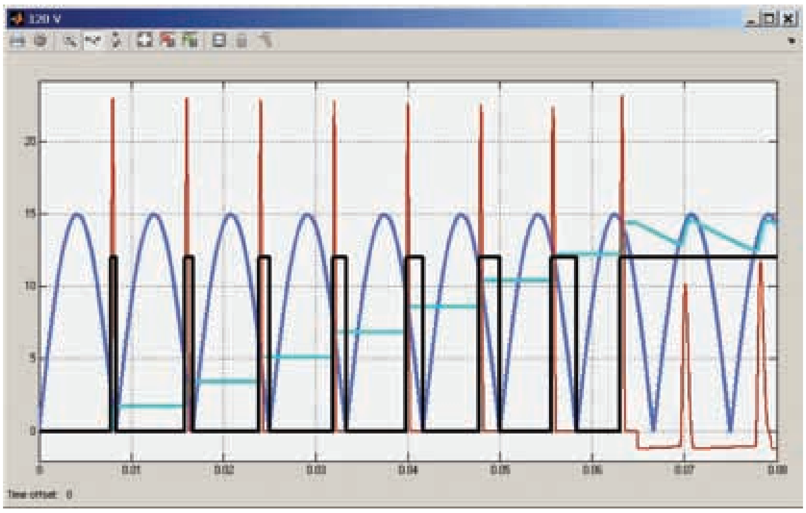


Figure 4: Capacitor C pre-charging (blue – rectified power line voltage, red – power line current, black – on time *T_on* for SW1, green – capacitor C voltage)

Figure 5: MCU module (a) and main power board with MCU module (b)

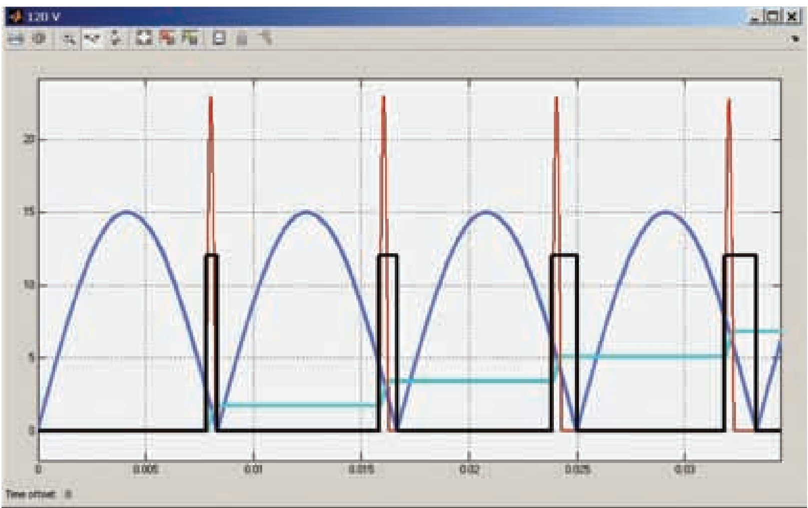
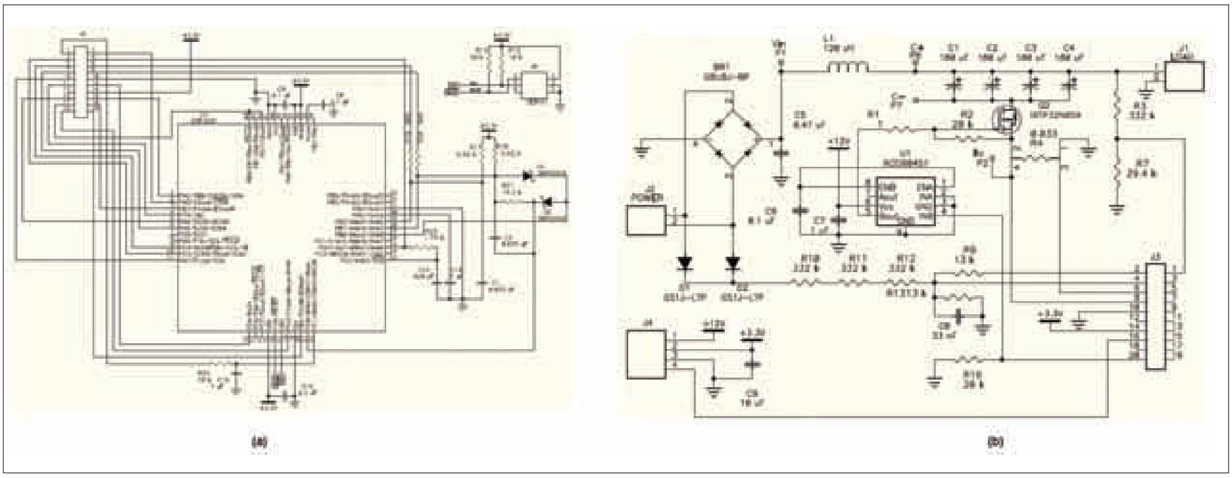
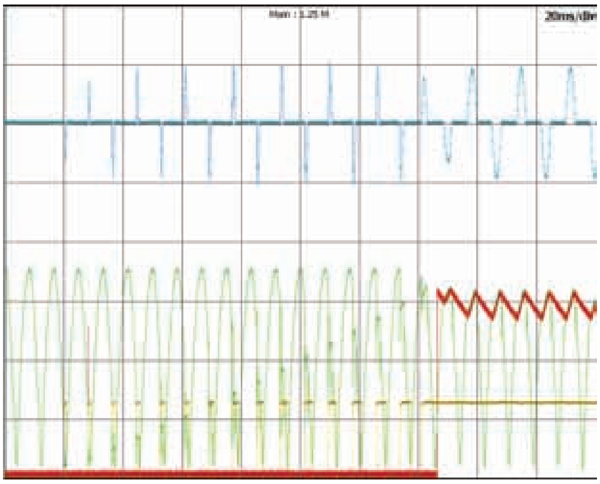


Figure 3: An illustration of *T_on* timing generation (blue – rectified power line voltage, red – power line current, black – on time *T_on* for SW1, green – capacitor C voltage)





ABOVE Figure 6: Detailed schematic diagrams of MCU module (a) and main power board (b)

LEFT Figure 7: Scope snapshot of the digital inrush current control (blue – power line current (10 A/div), red – load voltage (50 V/div), green – rectified input voltage (50 V/div), yellow – SW1 drive signal)

reliability state of the device and supply statistics of system performance.

Digital inrush controller

The digital inrush controller consisting of a MCU module and a main power board is shown in Figure 5. The detailed circuit schematics are included in Figure 6. The MCU module is implemented as an add-on device. The module comprises a connector for MCU programming. The MCU should be programmed before powering the entire system. The MCU module is powered by an auxiliary power supply +3.3 V for the MCU and 12 V for the gate driver applied to the connector J4 on the main power board.

The 2-layer PCB main power board contains the diode bridge and MOSFETs Q1 (SW1), mounted on small heat sinks. Power dissipation is less than 5 W at 375 W output power.

Performance of the design has been verified by several bench tests. A scope snapshot of the test result is shown in Figure 7. Testing confirmed that the inrush current is limited to predefined value and performance of the limiter is quite close to simulation results. The amplitude of the inrush current is limited to the value equal to the input current at maximum load to minimize the negative impact on the AC line, as well as limit electromagnetic interference (EMI), by selecting of number of inrush current pulses equal 16 and inductor 100 µH. During the test, the AC input line is connected through an isolation transformer as a precaution. The Power Good signal connecting load is generated at rectified voltage zero crossing one cycle after the output capacitor is completely charged (see the red line in Figure 7).

Figure 7 depicts SW1 gate drive pulse T_{on} time (yellow line) and rectified voltage (green line) at the input of the device. Rectified voltage slightly drops after load is connected due to the limited output power of the isolation transformer used during the test. Blue line depicts line current and red line depicts the load voltage. The system is verified to provide 2.5 A output current at full load or normal operation. Inrush current is limited to 10 A.

Measured efficiency of the inrush control path is 99.5 %. The device is capable of working in wide range of input voltages - from 80V to 240V. Tested power line frequency was 50 Hz and 60 Hz. Dedicated control pulse train was developed for each power line frequency. To apply higher power line voltage, a longer control pulse train is needed in the implementation. For instance, increasing the AC line voltage from 110 V to 220 V requires a double pre-charging time than that of 110 V to have the same peak inrush current.

Overload protection is based on continuous monitoring of the dynamic current from the bulk capacitor. In case of an overload condition, the current drawn from C instantly increases and the comparator inside the MCU initiates the system overload mode. Overload current threshold, number of overload instances, and the period between overload events are programmable. The system response is being verified successfully by testing an overload condition. The load has been increased to draw an output current of 3.5 A which triggers an overload protection. The system is also tested with continuous overload that results in multiple attempts to restart the system with immediate interruption.

Power Good status is not present in overload conditions. This overload protection is not sensitive to power interruptions, brownout, and temperature variations.

Conclusions

IXYS Digital Inrush Controller offers flexibility in implementing a unique control algorithm that aids in efficient power system. It achieves a high level of efficiency, increased stability, and reliable performance across a wide range of loads. Because of an innovative current measurement algorithm, it allows common input and load grounds. Users can optimize the device for a wide range of input voltages and frequencies. This design provides instant over-current protection, followed by an intervention by the MCU for corrective actions.

Literature

[1] Randhir Singh Malik, William Hemena, Circuit for limiting inrush current to a power source, US6445165 B1, Sep 3, 2002.

[2] Michael Allen, Understanding power supplies and inrush current, Electronic Products, March 2006, pp. 64, 65.

Making Battery Fuel Gauges Tell the Truth

A new and highly accurate technique for battery fuel gauging could help users of mobiles and other portable devices avoid the inconvenience and frustration of unexpected system shutdowns.

Steve Sheard, ON Semiconductor, USA

Battery-powered mobile devices have become vital to modern life. Users often need to continue operating their devices at low battery levels, and can suffer inconvenience if the system suddenly shuts down despite indicating that a few percent of battery energy still remains. Given the importance of knowing accurately how much energy is remaining in the battery at any time, accurate battery "fuel-gauging" is highly important. However, the coulomb-counting technique traditionally used in portable devices is not only inaccurate, leading to a high risk of unexpected shutdown, but is also subject to temperature-related errors and consumes precious battery energy that may be better utilized to power other functional circuitry.

Fuel gauging by coulomb counting

Coulomb counting uses a precision current-sensing resistor to monitor the battery output current continuously. The current is integrated over time, and the result is compared with the known maximum battery charge to calculate the remaining charge available.

Coulomb counting is inherently inaccurate because it is unable to detect battery self-discharge events, since the self-discharge current does not pass through the coulomb counter's sense resistor. Moreover, self-discharge events tend to increase the ambient temperature, which changes the resistance of the sense resistor thereby further impairing accuracy. In addition, the battery has to be fully charged every time for an accurate calibration. Further disadvantages of coulomb counting include the relatively high cost of the precision sense resistor, as well as the precious battery energy dissipated by this resistor as the sense current passes through continuously.

A coulomb counter may be accurate to within around 8 %. Hence if the indicator suggests 10 % of charge is remaining, the real value may be as little as 2 %. With such a level of inaccuracy, the user may become anxious about the remaining battery life even if the indicator shows 20 % or so of charge remaining. The worry of sudden plummets in indicated battery life only serve to add to the general sense of mistrust of the status information presented.

As the market waits patiently for improvements in battery technology (or indeed resigned to the status quo), and equipment designers conceive increasingly complex power-management schemes to conserve every possible scrap of battery energy, it is extremely important that the fuel gauge provides an accurate reading for the user while itself consuming as little of the battery's energy as possible.

A better way

ON Semiconductor has developed a proprietary method for calculating the remaining battery energy based on the voltage measured across the battery using a precision analogue-to-digital converter (ADC). Figure 1 illustrates a basic application circuit showing the major functional blocks of a fuel-gauging system using this technique.

A reference table describing the voltage-vs-capacity characteristic of the battery technology being monitored is stored in memory. By comparing the measured

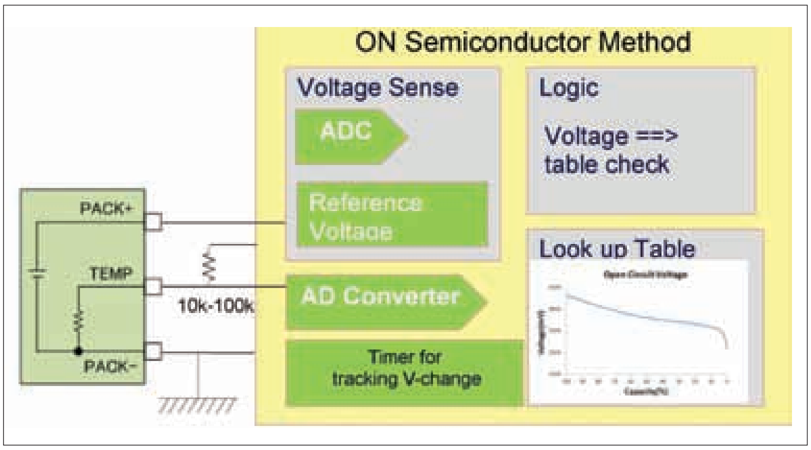


Figure 1: Voltage-sensing method for battery fuel gauging

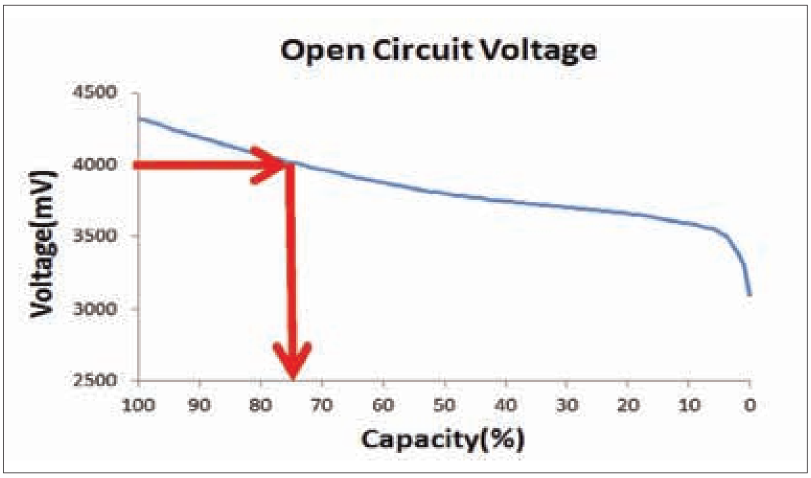


Figure 2. The remaining battery capacity is inferred from the measured voltage by referring to the battery reference table

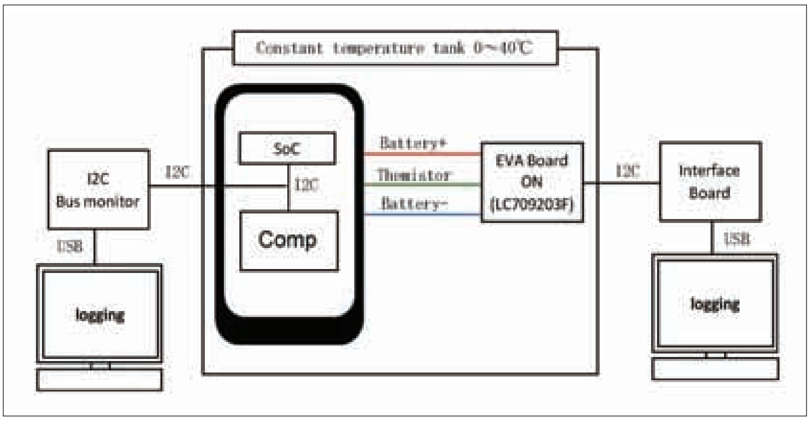


Figure 3. Comparison of built-in smartphone battery fuel gauge and voltage measurement technique using LC709203F

voltage with values stored in the table, the remaining battery capacity can be calculated. Figure 2 illustrates the principle: if the measured voltage is 4.0 V, comparison with the reference table suggests 75 % of battery charge is remaining.

Repeated voltage measurements are taken at known time intervals. The battery temperature is also monitored. The time remaining before the battery will be completely depleted can then be calculated, based on the voltage and temperature measurements and the changes in the voltage recorded at the known time intervals. More frequent readings are taken at lower battery voltages, to ensure accurate predictions as the remaining battery life becomes shorter.

By measuring the voltage across the battery pack, this approach is able to take account of battery self-discharge events. Moreover, the battery does not need to be fully charged for calibration. The remaining battery life can be calculated accurately even if the battery is only charged to 50 %.

Because measurements are taken at intervals, the monitoring circuitry does not need to be active continuously. This allows the fuel gauging circuitry to enter energy-saving sleep mode in between measurements. The active power consumption can also be reduced, in comparison with a conventional coulomb counter, since no sense resistor is needed.

Operation at low ambient temperatures is known to have a significant effect on the performance of Li-ion batteries. In particular, the battery impedance changes as the temperature falls to 0°C or lower, resulting in increased battery voltage drop when discharge current flows. A unique correction algorithm in its LC709203F battery-voltage sensing fuel gauge IC helps ensure fuel-gauging accuracy remains within 2.8 % over a wide ambient temperature range and at all battery voltages.

Experimental results

To compare fuel gauging using the LC709203F with the performance of a coulomb counting circuit, a smartphone with a new battery was adapted to allow the positive and negative battery connections and the thermistor output of the battery pack to be connected to the device while allowing the smartphone's built-in fuel gauge to continue operating. Data loggers were used to record the output of the built-in fuel gauge, which was monitored via the smartphone I^2C bus, and the output of the LC709203F. The smartphone was placed in a constant-temperature tank at 0°C, and operated in airplane mode with the backlight turned on. Figure 3 illustrates the experimental setup.

Figure 4 shows the results of the comparison. The accuracy achieved using the LC709203F is better than 2.8 % for the duration of the test, and is better than 2 % at the lowest levels of remaining battery energy. The standard fuel-gauge system operates with varying levels of error and reaches its highest level of more than 6 % as battery energy nears depletion. From the user's point of view, greater accuracy is desirable at lower levels of battery energy, to be able to predict when the equipment may shut down.

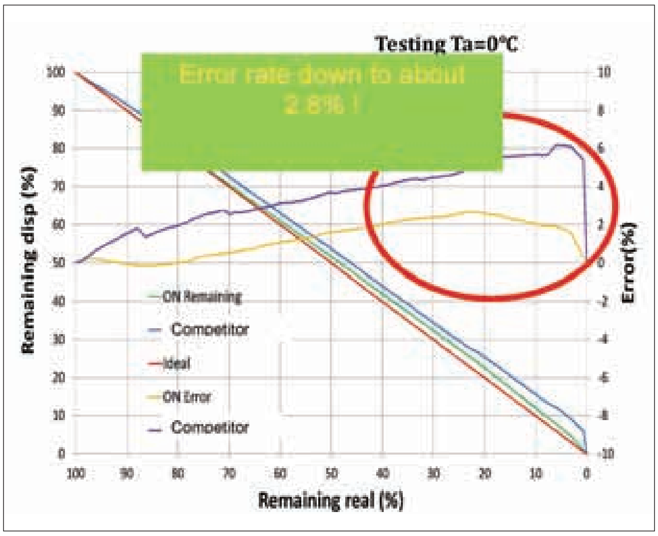


Figure 4. Results of comparison test

Size and power savings

The LC709203F allows effective fuel gauging using only one external component, whereas alternative devices may require two to five, or as many as 14, additional components. This delivers a valuable saving in Bill Of Material costs and design time, and also increases reliability. Moreover, the 1.76mm x 1.6mm package is about 45% smaller than alternative devices. Combined with the reduced component count, this allows the overall PCB footprint of the fuel gauge circuit to be reduced by around 77%. This can represent a crucial gain for smartphone designers who continually battle to squeeze in all the design elements to provide the functionality and user interface demanded by consumers, leaving little space for the components that actually make it all happen.

Total power consumption is also lower. The LC709203F operating current of 15 µA is approximately 1/10th that of the closest competing device, which draws 118 µA. In addition to this improvement of over 87 % in active consumption, the LC709203F draws up to 60 % lower current in sleep mode.

Conclusion

The relatively poor accuracy of conventional coulomb-counting battery fuel gauges leaves users of today's mobile devices vulnerable to inconvenient interruptions when using their devices, particularly when working close to the limits of remaining battery energy. A new technique that uses precision sensing of battery voltage, with error correction and temperature compensation built in, promises a more accurate, cost-effective and energy-efficient solution that will enable users to manage their mobile batteries more effectively.

48 V GaN Point-of-Load Converter

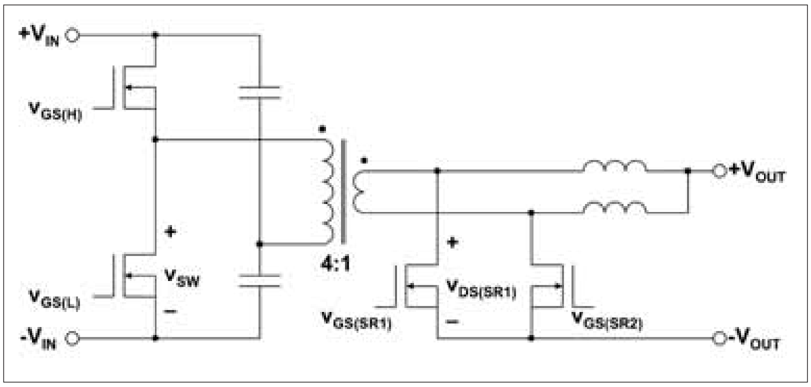
Gallium nitride (GaN) devices have hit the power electronics market with force. By offering lower capacitances and zero reverse recovery, they promise to dramatically improve efficiency and open up new markets. One of these new opportunities is powering high-current loads directly from the 48 V bus, common in server and telecommunications environments. This approach provides advantages over the traditional two-stage solution of using a bus converter followed by a point-of-load (PoL) voltage regulation module (VRM). The single-stage provides a more-efficient solution while providing improved transient response and form factor improvements. **Michael Seeman, Systems and Applications Engineering Manager, Texas Instruments, Dallas, USA**

This application is focused on 48 V bus rails, within the range of 36 V to 60 V, which are becoming more common in the server and telecommunication space. This design will be focusing on 40 A, 1.8 V output typical of many digital loads. The design can be scaled in a straightforward manner to lower output voltages and higher output currents. For processor-type loads, customers expect very fast transient response in both the current slew rate and voltage slew rate. This article addresses both of these design considerations when analyzing the converter.

Traditional designs are done in two stages. The 48 V bus, typically supplied by an AC/DC rectifier with a battery bank backup, is fed to the server module through the backplane. The 48 V bus is then down-converted to 9-12 V using a regulated or unregulated bus converter. These converters come in "brick" form factors (for example, quarter-brick and eighth-brick) and have efficiencies in the order of 96 %. The second stage is a multiphase buck converter that delivers current to the load. Operating at around 500 kHz, these converters are optimized to achieve fast transient performance and have efficiencies around 92 %. Since this second stage must convert voltage at a 5 :1 or higher ratio, a fairly-large inductor must be used to manage the ripple current to improve efficiencies, especially at light load. The proposed single-stage solution can operate at the same or higher switching frequency while reducing form-factor and improving efficiency.

Single-stage conversion

The selected topology for the single stage 48 V to 1.8 V conversion is a hard-switched, half-bridge isolated converter with current doubler output. Figure 1 shows the circuit construction. It has an identical number of switches as a two-phase buck converter, and its operation can be likened to the two-phase buck. The primary-side half-bridge is made up of a half-bridge GaN module and a set of DC-blocking capacitors for the other transformer terminal. The secondary-side current doubler comprises two synchronous rectifier (SR) transistors and two output inductors. The duty cycle of the primary-side switches determines the conversion ratio, while the SR FETs operate complementary to the primary side switches.



RIGHT Figure 1: Schematic of single-stage 48V to 1.8V converter

	GaN LMG5200	EPC 2023	Si 100 V, 16 mΩ	Si 25 V, 1.05 mΩ
	18 mΩ, 80V	1.3 mΩ, 30V	16 mΩ, 100V	1.05 mΩ, 25V
Q_G	3.4 nC @ 5V	20 nC @ 5V	19 nC @ 10V	29 nC @ 4.5V
Q_{OSS}	16 nC @ 50V	12 nC @ 5V	25 nC @ 50V	21.5 nC @ 5V
t_{SW}	~ 1.5 ns	~ 1.5 ns	~ 5 ns	~ 5 ns
Q_{RR}	0 nC	0 nC	83 nC	5 nC
Q_G Loss	117 mW		335 mW	
Q_{OSS} Loss	912 mW		1458 mW	
t_{SW} loss	180 mW		600 mW	
Q_{RR} loss	0 mW		60 mW	

Table 1: Device parameters and loss components

$$P_{sw}=f_{sw}\left(2\left(Q_{G,pri}V_{G,pri}+Q_{G,sec}V_{G,sec}\right)+2\left(Q_{OSS,pri}+\frac{Q_{OSS,sec}}{n}\right)V_{i}+t_{sw}I_{PRI}V_{i}+2\frac{Q_{RR,sec}V_{i}}{n}\right) \quad (1)$$

GaN provides a significant advantage in this application through its lack of reverse recovery and improved switching characteristics [1]. Because of the fast switching frequency required to achieve a small form factor and fast transient response, a low output capacitance and switching loss is necessary. On the secondary side, low reverse recovery charge switches are necessary for performance and to minimize power loss. Table 1 shows the relevant performance metrics of the LMG5200 GaN module compared with some comparable Silicon FETs.

The advantage of GaN comes in terms of switching loss, while magnetics loss and conduction loss remain the same as for silicon switches with the same on-resistance. The switching loss is given by the sum of the gate drive loss, output capacitance energy, V-I switching loss and the reflected reverse recovery of the secondary-side switches according to equation 1 (above), where $Q_{G,PRI}$ and $Q_{G,SEC}$ are the total gate charges, VG,PRI and $V_{G,SEC}$ are the gate drive voltages and $Q_{OSS,PRI}$ and $Q_{OSS,SEC}$ are the output charges of the primary-side and secondary-side switches, respectively. V_{IN} is the input voltage, T_{SW} is the switching time, I_{PRI} is the current flowing through the primary-side switches, QRR,SEC is the reverse recovery charge of the SR FETs, and n is the transformer turns ratio. Note that the first component of the loss can be reduced based on the ringing during the dead-time; partial valley switching would improve the efficiency.

Table 1 shows the per-cycle loss for each of these loss components for both a GaN implementation and a Silicon-based implementation. Note that these losses do not include magnetics or conduction loss, as these components do not change when using GaN. With a transformer turns ratio of 4 :1 and switching frequency of 500 kHz, GaN yields a gating and switching loss of 1.21 W, compared with a loss of 2.45 W with the Silicon-based solution.

Transient performance advantages

The single-stage 48 V to PoL converter exhibits transient response advantages over the traditional 12 V solution. The value of the output inductor determines how fast the load current can slew. The smaller the inductance, the larger the potential slew rate. Many buck PoL controllers have a minimum on-time which restricts the maximum operating frequency of the converter and, thus, minimum allowable inductance. Since the single-stage solution utilizes a transformer for the majority of the conversion ratio, the duty cycle can be effectively larger than a 12 V buck converter.

A higher duty cycle allows for a higher switching frequency and a smaller inductance for a given minimum on-time. As the converter topology and control are symmetric, the capacitors on the primary side balance any offset in the circuit, enabling fast duty-cycle transitions without having to worry about core saturation. Compared with soft-switched converter topologies, this hard-switched converter exhibits faster transients as there is no high-Q resonant network or other impedance network to enable soft-switching.

Experimental results

Figure 2 shows a photo of the prototype 48 V to PoL converter, which is optimized for 500 kHz operation. The LMG5200 80 V GaN half-bridge module [2] is located on the left of the transformer. The transformer has a 4 :1 turns ratio using stamped windings to reduce resistance. An ungapped core minimizes magnetizing current and leakage inductance. Two 440 nH output inductors are located on the right with the SR MOSFETs located on the underside of the PCB. The footprint of the power stage is 28 mm by 50 mm. This implementation is a hybrid Silicon/GaN combination, using the LMG5200 GaN device on the primary side and a 25 V, 1.05 mΩ Silicon MOSFET on the secondary side.

Figure 3 shows the converter's switching waveforms with a 48 V input and 1.8 V, 20 A output load. The converter is duty-cycle controlled with the primary-side switches operating with less than 50 % duty cycle and the SR FETs operating above 50 % duty cycle. During the dead-time on the primary side, the leakage inductance rings with the output capacitance of the primary-side switches. The leakage inductance causes some

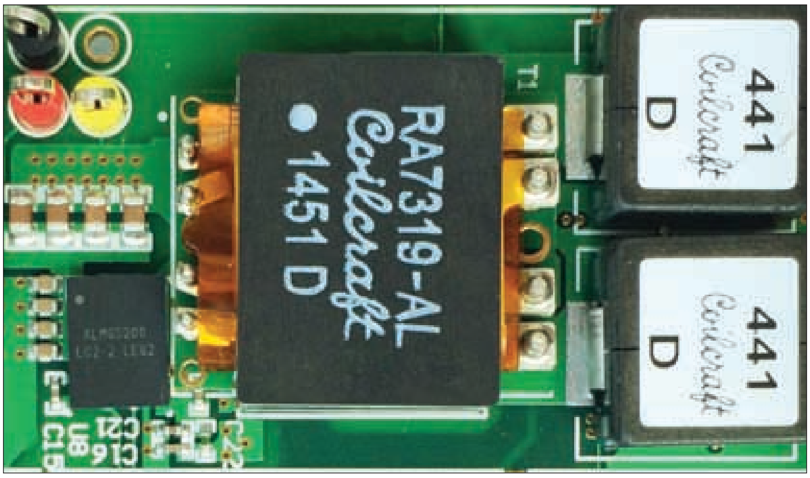


Figure 2: **PCB Layout of 48V to PoL converter**

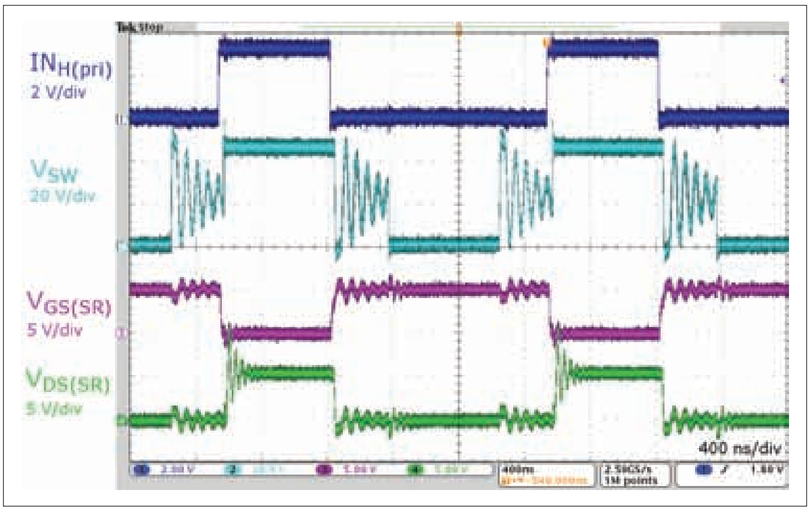


Figure 3: **Oscilloscope capture from 48 V to 1.8 V converter**

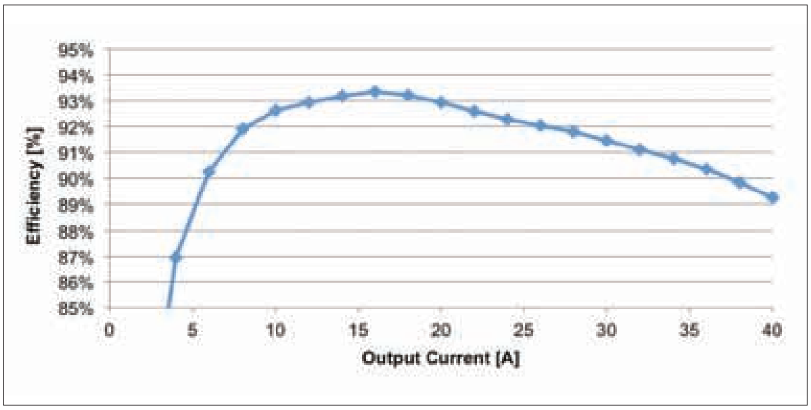


Figure 4: System efficiency 48 V to 1.8 V at 500 kHz

ringing on the output waveform which is minimized through good PCB and transformer design.

Figure 4 exhibits the efficiency of the converter operating at 500 kHz. It achieves a peak efficiency exceeding 93 % and a half-load efficiency of 92.9 %. This efficiency significantly exceeds the performance of a two-stage solution. At high load currents, the performance is impacted by DC and AC resistances in the circuit and the reverse recovery of the SR FETs. Further efficiency benefits can be realized by using GaN in the SR stage to eliminate reverse recovery loss.

Conclusion

The advantages of GaN show strongly in this application, where the single-stage conversion can be done with higher efficiency and smaller size than traditional solutions, while simultaneously improving transient response. This article discussed the design of such a converter using a GaN half-bridge module which integrates two GaN FETs and an optimized driver inside a low-inductance package. This module, along with TI's controllers and MOSFET drivers, enables a compact, flexible solution for 48 V PoL converters such as the described 48 V to 1.8 V, 40 A converter achieving over 92 % peak efficiency.

Literature

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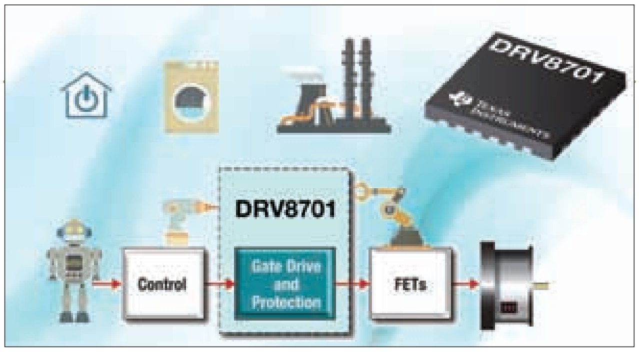
[2] Texas Instruments, 80-V, GaN Half-Bridge Power Stage, LMG5200 datasheet, March 2015



Brushed DC Gate Driver with Adjustable Current Drive

Texas Instruments introduced an integrated gate driver that offers adjustable gate drive settings with the flexibility to drive a wide range of external FETs, supporting multiple motors, speeds or varying loads. The DRV8701 enables designers to scale their platforms using a single gate driver across various brushed DC motor models in equipment such as white goods, household appliances, robotics, home automation, power tools, and industrial pumps and valves. With its adjustable gate drive, integrated two low-dropout regulators (LDOs), a current-sense amplifier and full protection features reduces system board footprint by 40 % compared to and discrete solutions by replacing up to 45 discrete components. The DRV8701 is available now in a 4 mm by 4 mm quad flat no-lead (QFN) PowerPAD™ package, a thermally enhanced standard-size package designed to eliminate the need for bulky heat sinks and slugs. Pricing starts at $0.92 in 1,000-unit quantities. Engineers can test the new gate driver in their system with the DRV8701EVM evaluation module, which also incorporates the MSP430G2553 ultra-low power microcontroller and CSD18532Q5B NexFET. The EVM supports up to 15 A current in a compact form factor that is about the size of a business card.

www.ti.com/drv8701-pr-eu

PRODUCT UPDATE

AC/DC SiC Control IC

ROHM has recently announced the development of an AC/DC converter control IC BD7682FJ-LB designed specifically for SiC MOSFET drive in industrial equipment such as servers and other high-power applications. Compared to Silicon MOSFETs used in conventional AC/DC converters, SiC MOSFETs enable AC/DC converters with improved power efficiency by up to 6 %. Furthermore, components used for heat dissipation are not required (50W class power supplies), leading to greater compactness. However, until now there has not been a control IC that can sufficiently draw out the performance of SiC MOSFETs, particularly in AC/DC converter systems. As a result designers are faced with numerous problems related to power consumption and stability in a variety of high power applications. ROHM utilizes market-proven analogy technology with SiC power semiconductor expertise to develop the industry's first AC/DC converter controller specialized for driving SiC MOSFETs. The specification of the new BD7682FJ-LB also include multiple protection functions that enable support for high voltages up to 690 VAC, making them suited for general 400 VAC industrial applications. And in addition to overvoltage protection for the supply voltage pin and brown in/out (undervoltage) countermeasure for the input voltage pin, overcurrent and secondary overvoltage protection functions are included, enabling continuous operation in industrial equipment while improving reliability considerably.

www.rohm.com/eu

6.5 kV Reverse Conducting IGBT Module with Diode Control

Infineon has launched a 6.5 kV power module that features IGBT and freewheeling diode functionality integrated into a single chip. This new RCDC (Reverse Conducting IGBT with Diode Control) chip is intended for traction applications as well as for future HVDC electric power transmission systems and medium voltage drives. Compared to previous modules with the same footprint, the RCDC technology delivers a 33 % increase in current density and improved thermal performance. RCDC solution is supplied in an IHV-A high isolation package with an industry-standard footprint, supporting 'drop-in' replacement for existing applications. As well as facilitating higher power densities, the monolithic integration of IGBT and diode results in a significant improvement in the diode I?t value and the IGBT and diode thermal impedance. The latter ensures good thermal performance over the full range of operation. A lower virtual junction temperature ripple supports extended lifetime operation, while the option to use gate control allows designers to optimize overall efficiency by trading off conduction and switching losses. Engineering samples of the RCDC modules are available now, with starter kits including driver evaluation board are scheduled for Q4 2015.

www.infineon.com

Shielded Power Inductors

Mouser Electronics is now stocking Coilcraft's MLC75xx series shielded power inductors. These inductors feature soft saturation characteristics, making them ideal for voltage regulator module (VRM) and voltage regulator down (VRD) designs and other applications with occasional over-current requirements. With an low DC resistance of 1.2 mΩ, these inductors also have an excellent current handling of up to 59 A. Devices measure 7.0 mm x 7.5 mm, with a profile of 4.2 mm. Seven inductance values are offered, ranging from 0.10 to 2.17 µH. The RoHS-compliant, halogen-free MLC75xx inductors employ tin-silver (96.5/3.5) over copper terminations and can withstand a maximum reflow temperature of 260°C. Coilcraft uses proprietary materials and construction techniques to avoid thermal aging issues associated with other iron-powder-core inductors.

www.mouser.com/new/coilcraft/coilcraft-mlc75/

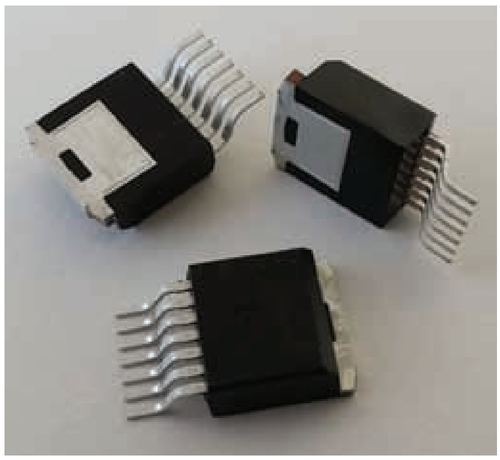
High-Temp Long Lifetime Wet Tantalum Capacitors

AVX Corporation has introduced a new series of wet tantalum capacitors designed for use at 200°C, many of which are capable of up to 2,000 hours of operation with applicable derating. Featuring a high capacitance cathode system that enables high CV performance in standard DSCC case sizes spanning T1 – T4, the new TWA-Y Series delivers high reliability, high temperature, and long lifetime performance, and exhibits stable electrical parameters over temperature (-55 to +200°C). Hermetically sealed in a welded tantalum can and header assembly, TWA-Y Series capacitors satisfy the harsh mechanical shock and high frequency vibration requirements for both MIL-PRF-39006 and MIL-STD-202, making them ideal for use in high temperature avionics, industrial, down-hole, and military applications. Manufactured in accordance with CECC 30 202-01 (EN 130202), the TWA-Y Series is currently rated for capacitance values spanning 150 – 1,000µF with a ±10% or ±20% capacitance tolerance, and voltages spanning 50 – 125 V.

http://partbuilder.avx.com/p/pb/pdf/TWA_Y.PDF

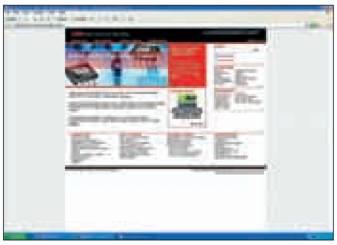
First 900V SiC MOSFET

Cree has introduced the industry's first 900V MOSFET platform. Optimized for high frequency power electronics applications, including renewable energy inverters, electric vehicle charging systems, and three-phase industrial power supplies, the new 900V platform enables smaller and higher efficiency next-generation power conversion systems at cost parity with Silicon-based solutions, according to the vendor. The C3M0065090J is rated at 900 V/32 A, with an on-resistance of 65mΩ at 25°C. Packaged parts will be stocked through DigiKey & Mouser. In addition to the industry standard TO247-3 and TO220-3 packages, the new device is also offered in a low-impedance D2Pak-7L surface mount package with a Kelvin connection to help minimize gate ringing. When compared to equivalent silicon MOSFETs, this 900V platform is able to outperform lower voltage superjunction Silicon MOSFET technology at 900V.



www.cree.com/power

AC/DC Connverters



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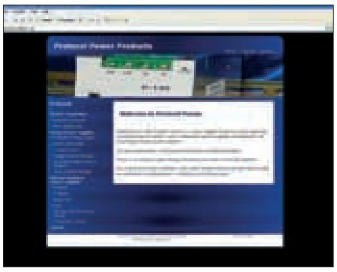

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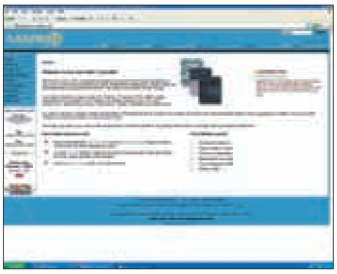

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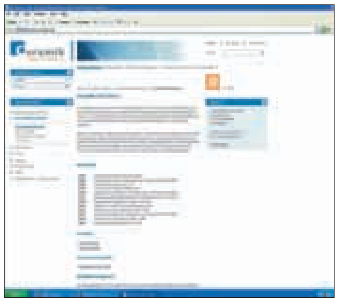

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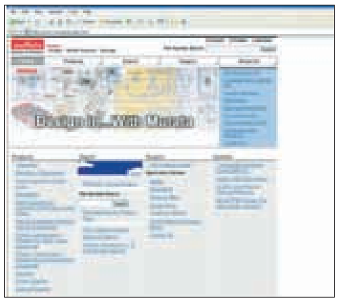

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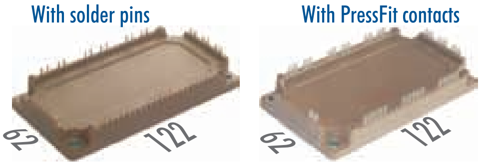
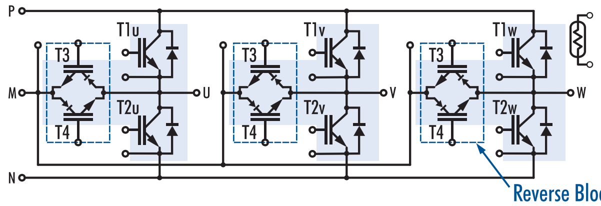
3 Phase

T-Type

With solder pins — With PressFit contacts

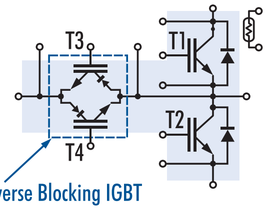




Ic	T1 & T2	T3 & T4
50A	1200V	600V
75A		
100A		

1 Phase

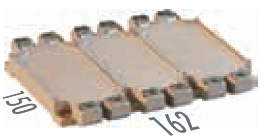
T-Type

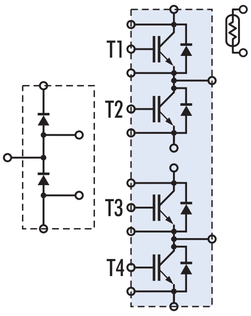


Ic	T1 & T2	T3 & T4
220A	1700V	1200V
300A	1200V	600V
	1200V	900V
340A	1200V	600V
400A	600V	600V
	1200V	600V

1 Phase

I-Type



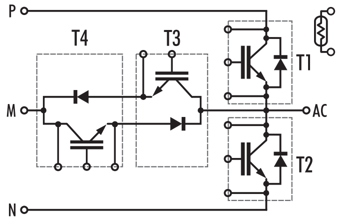


Ic	T1, T2, T3, T4
600A	1200V

1 Phase

T-Type

With PressFit contacts

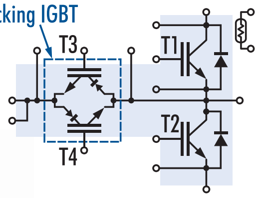


Ic	T1 & T2	T3 & T4
300A	1200V	600V
400A	1200V	600V

1 Phase

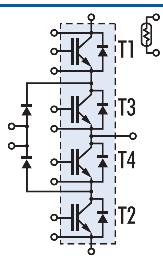
T-Type

Reverse Blocking IGBT



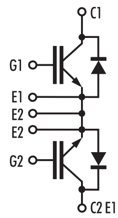
Ic	T1 & T2	T3 & T4
450A	1200V	900V
650A		
900A		
450A	1700V	1200V
600A		

I-Type



Ic	T1, T2, T3, T4
600A	1200V

AC-switch



Ic	1200V
450A	●

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