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POWER SEMICONDUCTORS
Fast Thyristors for Induction Heating Solutions

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Also inside this issue

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COVER STORY

Fast Thyristors for Induction Heating Solutions

Induction heating is one of the key metal industry applications using high-power resonant converters. The power range of such converters goes up to 10 MW and there is no more efficient alternative as switching device than the bipolar fast thyristor. It has been proven for years that the heavy metal industry relies on the reliability and performance of fast thyristors. And as in many other market segments also in the heavy metal industry there is a general trend towards increased power and power density, higher efficiency and productivity. Fast thyristors are one of the key enablers to follow these trends. The most powerful applications are melting and pouring in the heavy metal industry with furnace capacities of up to 50 tons and inverter powers of up to 50 MW. ABB provides for years fast switching thyristors and further expands its portfolio for high-power resonant inverters. More details on page 25.

Cover supplied by ABB Semiconductors

Waiting for Widespread GaN Adoption

The year 2020 could see an estimated GaN device market size of almost $600 million, expects market researcher Yole. Ramp-up will be quite impressive starting in 2016, at an estimated 80% CAGR through 2020, based upon a scenario where EV/HEV begins adopting GaN in the 2018-2019 time frame. Recent announcements show that the GaN industry is taking shape as mergers, acquisitions and license agreements are settled. The latest Transphorm-Fujitsu agreement, in addition to Furukawa's IP portfolio's exclusive licensing, are positive signs that GaN technology is spreading across the value chain, reinforcing the leaders' market position but likely leaving the weakest players by the wayside. One example of this statement is the Germany-based MicroGaN – previously participating in the German research project NEULAND. Yole forecasts that 2014 will only generate $10 – 12 million in device sales (in addition to R&D contracts and so forth). Such a moderate business means only the strongest will survive, and that several early-birds will see their cash-flow swiftly dissipate. The GaN business will really ramp up in 2016, exceeding the "psychological threshold" of $50 million in revenue.

In the NEULAND project (2010-2013) six companies from the semiconductor and solar industries joined forces to explore new technologies for renewable power sources. NEULAND stands for innovative power devices with high energy efficiency and cost effectiveness based on wide bandgap compound semiconductors. The project aims to reduce the losses in feeding electricity into the grid, e.g. in photovoltaic inverters, by as much as 50 percent – without significantly increasing system costs by using semiconductor devices based on SiC and GaN-on-Si. The NEULAND project was headed by Infineon. Before NEULAND, SiC was a very expensive wafer material. Now more SiC vendors and the number of possible applications has grown. The project partners were able to demonstrate that the efficiency of power electronics can be increased by more than a third using SiC and GaN-based components. A new German research and development project "Future efficient energy conversion with gallium-nitride-based power electronics for the next generation (ZuGaNG)" aims at the realization of a new product generation for power electronics. In the scope of the project, scientists from an association of industry and research partners develop high voltage GaN transistors for applications in voltage converters. The project is funded by the German Federal Ministry for Education and Research with approximately 4 million Euros. The project aimes for both a significant increase in the energy efficiency of voltage converters and a reduction of production costs for GaN-based power transistors of up to 50 %. Due to their high switching frequency, the transistors reduce losses of voltage converters and work reliably, even in high temperatures. Physical properties of the semiconductor gallium nitride, such as the high electron mobility and critical field strength facilitate the realization of power transistors with a longer lifetime and higher robustness in comparison to conventionally used silicon devices. An approach for a lasting reduction of production costs is, among others, an integration of the GaN-based transistors in CMOS production lines.

Infineon Technologies AG is expanding its Austrian site in Villach. Core emphasis is the on the expansion of expertise for the manufacturing of the future as well as R&D. The expansion plan foresee investments and research costs amounting to a total of Euro 290 million, creating approximately 200 new jobs in the period from 2014 to 2017, primarily in R&D. This investment plan focuses on the integration of substrates such as GaN and SiC – a first official statement on power GaN from this company.

According to market researcher IDTechEx very different options for the elements of an EV are now emerging. It may be possible to have flexible batteries over the skin of the car in due course. Sometimes such laminar batteries permit faster charging and greater safety. In about ten years structural components - load-bearing supercapacitors and batteries will save even more space and weight in the most advanced vehicles. Vehicle electrics/electronics will be a greater part of the cost of the vehicle as they replace hardware and give greater safety and performance. Electronics will change radically from the introduction of wide bandgap power semiconductors to printed electronics. There is scope for energy harvesting from shock absorbers, thermoelectric harvesting which will be viable around 2017 and there will be some local harvesting for devices around the vehicle. Launches of production models of fuel cell cars are promised around 2015 by companies such as Hyundai, Toyota, Daimler and Tata Motors, bringing these center stage to the contempt of competitors that consider them to be a dead end. New car technologies such as supercapacitors, SiC and GaN power components, switched reluctance motors, merged and structural electric components, contactless charging and harvesting heat, light and vertical movement are on the horizon.

Enjoy reading!

Achim Scharf
PEE Editor

Electric Cars Reinvented

Market researcher IDTechEx finds that the global sale of hybrid and pure electric cars will triple to around $180 billion in 2024 as they are transformed in most respects. Ten year forecasts are provided in a new report, "Hybrid and Pure Electric Cars 2014-2024" - unique in revealing how everything about such cars is being reinvented.

There are chapters on in-wheel motors, fuel cell cars and the transformed battery situation. In-wheel motors are at last appearing in born-electric vehicles optimized for this disruptive change. 140 lithium-ion battery manufacturers and their changing success with EVs and changing chemistry are analyzed. They are now threatened by Tesla planning a mega factory to dwarf all of them put together.

Launches of production models of fuel cell cars are promised around 2015 by companies such as Hyundai, Toyota, Daimler and Tata Motors, bringing these center stage to the contempt of competitors that consider them to be a dead end. New car technologies such as supercapacitors, SiC and GaN power components, switched reluctance motors, merged and structural electric components, contactless charging and harvesting heat, light and vertical movement are presented. IDTechEx sees a gathering trend towards OEMs making their own key enabling technologies. It reveals that there are far more than the traditional three key enabling technologies now and explains their future.

Very different options for the elements of an EV are now emerging. It may be possible to have flexible batteries over the skin of the car in due course. Sometimes such laminar batteries permit faster charging and greater safety. In about ten years structural components - load-bearing supercapacitors and batteries will save even more space and weight in the most advanced vehicles.

Vehicle electrics will be a greater part of the cost of the vehicle as they replace hardware and give greater safety and performance. Electrics will change radically from the introduction of wide bandgap power semiconductors to printed electronics. There is scope for energy harvesting from shock absorbers, thermoelectric harvesting which will be viable around 2017 and there will be some local harvesting for devices around the vehicle (eg Fiat vision).

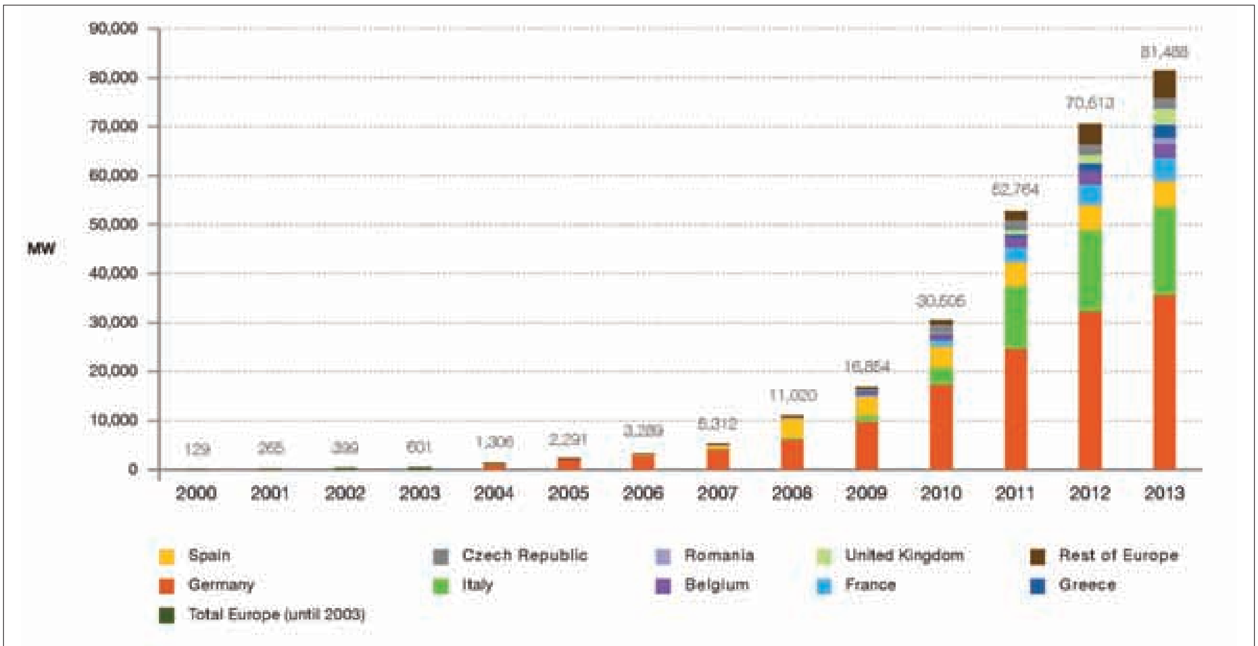
www.IDTechEx.com/cars

Record-Year for Photovoltaics

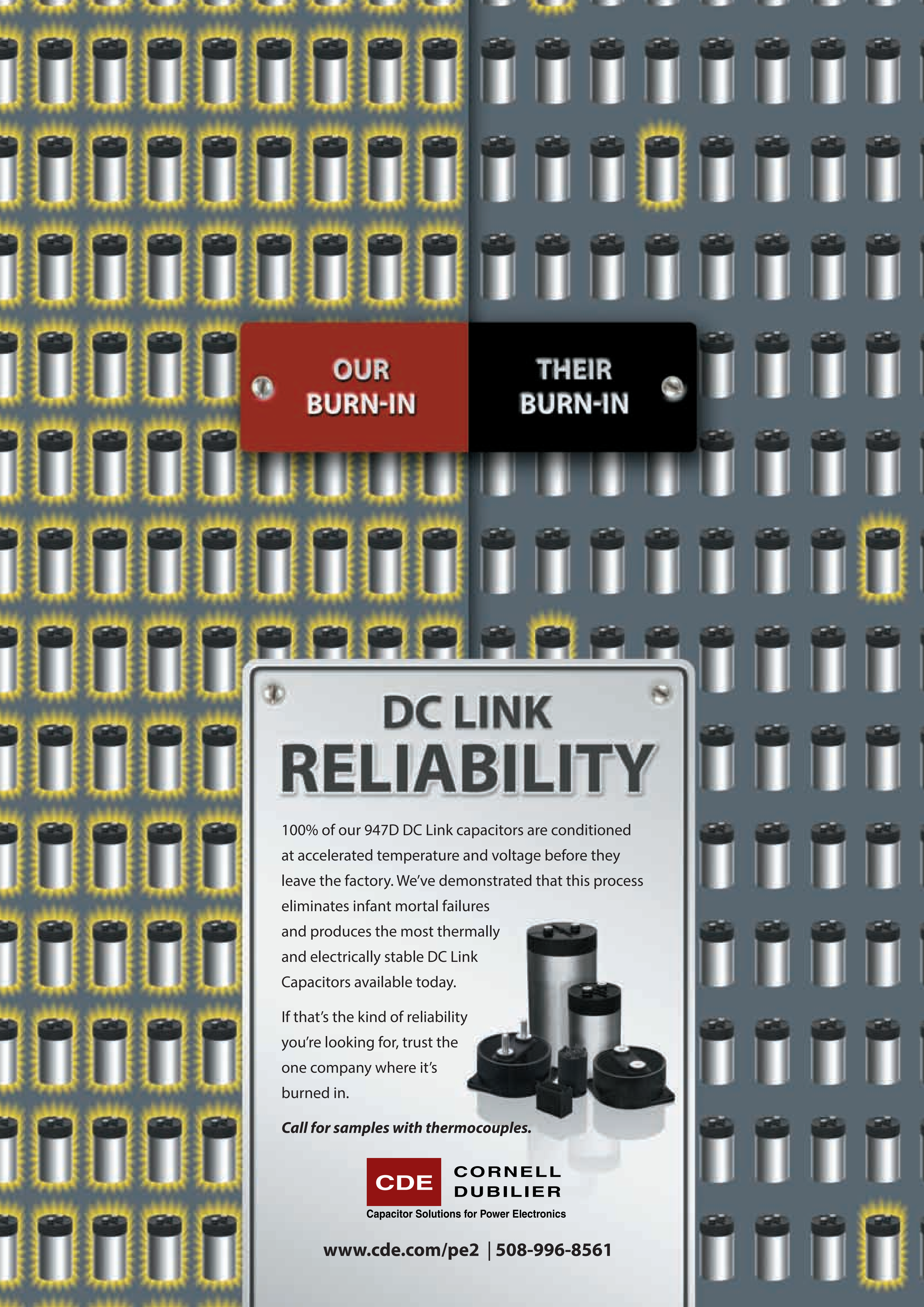
With at least 38.4 gigawatts (GW) of newly-installed solar photovoltaic (PV) capacity worldwide and a global cumulative installed capacity of 138.9 GW, 2013 was another historic year for solar PV technology.

The European Photovoltaic Industry Association (EPIA) released at Intersolar in Munich its new report "Global Market Outlook for Photovoltaics 2014-2018". Compared to the two previous years, where global installed capacity hovered slightly above 30 GW annually, the PV market progressed remarkably in 2013, reaching a new record-level. Nevertheless, for the first time since 2003, Europe, with a very high and stable level of nearly 11 GW connected to the grid in 2013, lost its leadership to Asia. EPIA forecasts indicate that the globalization trend of PV markets observed in 2013 will continue and further accentuate in the coming years. "The forecast for Europe in the next years should, however, be put into perspective and be considered as a stabilization towards a solid level, around 10 GW a year," stated Oliver Schäfer, EPIA President. "Europe's situation at the end of last year shows that PV, as any other energy business, remains policy-driven. A series of retrospective measures were implemented in the last years in various European countries, leading to the sharp market decrease observed in 2013. Sustainable, predictable and dynamic framework condition and policies are needed in Europe and globally to provide enough visibility to investors," he added. For the third year in a row, PV in 2013 was amongst the two most installed sources of electricity in the EU. "PV is becoming a major part of the electricity system all over the globe, changing the way our world is powered. Policymakers and energy stakeholders should now understand that electricity grids and markets need to be adapted to fit these new realities and facilitate a cost-efficient energy transition," Schäfer concluded.

www.epia.org



Evolution of European PV cumulative installed capacity 2000-2013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Battery Management IC in Hybrid Car

Maxim Integrated, a $2.4 billion US-based company, announced that its lithium-ion (Li+) battery monitor is being used by Nissan Motor Co. Ltd. for the Nissan Pathfinder Hybrid. The Li+ battery system is supplied by Hitachi Automotive Systems.

Hitachi Vehicle Energy developed the system and incorporated the battery monitor. The Li+ battery monitor provides self-diagnostics and daisy-chained data communications that handles the high-voltage requirements of the automotive industry. "Maxim's battery cell-monitoring IC was integral to achieving the highly reliable, smaller, lighter, and high-power Li+ battery system required for the newest hybrid car," said Mr. Koji Masui, Department Manager, Lithium Ion Battery Development Dept., Hitachi Automotive Systems, Ltd. "The automotive market is a major focus for us, and I am pleased that Nissan selected our cell-monitoring IC for its Pathfinder Hybrid," said Kent Robinett, Managing Director, Automotive Marketing for Maxim Integrated. "Maxim is advancing into a next-generation EV/HEV powertrain system, and we will continue to develop highly integrated products for this important market."

www.maximintegrated.com

Incentives for Solar Storage Systems

The German state incentives in place for solar storage systems are entering their second year. Since the program was launched in May, the purchase of around 4,000 solar batteries has been supported so far by low-interest loans of roughly 66 million Euros as well as subsidies exceeding 10 million Euros.

"The government covers a proportion of the purchase costs, making solar storage systems affordable for both homeowners and business enterprises. Increasing numbers of people are becoming more independent from fossil energy sources by making the wise decision to invest in a photovoltaic storage system and, in doing so, they are in turn driving forward the energy transition," stated Jörg Mayer, CEO of the German Solar Industry Association at Intersolar Europe in June. By balancing out peaks in production, battery storage systems contribute towards easing the burden on power grids as well as increasing the connection capacity for further solar installations without additional costs being incurred. The incentive program has the potential to issue enough repayment grants to support double the amount of battery storage systems per year, which is why the German Solar Industry Association is expecting a significantly higher drawdown of funds in 2014. "Anyone planning to invest in a photovoltaic installation with a capacity of up to 30 kWp should certainly consider fitting a battery storage system as well. It is even possible to retrofit photovoltaic installations with storage devices, provided that the existing installation came into operation after December 31, 2012," said Mayer.

www.solarwirtschaft.de

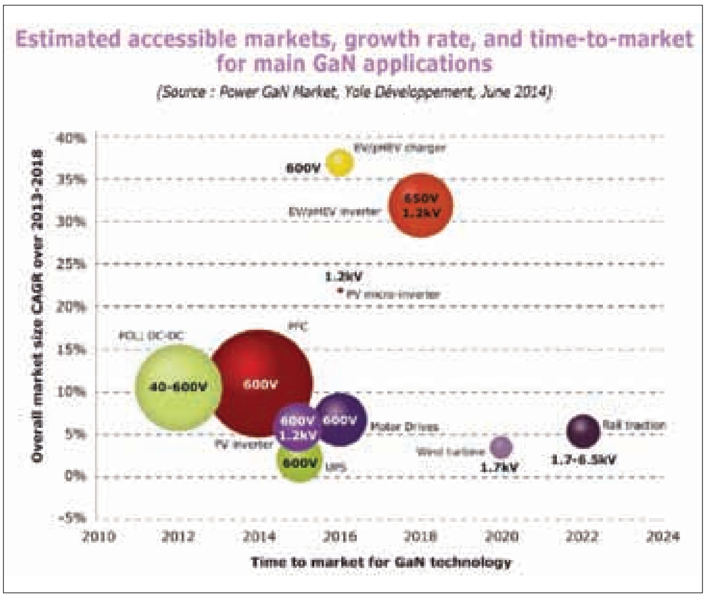
Power GaN to Ramp Up in 2016

Yole Développement analyses the Power GaN industry in its new report, Power GaN Market released in June. In this analysis, the company provides a bill-of-material comparison of GaN versus Silicon at system level as well as a payback-time simulation focused on GaN's extrat costs.

2020 could see an estimated GaN device market size of almost $600 million, leading to approximately 580,000 x 6" wafers to be processed", explains analyst Philippe Roussel. "Ramp-up will be quite impressive starting in 2016, at an estimated 80% CAGR through 2020, based upon a scenario where EV/HEV begins adopting GaN in 2018-2019". The power supply/PFC segment will dominate the business from 2015-2018, representing 50 % of device sales. At that point, automotive will then catch-up. "In UPS applications, the medium-power segment is likely to be very much in line with the GaN value proposition, and savings at system level will be demonstrated. We think GaN technology could grab up to 15 % of market share in this field by 2020", details Roussel.

Room for extra cost in motor drive applications is unlikely. Therefore, the incentives to implement new technologies such as GaN have to be serious and strong. Considering the possible improvement of conversion efficiency, and augmented by a predictable price parity with Si solutions by 2018, Yole Développement expects GaN to start being implemented at a slow rate in motor control by 2015-2016, and reach around $45 million in revenue by 2020. The PV inverters segment has already adopted SiC technology, and products are now commercially available. It is possible that GaN could partially displace SiC thanks to better price positioning. However, now that SiC is in place, qualifying GaN may be more challenging. Recent announcements show that the GaN industry is taking shape as mergers, acquisitions and license agreements are settled. "The latest Transphorm-Fujitsu agreement, in addition to Furukawa's IP portfolio's exclusive licensing, are positive signs that GaN technology is spreading across the value chain, reinforcing the leaders' market position but likely leaving the weakest players by the wayside", comments Roussel. Yole forecasts that 2014 will only generate $10 – 12 million in device sales (in addition to R&D contracts and so forth). Such a moderate business means only the strongest will survive, and that several early-birds will see their cash-flow swiftly dissipate. The GaN business will really ramp up in 2016, exceeding the "psychological threshold" of $50 million in revenue.

www.yole.fr



Future Plans for Infineon's Villach Site

Infineon Technologies AG is expanding its Austrian site in Villach. Core emphasis is the on the expansion of expertise for the manufacturing of the future as well as R&D. The expansion plan foresee investments and research costs amounting to a total of Euro 290 million, creating approximately 200 new jobs in the period from 2014 to 2017, primarily in R&D.

"The continuing development of Villach is a part of our group-wide manufacturing strategy. At the site, important developments will be advanced and production-ready innovative technologies will be transferred by Infineon to other sites. At the same time our strategy will include expansion of our volume manufacturing on 300 millimeter thin wafers in Dresden and on 200 millimeter wafers in Kulim, Malaysia", said Peter Schiefer, President of Operations. The pilot operation in Villach will feature production based on a cyber-physical system in the sense of Industry 4.0 with highly modern production control and automation systems. Under the prerequisite of the highest possible data security and data integrity levels, the interaction of man and machine will attain a new dimension in the pilot facility. At the same time, Infineon will continue to pursue its goal of increased energy efficiency in production. A wide-scale research program with innovations in materials, processes, technologies and system expertise is the second pillar of the Villach site expansion, supporting development of the next generation of energy-efficient products. Here the program focuses on the integration of substrates such as GaN and SiC, on MEMS (Micro-Electro-Mechanical Systems) and sensor technologies as well as on the continuing development of 300 mm thin wafer technology.

www.infineon.com

Murata and Ericsson to Collaborate on Digital Power

Murata Power Solutions and Ericsson have entered into a technical collaboration agreement with the goal of accelerating the adoption of digital power products. Under the terms of this agreement each company will introduce a range of standardized digital power modules. This will result in the availability of multiple product sources to manufacturers that are considering migrating designs from analog to digitally monitored and controlled units. "We believe this joint initiative will encourage manufacturers to speed up their adoption of digitally controlled power systems. Initially, the benefits of using digitally controlled power sources were considered not to be worth the extra price. However, customers now can see the advantages digital control and monitoring can bring to their end application, so we believe that by introducing a second-source route of Ericsson's products we will speed the development of this market", commented Tatsuo Bizen, CEO of Murata Power Solutions. Murata aims to launch the first of their standardized digitally controlled power modules into the market during summer 2014.

www.murata-ps.com

With Ericsson Power Modules as second source Murata Power Solutions' CEO Tatsuo Bizen will accelerate digital power adoption

Power Electronics Conference in Lapland

Challenges from industry and science, in addition to the pressure from the European Community to give priority attention to energy efficiency issues, continue to provide stimulus for new research directions for the power electronics discipline. Energy efficiency is the field where both academia and industry need and want to achieve and excel. In this field, power electronics is considered the key to developing new energy efficient technologies for sustainable energy systems. EPE'14 ECCE from August 26 to 28 in Lappeenranta/Finland covers a wide range of topics at the cutting edge of research and applications of power electronics. Those of you who have not had the opportunity to attend 2014 conferences such as CIPS, APEC, PCIM or ISPSD (Hawaii) can now travel to the very North-East.

"An adult flying a kite on a darkly cloudy day – symbolizing the largest European conference in power electronics. Many people have wondered about the message behind our conference banner. It is a story of science. Once upon a time Benjamin Franklin was flying a silk kite during a thunderstorm. The story tells that Franklin was conducting a science experiment to prove that thunderclouds contained electricity. And it goes on to say that Franklin knew that getting struck by lightning would kill him. Every banner tells a story. The EPE'14-ECCE banner tells about a commitment to science and a passion in proving the way things are working. It tells about us", explains Juha Pyrhönen, General Chair.

The EPE'14-ECCE event provides a programme of over 40 working sessions, high profile keynotes and plenary presentations, and live debate. It attracts in excess of 600 delegates from the full range of professions, expertise and business within power electronics. Alongside an exhibition featuring suppliers and manufacturers whose business, products and services meet the needs of our delegates.

The three keynote will cover

- Power Electronics for Electric Drives – Advancement in technology and its implications – A Finnish Perspective by Matti Kauhanen, Vice President, Head of Research and Development, Drives and Controls Business Unit, ABB Group
- Power Electronics for hybrid work machines, a real-world case with under two-year payback time by Kimmo Rauma, CTO and co-founder of Visedo Oy in Finland
- Megatrends affecting frequency converters by Timo_Heikkila, Vice President, Research and Development, Vacon Plc

The conference aims to inspire excellence in power electronics through personal and professional development. The Exhibition will help the delegate to achieve this by providing opportunities to enhance knowledge and understanding of what is new in the field, to explore new ideas, products and services in the field, to learn about new technologies, tools, techniques that enable to develop new skills and unlock potential for professional growth and new perspectives into work and career development, and – last but not least – to widen professional networks.

"Our aim at the EPE'14-ECCE event is to create a different experience. We dedicate our time to ensure our delegates will by impressed by the magnificent atmosphere of a quality event and by the beautiful surroundings of the conference venue, Lappeenranta and its university, a place that will showcase the future of power electronics. The conference program will keep you on track by day. The technical program will give you the opportunity to explore the industrial environment of Lappeenranta. A pre-conference program invites you to join us at the event after first having experienced the bright nights of Lapland. And of course, once in Lappeenranta, St. Petersburg next door is a must-visit. A tour to Russia's second largest city is made possible for you in a post-conference program. In St. Petersburg, an attempt to replicate Franklin's experiment killed Professor Georg Wilhelm Richmann, and Priestley quoted this in 1767: It is not given to every electrician to die in so glorious a manner as the justly envied Richmann", Pyrhönen underlines.

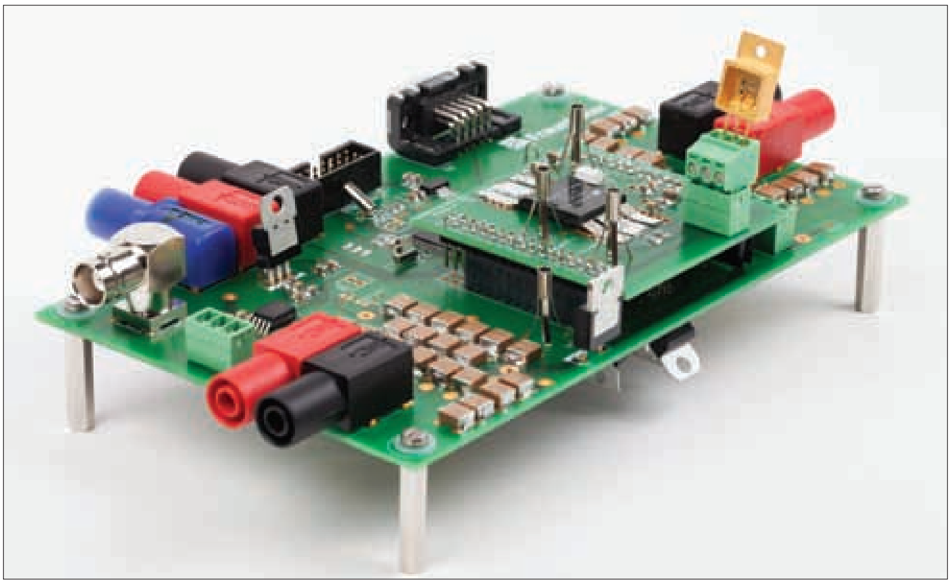
Gallium Nitride Converters for Future Energy Systems

With the help of the semiconductor gallium nitride (GaN), considerable energy savings in electronic systems can be achieved. Due to its physical properties, power electronics systems based on GaN can be operated more efficiently and lower cooling efforts, than conventional Silicon devices. Under the project management of the Fraunhofer Institute for Applied Solid State Physics IAF, a group of scientists is now developing a new generation of voltage converters.

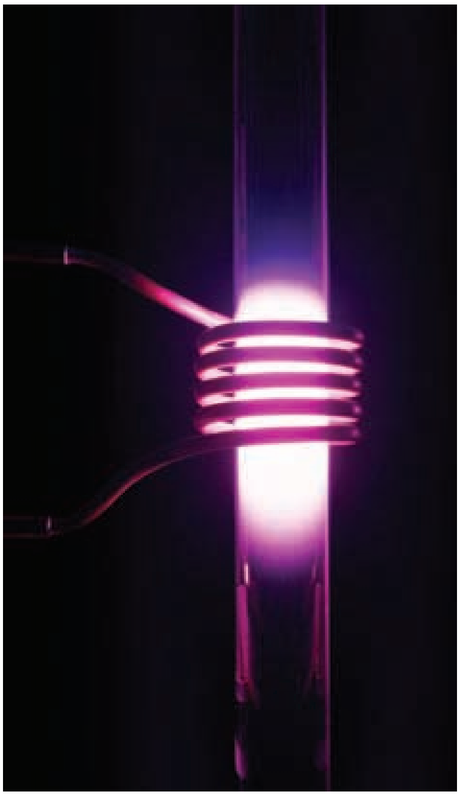
Applying novel technologies, the German research and development project "Future efficient energy conversion with gallium-nitride-based power electronics for the next generation (ZuGaNG)" aims at the realization of a new product generation for power electronics. In the scope of the project, scientists from an association of industry and research partners develop high voltage GaN transistors for applications in voltage converters. The project is funded by the German Federal Ministry for Education and Research (BMBF) with approximately 4 million Euros over the next three years and is part of the BMBF's funding measure "Power electronics for increased energy-efficiency – Part 2: Electronics for energy of the future".

With the improvement of the applied technology, the scientists are aiming for both a significant increase in the energy efficiency of voltage converters and a reduction of production costs for gallium-nitride-based power transistors of up to 50 %. Due to their high switching frequency, the transistors reduce losses of voltage converters and work reliably, even in high temperatures. Physical properties of the semiconductor gallium nitride, such as the high electron mobility and critical field strength facilitate the realization of power transistors with a longer lifetime and higher robustness in comparison to conventionally used silicon devices.

"Furthermore, thanks to the high pulse frequency of our transistors, a miniaturization of the systems is possible, as we are able to design also smaller passive devices", explains Dr. Patrick Waltereit, project leader at Fraunhofer IAF. "This allows reducing the volume of the components, the cooling efforts, as well as the modules necessary for the cooling, thus leading to a reduction of production as well as operating costs". Together with their industry and research partners, the scientists at Fraunhofer IAF strive for the development of novel concepts for design, material production and process technologies for the production of power electronics components. First demonstrators will soon validate the voltage converters' performance in heating, household and manufacturing technologies, in electro mobility or in the generation of renewable energies. The power transistors could help to save energy in future pump motors of washing machines or heatings, in chargers for electronic vehicles, generators for plasma or laser systems, or in photovoltaic plants.



Prototyping board for the analysis of the switching properties of GaN-based high-voltage transistors
Photo: Fraunhofer IAF



Example for GaN-based converter applications - inductively coupled plasma in a quartz glass tube for material processing **Photo: TRUMPF Group**

Besides the construction of demonstrators, the project partners pursue an embracing characterization of the GaN-based transistors, in order to achieve a comprehensive understanding of the correlations between the production process on the one hand, and structural, electric and thermal properties on the other hand. Furthermore, it is the goal to further optimize the technology regarding the robustness and reliability of the devices, so that it can finally qualify for industrial production.

GaN in a CMOS Environment

An approach for a lasting reduction of production costs is, among others, an integration of the GaN-based transistors in CMOS production lines. This would allow a cost-efficient volume production. In the upcoming years, scientists furthermore want to combine the special integration potential, the high output and the extraordinary functionality of the Silicon-CMOS-technology with the high electric power density and robustness of components based on gallium nitride.

Besides Fraunhofer IAF Robert Bosch GmbH, TRUMPF Hüttinger GmbH, KACO new energy GmbH, X-FAB Semiconductor Foundries AG, Lewicki microelectronic GmbH, EDC Electronic Design Chemnitz GmbH, Fraunhofer Institute for Silicon Technology ISIT, Ferdinand-Braun-Institute, University of Erlangen, University of Reutlingen, as well as the University of Magdeburg are involved in the ZuGaNG project.

www.iaf.fraunhofer.de

Contactless Inspection of SiC Epiwafers

Operator loading a 100 mm SiC epiwafer in the defect luminescence scanner at Fraunhofer IISB

A new fast and contactless Defect Luminescence Scanner (DLS) for photoluminescence imaging of 4H-SiC epiwafers was developed under coordination of German Fraunhofer IISB together with Intego GmbH. This DLS system enables a more efficient optimization of the production process of SiC epiwafers as well as an inline quality control along the device production chain. This will contribute to cost reduction in material and device production, and helps accelerating the further commercialization of SiC power devices.

With respect to structural defects, such as micropipes or other dislocation types, and their densities in substrates and epilayers, the material quality of silicon carbide (4H-SiC) has been improved greatly within the last years. But still, the performance of especially SiC bipolar devices and the yield of device production may be limited by residual structural defects in the epiwafers. Such defects originate in the substrate material or are generated during the epitaxial process like down-fall particles, stacking faults, and dislocations.

To date, several characterization methods are well established for identification and distribution of such defects on the wafer level, but they are destructive (defect selective etching), cost-intensive (synchrotron x-ray topography), or time-consuming (both defect selective etching and x-ray topography). Hence, they are not suitable for a fast inline quality control of the material preparation and device production.

Half-Hour Scanning Time

As a non-destructive, contactless method allowing for identification of structural defects of 4H-SiC at room temperature, the photoluminescence (PL) technique is well known. In PL images, structural defects appear either as bright or dark items on the "grey" SiC background as 4H-SiC itself shows a low PL intensity due to its indirect bandgap.

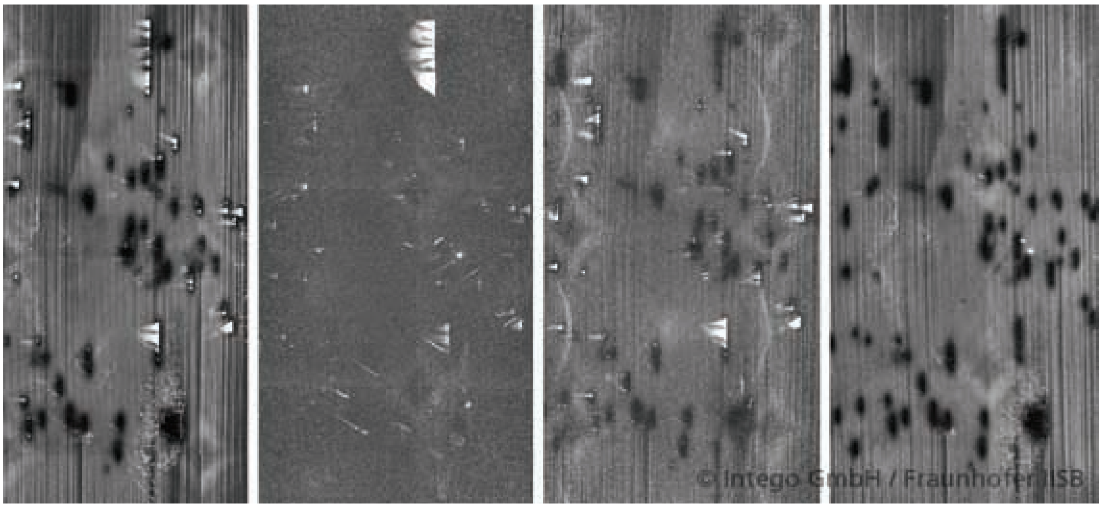
However, so far no PL setup exists which is fast enough for an inline defect analysis on full waferscale within a production environment. This obstacle has now been overcome in the course of the "SiC-WinS" project, funded by the Bavarian Research Foundation (BFS). Together with the metrology specialist Intego Vision Systeme GmbH, the new defect luminescence scanner (DLS) was designed and fabricated under coordination of Fraunhofer IISB. The DLS allows for short PL measurement cycles and high throughput of SiC epiwafers at a high lateral resolution of 5 µm.

The DLS system is installed at Fraunhofer IISB in Erlangen and consists of a UV laser operating at 325 nm wavelength for PL excitation, a sample stage for scanning the SiC epiwafer, and an electron multiplying charge-coupled device (EMCCD) camera for fast image recording at a high signal-to-noise ratio. The high lateral resolution of 5 µm is achieved by a magnifying objective lens in front of the camera. For identification of defect types by their spectral fingerprints, different band-pass filters are installed.

The DLS system can determine the defect types and their distribution on SiC epiwafers up to 150 mm diameter in less than 30 minutes. A routine for automated defect identification and counting in order to predict directly the device yield per epiwafer is currently under development.

Fraunhofer IISB performs service measurements with the new DLS system and identifies the defects and their distribution on SiC epiwafers on the full waferscale for epi houses and device manufacturers. The Fraunhofer Institute for Integrated Systems and Device Technology IISB is one of the 67 institutes of the Fraunhofer-Gesellschaft. It conducts applied research and development in the fields of power electronics, mechatronics, micro and nanoelectronics. A staff of 200 works in contract research for industry and public authorities. The institute is internationally acknowledged for its work on power electronic systems for energy efficiency, hybrid and electric cars and the development of technology, equipment, and materials for nanoelectronics.

www.iisb.fraunhofer.de/sic, sic@iisb.fraunhofer.de



LEFT: Example for spectral fingerprints of defects in 4H-SiC epiwafers: "panchromatic" image with full spectral range (left), band-pass filter in blue, green, red ranges

German Researchers Cut Energy Loss in Half

Six companies from the semiconductor and solar industries joined forces in the NEULAND project funded by the Federal Ministry of Education and Research (BMBF) to explore new technologies for renewable power sources. NEULAND stands for innovative power devices with high energy efficiency and cost effectiveness based on wide bandgap compound semiconductors. The project aims to reduce the losses in feeding electricity into the grid, e.g. in photovoltaic inverters, by as much as 50 percent – without significantly increasing system costs. This is to be achieved using semiconductor devices based on silicon carbide (SiC) and gallium nitride on silicon (GaN-on-Si). The NEULAND project will (May 2010- April 2013) was headed by Infineon. The project received funding at 52.6 percent to the tune of approximately Euro 4.7 million (in total Euro 8.9 million) from the BMBF under the Federal Government's High-Tech Strategy ("Information and Communications Technology 2020", ICT 2020 program) as part of the call for proposals on "Power Electronics for Energy Efficiency Enhancement".

Cutting energy losses

The key to reducing energy losses by half is use of the semiconductor materials silicon carbide (SiC) and gallium nitride on silicon (GaN-on-Si), whose electronic properties enable compact and efficient power electronics circuits. Today Infineon already uses the material SiC in its JFETs and diodes for the 600 V to 1700 V voltage class. These power semiconductors are primarily used in switched-mode power supplies for PCs or televisions and in motor drives. In the future they may also gain major significance for solar inverters. In future, also solar inverters could considerably profit.

Before NeuLand, SiC was a very expensive wafer material. Now more SiC vendors and the number of possible applications has grown. The project partners were able to demonstrate that the efficiency of power electronics can be increased by more than a third using SiC and GaN-based components. Solar inverters for example profit from considerable material savings with no change in effectiveness, making them even more cost-efficient. However, results also showed that the cost of SiC components will have to drop even more for the wide-scale application in solar inverters and that for GaN-based components further intensive research is required on reliability, service lifetime and costs.

AIXTRON (www.aixtron.com) was represented as an equipment provider for semiconductor production, while as a wafer manufacturer SiCrystal (www.sicrystal.de) was on board for SiC. The semiconductor manufacturer Infineon (www.infineon.com) researched the power semiconductor devices and the production steps for SiC and GaN-based components, while the system technology expertise in the solar sector was provided by SMA Solar Technology (www.sma.de). With NeuLand the project partners were able to further expand their respective proficiencies in future-oriented SiC and GaN technologies along a very wide segment of the value creation chain. In the meantime the German GaN partner MicroGaN has given up its activities.

SiC-Based Transformers for the Future Grid

Today's grid has very little ability to precisely control the voltage delivered to the customer while the voltage at all load points must be within certain limits. The voltage regulation is assured so far through planning, network design, load estimation and fine tuning through capacitor switching and LTC (load tap changer) operation. This will not work in the future due to distributed PV, electric vehicle charging, and voltage drop across the leakage reactance of the distribution transformer. At PCIM Europe Alex D. Huang, head of NSF FREEDM Systems Center at NC State University, sketched the architecture of a future grid.

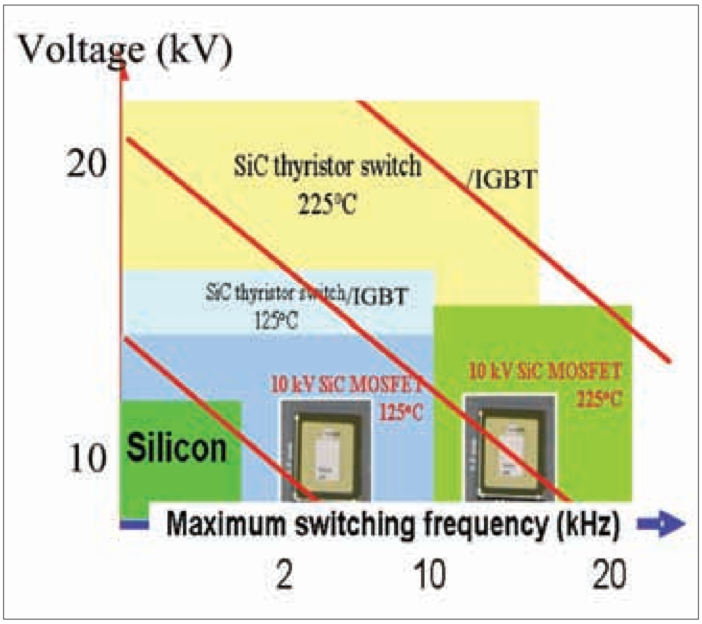
The level of voltage drop varies with transformer loading level and load power factor. Utility companies are increasingly demand abilities to precise control the voltage so energy saving programs can be implemented. Addressing the voltage issue therefore requires a new generation of intelligent device that is close to the customer and can automatically correct over- and under-voltage issues in real time. Regarding power factor, 1.0 is the ideal case because only real power present on the electrical network. However, modern loads tend to be inductive and residential and industrial load have significant amount of reactive power consumption. When reactive power is present, the currents increase in the wiring and in the devices operating on the network. This is undesirable because power dissipation is proportional to the square of the current.

"The FREEDM system is totally feasible due to the remarkable progress of power electronics technology in the last few decades", Alex Huang stated at PCIM Photo: AS

How to meet the increased energy demands while not impacting the climate is another major issue facing the industry. This results in the push for more and more renewable and alternative energy integrations into the grid, mostly at the distribution level. High penetration of distributed generation (DG) will cause more problems in voltage and frequency control. An intelligend device or a grid that that can address this problem should have the ability to control voltage, frequency and power flow, and to integrate and manage different energy sources - effectively making this a microgrid controller. With visibility to utility via communication network, it can be controlled and managed in an aggregated manner to achieve even greater benefit to utility when such a solution is widely adopted. For example, today's utility is over designed to support the peak load which only happens for less than 10 % of the time while another 10 % of the time the load is so low that over 50 % asset is idle. This issue can be addressed by moving towards high penetrations of DGs that are dispatchable. Again, an intelligent device that is not only able to facilitate the integration of DGs (PV, storage, microturbine, EV etc) but also provides the visibility for utility control and management is indispensable.

Direct Voltage Conversion

A future power delivery system (FREEDM System) has been proposed by researchers including Alex Huang at NC State University which integrates the advanced power electronics and information technology. The medium voltage AC distribution grid (12.47 kV) is converted to the low voltage AC (120 V) and DC (380 V) system by a solid state transformer (SST). These DC or AC ports deliver AC or DC power to the load and enable the formation of residential AC or DC microgrids (MG). A new class of circuit breakers called Fault Isolation Device (FID) is used to identify and isolate the malfunction area when the grid is in abnormal condition. Due to the software and hardware capability of the SST, plug-and-play of AC and DC MG can be realized to allow the integration of



Voltage/frequency capabilities of medium-voltage SiC devices distributed renewable energy resources (DRER) and distributed energy storage devices (DESD). The new grid can precisely control all major power parameters of the grid: voltage, frequency and power factor at each port of the SST. This capability is enabled by the high bandwidth power electronics of the SST. Additional power management capability such as low voltage ride through (LVRT) can also be achieved by the SST. Under normal operating conditions, aggregated resources connected through the AC and DC MGs are managed by software embedded in the SST to achieve certain energy management objectives such as economic benefit to the customers.

One of the key reasons why Huang believes that the FREEDM system is totally feasible is due to the remarkable progress of power electronics technology in the last few decades. It is well understood that power semiconductor device technology drives the growth of power electronics market and application field. The capability of power semiconductor device is frequently measured by the available voltage and current ratings. However, it is important to point out that the switching speed of the power device is a much more important parameter for power electronics applications. Low voltage Silicon power devices such as IGBT and MOSFET at voltages below 1700 V can switch at a frequency of 10 to 100 kHz. This capability has fundamentally changed the way we deliver power at low voltage levels such as power supplies used in computers and data centers.

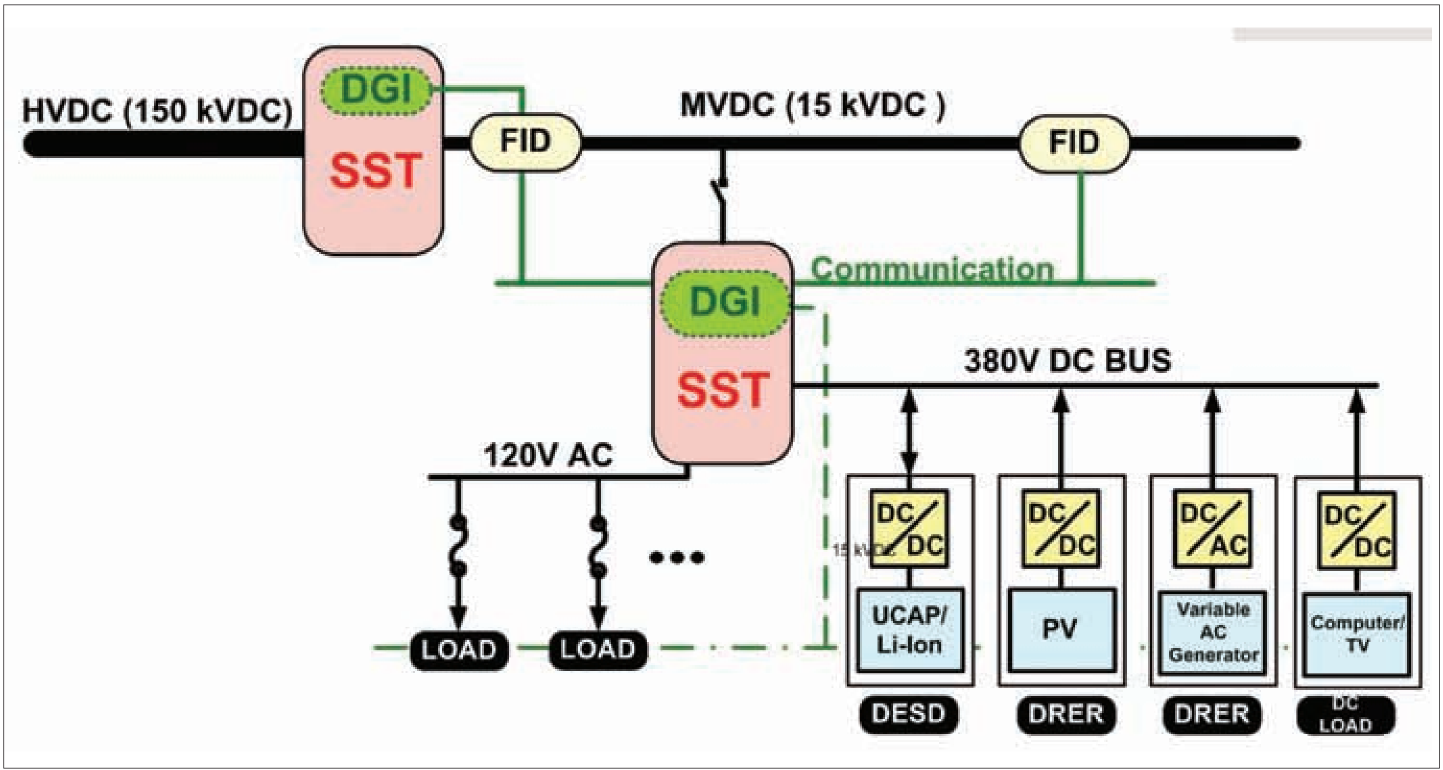
15 kV SiC SST

High-frequency power conversion is the norm for voltage transformation and power management control. High-frequency power conversion at low voltage levels (480V AC) is a reality and is the most important contribution of power electronics to industry. Power devices based on wider bandgap materials such as SiC and GaN are expected to further increase the applications field of power electronics due to their capability of operating at high voltage, high frequency and higher temperature. For medium voltage power devices (3300V), SiC based power devices offer even greater improvement in the switching speed because Silicon IGBTs and IGCTs are both bipolar devices with very low switching speed. Power devices such as SiC MOSTETs, IGBTs and thyristors with breakdown voltages from 3.3 to 50 kV can be developed to cover a wide range of applications including the SST. A test device that of a 15 kV SiC power MOSFET developed by Cree verifies 40 kHz operation. The switching speed of these SiC power devices can be increased 60 to 120 times when compared with Silicon bipolar power devices such as Si IGBT or IGCT, Huang expects.

This switching speed improvement in medium voltage SiC power devices will enable a fundamental new capability of power electronics - Direct Medium Voltage Power Conversion; basically repeating the power electronics success we had in low voltages systems at medium voltages using high frequency power conversion techniques at 10 to 100 kHz range. This new capability is the basis of the FREEDM system because the SST uses the direct medium voltage power conversion concept. At the heart of the direct medium voltage power conversion is a medium voltage DC/DC converter that uses medium voltage high frequency power switches such as the 15 kV SiC MOSFET. A comparison of several 15 kV devices developed at Cree show, from the conduction point of view, bipolar devices such as the GTO have the best capability, especially when operating at 125°C or higher. On the other hand, MOSFET shows the best switching speed or the lowest switching loss. Turn-off loss for 15 kV MOSFET is virtually zero, while the turn-off loss for 15 kV p-GTO and IGBT is still significant. For high frequency DC/DC converter application, the MOSFET is the preferred device while IGBT and GTO can be used in lower frequency applications.

As an example to demonstrate the SiC power device's capability, a 20 kVA SST based on 15 kV SiC MOSFET has been designed. Tested efficiency for the medium voltage DC/DC converter stage at half of the desired voltage (6 kV instead of 12 kV) is around 97.6 %. Additional improvement in the high frequency transformer design in the future will demonstrate DC/DC conversion efficiency at 99 % level. Since a bipolar device such as the SiC GTO has the best conduction capability, a 15 kV fault Isolation device (FID) based on the 15 kV SiC p-GTO has been developed. Since the SiC p-GTO blocks voltage only in one direction, an AC switch is needed. The AC switch is based on two 15 kV SiC p-GTO devices and two 15 kV SiC PiN diodes. Such an AC switch, can be used as a single phase solid-state circuit breaker.

www.freedm.nscu.edu



Future DC power delivery system

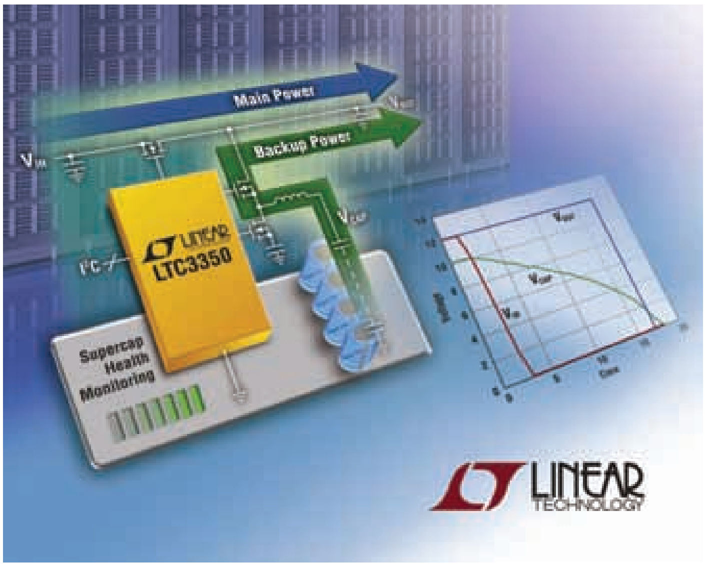
10 A Supercapacitor Charger and Backup Controller IC

Many applications require reliable short-term uninterrupted power in the event of a main power failure. Supercapacitors provide a simple and inexpensive source of short-term backup energy. They lack many of the safety and cycle life trade-offs associated with batteries, and provide excellent power density for high current backup. However, supercapacitors suffer from lost capacity and increased ESR over time, particularly at high operating temperatures. Therefore, monitoring capacitor "state of health" in a capacitor-based backup system is important for two reasons - to ensure adequate energy and power handling for proper backup, and to extend capacitor lifetime by minimizing capacitor charge voltage.

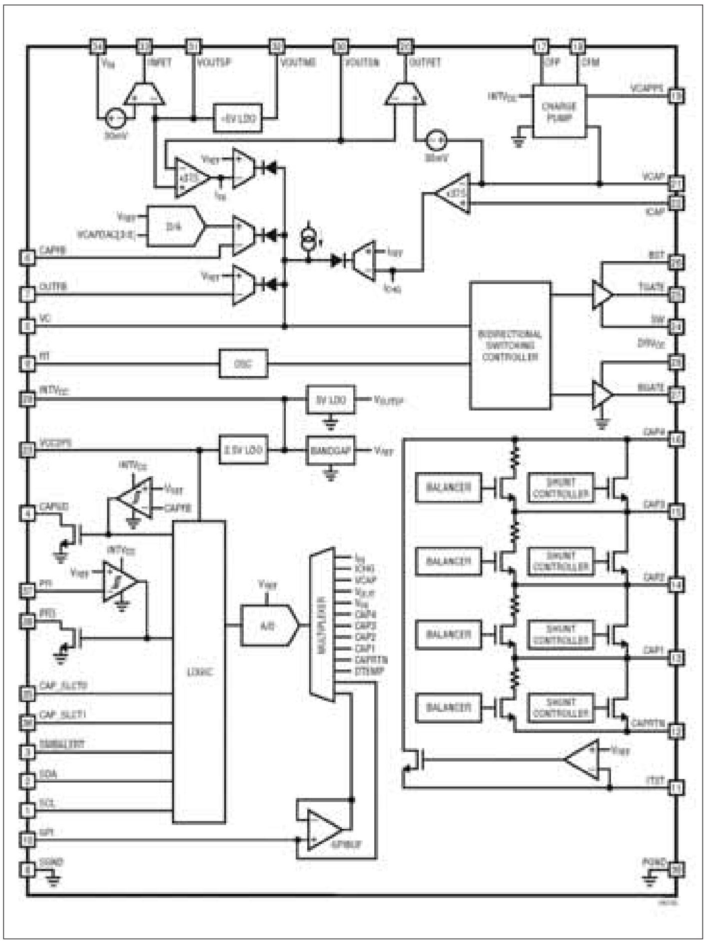
Linear Technology Corporation introduces the LTC3350, a supercapacitor charger and backup controller IC that includes all of the features necessary to provide a complete, standalone capacitor-based backup power solution. The device provides all PowerPath™ control, capacitor stack charging and balancing, and capacitor "health" monitoring to ensure that the backup system is capable of reliable operation.

The LTC3350 features a wide 4.5 V to 35 V input voltage range and over 10 A of charge/backup current capability. The device also provides balancing and over-voltage protection for a series stack of one to four supercapacitors. The LTC3350's synchronous step-down controller drives N-channel MOSFETs for constant current/voltage charging of the capacitor stack at up to 5 V per cell. In backup mode, the step-down converter runs in reverse as a synchronous step-up DC/DC to deliver power from the supercapacitor stack to the system supply to be backed up. The LTC3350's dual ideal diode controller uses N-channel MOSFETs for low loss power paths from the input and supercapacitors to the backup system supply. The device is suited for high current 12 V ride-through supplies and short-term uninterruptible power supplies (UPS) for servers, mass storage and high availability systems.

The LTC3350 contains an accurate 14-bit analog-to-digital converter (ADC), which continuously monitors input and output voltage and current. In addition, the internal measurement system monitors parameters associated with the backup capacitors themselves, including capacitor stack voltage, capacitance and stack ESR (equivalent series resistance) to



Linear's new Backup Power Controller UPS & Supercap Charger/Monitor IC



LTC3350 block diagram

ensure adequate energy storage and power delivery during backup. By monitoring the actual capacitance of the backup supercapacitors, the LTC3350 provides longer capacitor life by enabling the system to set the capacitor voltage to a minimum value while ensuring the required backup energy is maintained. All system parameters and fault status can be monitored via a two-wire I^2C interface, and alarm levels can be set to alert the system to a sudden change in any of these measured parameters.

Operation Principle

The LTC3350 contains a fast power-fail (PF) comparator which switches the part from charging to backup mode in the event the input voltage, V_{IN}, falls below an externally programmed threshold voltage. In backup mode, the input ideal diode shuts off and the supercapacitors power the load either directly through the output ideal diode or through the synchronous controller in step-up mode. The PF comparator threshold voltage is programmed by an external resistor divider via the PFI pin. The output of the PF comparator also drives the gate of an open-drain NMOS transistor to report the status via the PFO pin. When input power is available the PFO pin is high impedance.

When VIN falls below the PF comparator threshold, PFO is pulled down to ground. The output of the PF comparator may also be read from the chrg_pfo bit in the chrg_status register.

If V_{IN} is above an externally programmable PFI threshold voltage, the synchronous controller operates in step-down mode and charges a stack of supercapacitors. A programmable input current limit ensures that the supercapacitors will automatically be charged at the highest possible current that the input can support. If V_{IN} is below the PFI threshold, then the synchronous controller will run in reverse as a step-up converter to deliver power from the supercapacitor stack to V_{OUT}.

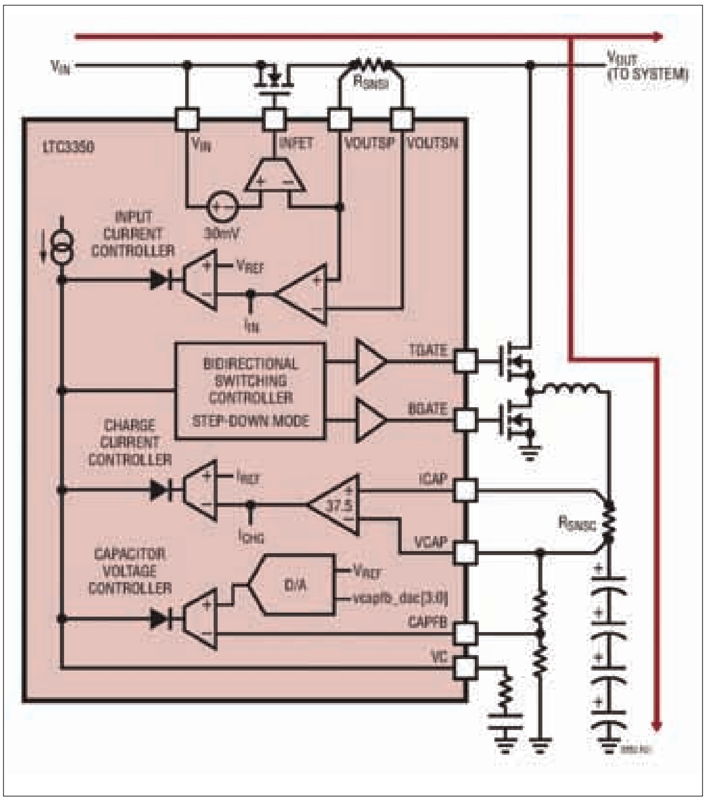
The two ideal diode controllers drive external MOSFETs to provide low loss power paths from V_{IN} and V_{CAP} to V_{OUT}. The ideal diodes work seamlessly with the bidirectional controller to provide power from the supercapacitors to V_{OUT} without backdriving V_{IN}.

The ideal diodes consist of a precision amplifier that drives the gates of N-channel MOSFETs whenever the voltage at V_{OUT} is approximately 30mV (V_{FWD}) below the voltage at V_{IN} or V_{CAP}.

Within the amplifier's linear range, the small-signal resistance of the ideal diode will be quite low, keeping the forward drop near 30 mV. At higher current levels, the MOSFETs will be in full conduction. The input ideal diode prevents the supercapacitors from back driving V_{IN} during backup mode. A Fast-Off comparator shuts off the N-channel MOSFET if V_{IN} falls 30 mV below V_{OUT}. The PFI comparator also shuts off the MOSFET during power failure. The output ideal diode also provides a path for the supercapacitors to power V_{OUT} when V_{IN} is unavailable. In addition to a Fast-Off comparator, the output ideal diode also has a Fast-On comparator that turns on the external MOSFET when V_{OUT} drops 65 mV below V_{CAP}. The output ideal diode will shut off when pin OUTFB is just above regulation allowing the synchronous controller to power V_{OUT} in step-up mode.

Charging proceeds at a constant current until the supercapacitors reach their maximum charge voltage determined by the CAPFB servo voltage pin and the resistor divider between V_{CAP} and CAPFB. The maximum charge current is determined by the value of the sense resistor, R_{SNSC}, used in series with the inductor. The charge current loop servos the voltage across the sense resistor to 32 mV. When charging begins, an internal soft-start ramp will increase the charge current from zero to full current in 2 ms. The V_{CAP} voltage and charge current can be read from the meas_vcap and meas_ichrg registers, respectively.

The bidirectional switching controller acts as a step-up converter to provide power from the supercapacitors to V_{OUT} when input power is unavailable. The PFI comparator enables step-up mode. V_{OUT} regulation is set by a resistor divider between V_{OUT} and OUTFB. Step-up mode can be used in conjunction with the output ideal diode. The V_{OUT} regulation voltage can be set below the capacitor stack voltage. Upon removal of input power, power to V_{OUT} will be



Power path block diagram with power available from input pin

provided from the supercapacitor stack via the output ideal diode. V_{CAP} and V_{OUT} will fall as the load current discharges the supercapacitor stack. The output ideal diode will shut off when the voltage on pin OUTFB falls below 1.3 V and VOUT will fall a PN diode (~700mV) below V_{CAP}. If OUTFB falls below 1.2V when the output ideal diode shuts off, the synchronous controller will turn on immediately. If OUTFB is above 1.2V when the output ideal diode shuts off, the load current will flow through the body diode of the output ideal diode N-channel MOSFET for a period of time until OUTFB falls to 1.2V. The synchronous controller will regulate OUTFB to 1.2V when it turns on, holding up V_{OUT} while the supercapacitors discharge to ground.

The synchronous controller in step-up mode will run non-synchronously when V_{CAP} is less than 100 mV below V_{OUT}. It will run synchronously when V_{CAP} falls 200 mV below V_{OUT}.

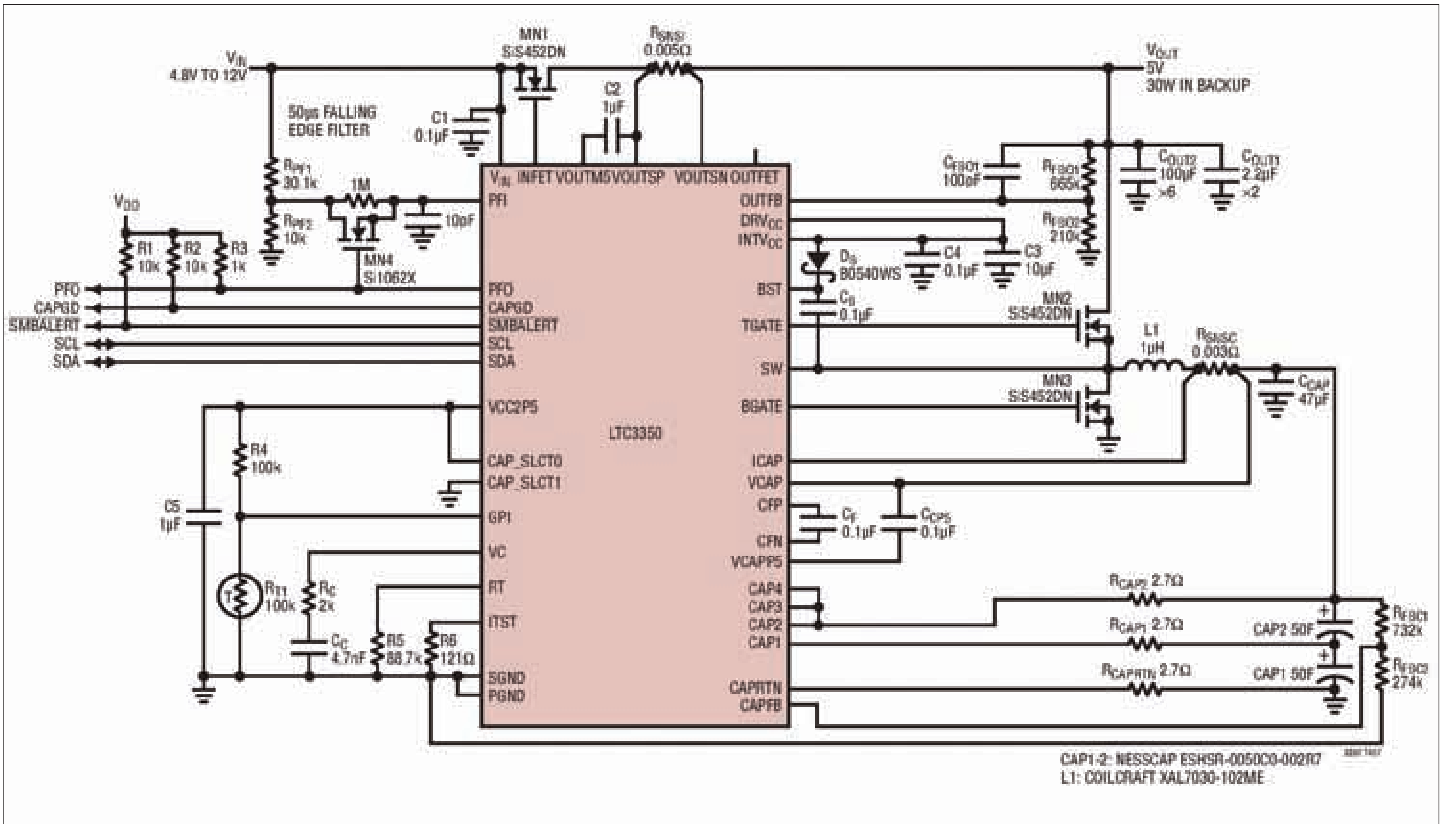
The device monitors system voltages, currents, and die temperature. A general purpose input (GPI) pin is provided to measure an additional system parameter or implement a thermistor measurement. In addition, the capacitance and resistance of the supercapacitor stack can be measured. This provides indication of the health of the supercapacitors and, along with the V_{CAP} voltage measurement, provides information on the total energy stored and the maximum power that can be delivered.

The device operates over a –40°C to 125°C junction temperature range and is available from stock. Pricing starts at $5.25 each for the E grade in 1,000-piece quantities.

Power MOSFET Selection

Two external power MOSFETs must be selected for the LTC3350's synchronous controller: one N-channel MOSFET for the top switch and one N-channel MOSFET for the bottom switch. The selection criteria of the external power MOSFETs include maximum drain-source voltage (V_{DSS}), threshold voltage, on-resistance ($R_{DS(ON)}$), reverse transfer capacitance (C_{RSS}), total gate charge (Q_G), and maximum continuous drain current. V_{DSS} of both MOSFETs should be selected to be higher than the maximum input supply voltage (including transient). The peak-to-peak drive levels are set by the DRVCC voltage. Logic-level threshold MOSFETs should be used because DRV_{CC} is powered from either $INTV_{CC}$ (5V) or an external LDO whose output voltage must be less than 5.5 V.

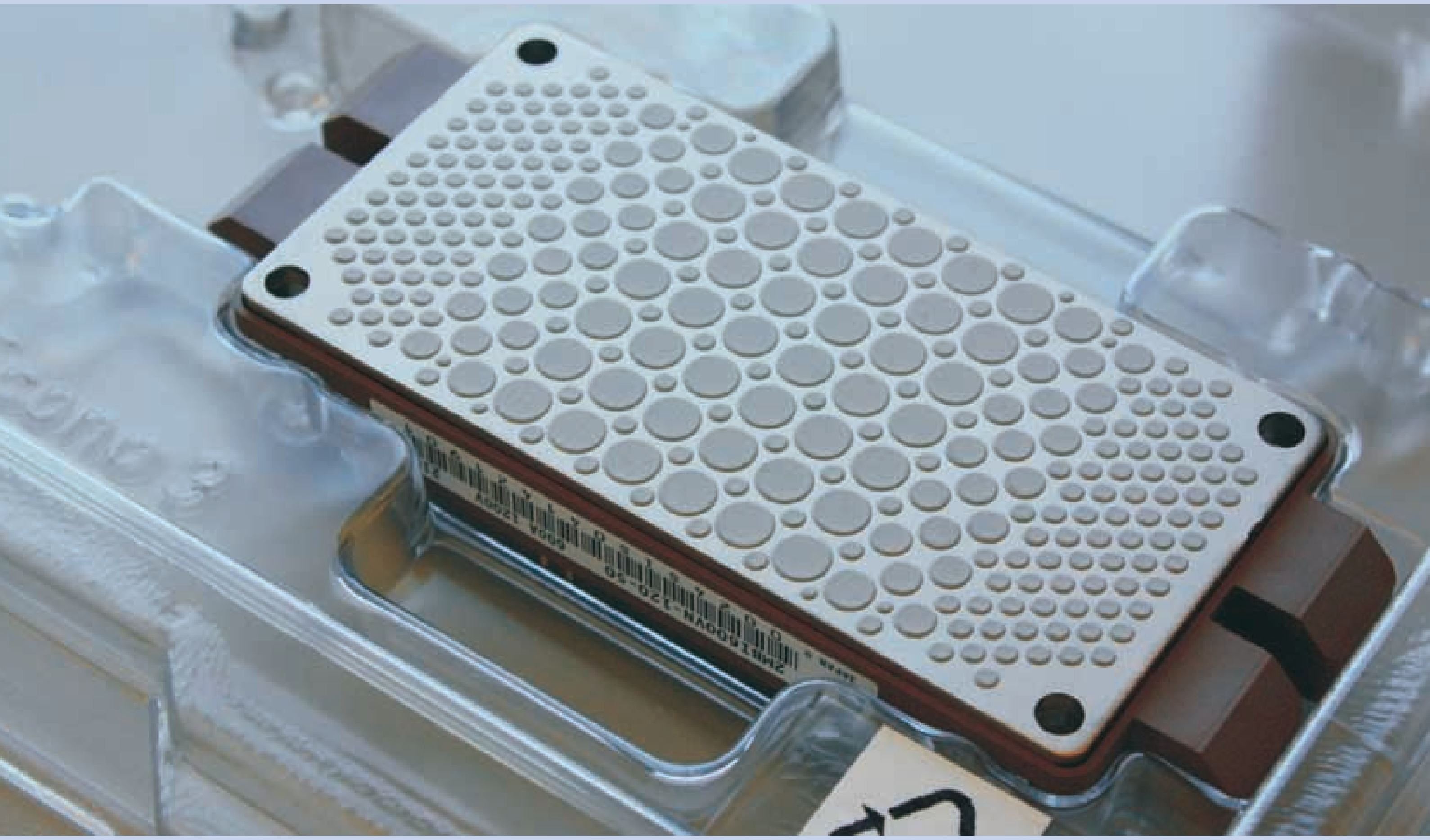
www.linear.com/product/LTC3350



One of the typical applications: 4.8 V to 12 V, 10 A supercapacitor charger with 6.4 A input current limit and 5 V, 30 W backup mode

Fuji Electric

Innovating Energy Technology



TIM

Pre-applied Thermal Interface Material Optimized for Fuji Electric's IGBT-Modules

The ongoing increase of power densities within the thermal interface between power module and heat sink requires an optimized thermal distribution.

Fuji Electric has developed the pre-applied thermal interface material (TIM) which achieves a stable quality and reproducible thermal performance level of power electronic devices.

TIM provides a significantly low thermal resistance and fulfills the highest quality standards given for power modules to achieve the longest lifetime and highest system reliability.

Features

+ Optimized for Fuji Modules
+ Increased lifetime of IGBT
+ Advanced IGBT power density

Process - Benefits

+ Outsourcing a dirty process
+ Stable quality level
+ Increased system reliability

Thermal - Benefits

+ Higher thermal conductivity
+ Decrease R_{th} significantly

TIM → **Significant Lower R_{th}**

→ **Lower T_j & smaller ΔT_j *at same current/load*** → **Significant higher power cycling lifetime**

→ **Enables higher current/load *at same Tj*** → **Improved cost/performance ratio**

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Innovative IGBT Driver IC Resolves Dilemma of Gate Resistor Selection

The use of motor line inductors, dv/dt filters or sine wave filters helps to adapt the variable frequency inverter with its fast switching IGBT to the motor. This is normally much easier than an individual adaption to the application requirements of the inverter itself by individual selection of gate resistors. However, such a dv/dt filter increases the price, losses and size of a variable speed drive. This article describes a smart way to implement an easy-to-use adaption by means of an intelligent selection of an IGBT gate driver IC combining both, lower EMI and higher efficiency. **Dr. Wolfgang Frank, Infineon Technologies AG, Germany**

The operation of modern variable frequency inverters with pulse width modulation techniques results in a lot of negative side effects to motor drive applications. These side effects are e.g. degradation of the winding insulation in both non-potted windings and especially in potted ones, inverter operation with shielded cables [1], and motor bearing degradation. Especially voltage reflections at the motor clamps show a voltage doubling effect which, according to Figure 1, can already be measured after a few meters of cable length. Since this doubling effect occurs at every turn-on of the IGBT, the winding insulation degrades over time and reduces the lifetime of the motor as a consequence.

A simple countermeasure is to use dv/dt filters. However, the implementation of such filters leads to losses [2], which can be considerable especially in the lower motor power ranges. This has a negative impact on the efficiency of variable speed drives. Investigations already showed that the cost for filters or other countermeasures to limit the dv/dt are expensive [3] compared to the cost of the drive. The filters consist of inductors, capacitors and resistors. Therefore, the inductors have a reactive voltage drop, which reduces the motor voltage. The filters are also usually a limiting factor for the switching frequency of the inverter. A switching frequency up to 16 kHz is difficult for most dv/dt filters and also a derating of the filter must be considered in terms of motor current frequency and temperature.

Dilemma of gate resistor selection for turn-on

The proper selection of the turn-on gate resistor contributes significantly to the EMI characteristic of a frequency inverter. Because of the excellent switching behaviour of modern IGBTs, design engineers want to make use of their fast switching capabilities. On the other hand, power diodes show the tendency to tear off the current, when a relatively low diode forward current commutates to an IGBT. The results are strong, high-frequency oscillations as given in a) of Figure 2 as well as a high dv/dt. These oscillations may even damage the diode or IGBT. Therefore, some IGBTs have integrated gate resistors which prevent damage, but not oscillations.

The high-frequency portion of the collector current is certainly influencing the conducted EMI spectrum. This is visible in a range, where the line filter is not active any more. Therefore, the oscillations must be avoided in any case.

The second picture b) of Figure 2 depicts the commutation of the same forward current when using a turn-on gate resistor of 1.5 Ω instead of 0 Ω in the measurement of a) in Figure 2. This small difference in the gate resistance has a large influence on the switching behavior. All oscillations vanish and the turn-on is stable.

In order to prevent EMI hardware engineers typically select a higher gate resistance. However, as a disadvantage a higher gate resistor slows down the turn-on speed of the IGBT at higher collector currents. The turn-on behavior at collector

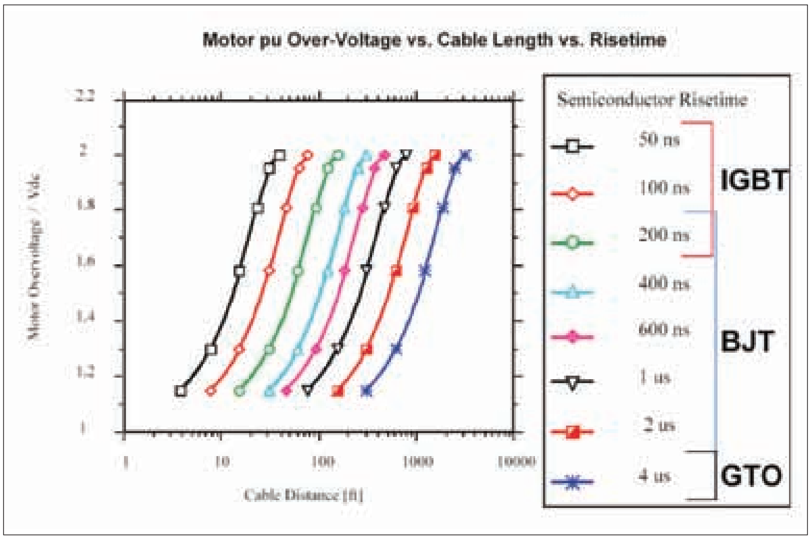

Figure 1: Motor per unit over-voltage as a function of the cable length and rise time of power transistors [2]

Figure 2a

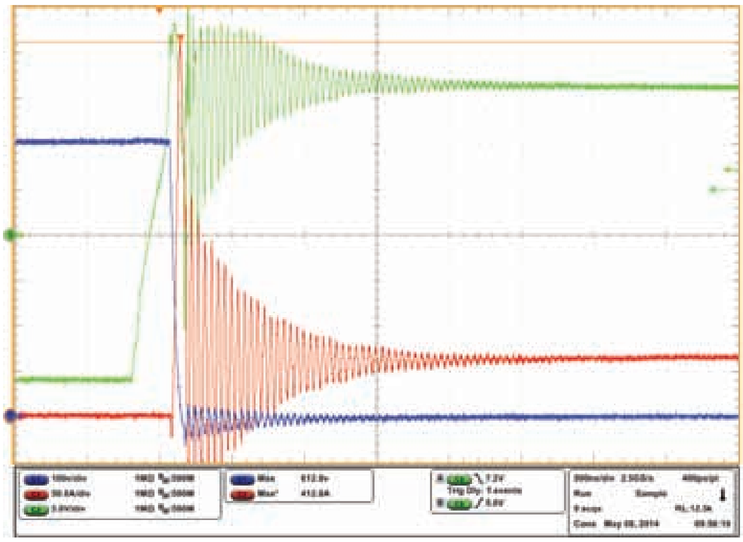

Figure 2b

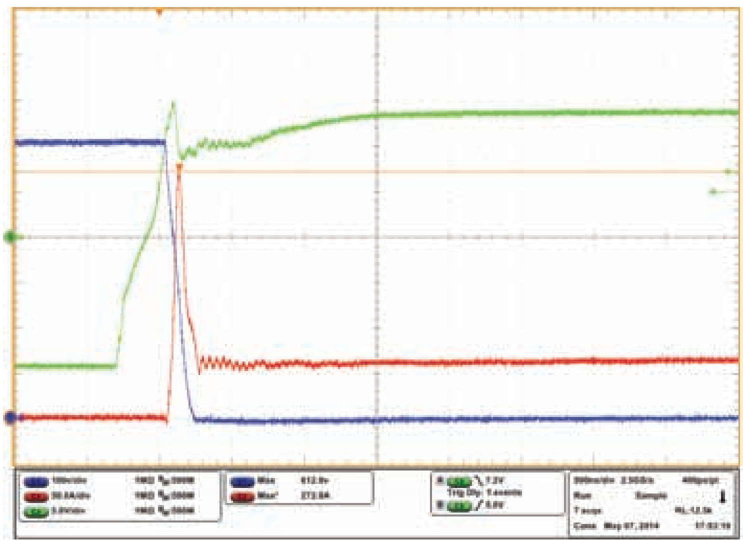

Figure 2: Commutation of low currents at 10 % of nominal current level (a: $R_{Gon} = 0\Omega$, b: RGon = 1.5Ω; V_{DC} = 600V; I_C = 60A; -15V < V_{GE} < 15V) with collector-emitter voltage (blue), collector current (red) and gate-emitter voltage (green) with a standard gate driver

current levels above e.g. 15 % to 20 % of the nominal current is not tending to oscillate any more. Fewer losses will be achieved, if a lower gate resistor is used in the operating area above.

The dilemma described can be resolved with the new gate driver IC EiceDRIVER™ 1EDS20I12SV. It can softly turn-on the IGBT when it is operating at low collector current levels and it can also quickly turn-on at high collector current levels. This is made possible by a user controlled current source providing 11 different levels. These levels can be selected by the system control pulse-by-pulse in real-time.

Gate current control IC during turn-on process

The most innovative feature of the new EiceDRIVER is its gate current control function. It divides the turn-on process into three sections according to a) in Figure 3: The first section (t0 to t1) is the charging from a negative voltage to a defined value in the range of $V_{GE} = 0$. This section is called the pre-boost section and lasts for a fixed duration of t_{PRB} = 135 ns. The preboost current level I_{PRB} during this phase is adjustable for each individual IGBT type. The second section (t_1 to t_3) is the turn-on control section. The instantaneous constant gate drive current I_{gg} can be adjusted within 11 different values. The IGBT gate voltage passes the Miller voltage level during this time. The practical application of the device proposes usually a smaller turn-on gate current I_{gg} compared to the preboost current I_{PRB}. Nevertheless, it is also possible to achieve even larger turn-on currents Igg than the preboost current I_{PRB}. This is shown in b) of Figure 3. Finally, the gate capacitance of the IGBT is fully charged correlating to the desired gate voltage level in section 3 ($t > t_3$).

The used gate driver IC is able to control the dvCE/dt transient of the IGBT by selecting a suitable current level during section 2. The turn-on delay time $t_{d(on)}$ is constant and predictable. This has an effect on the design of the IGBT dead time and the motor current control loop, offering additional potential for improvement.

The IC controls the gate current by means of a closed loop with the controlled current source circuit, which consists of a p-channel MOSFET and a current sense resistor. The current source is extremely precise with a tolerance of ± 10 % during

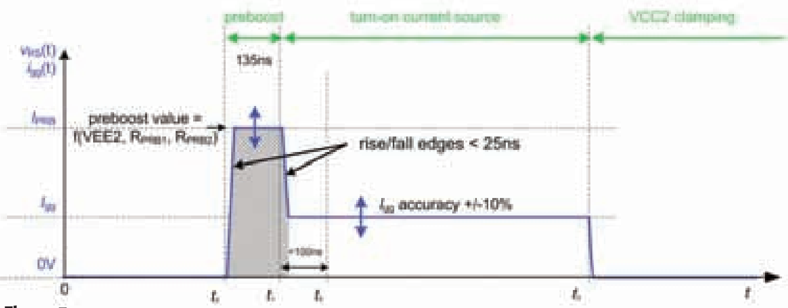

Figure 3a

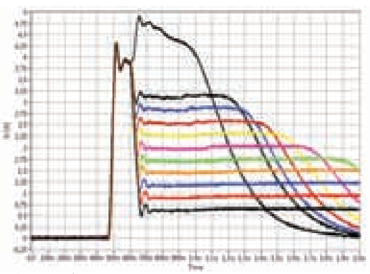

Figure 3b

Figure 3: The three phases of a turn-on process with (a) theoretical waveforms for gate current (blue) and voltage (green) and (b) example of measured waveforms of gate current for speed levels 1-11

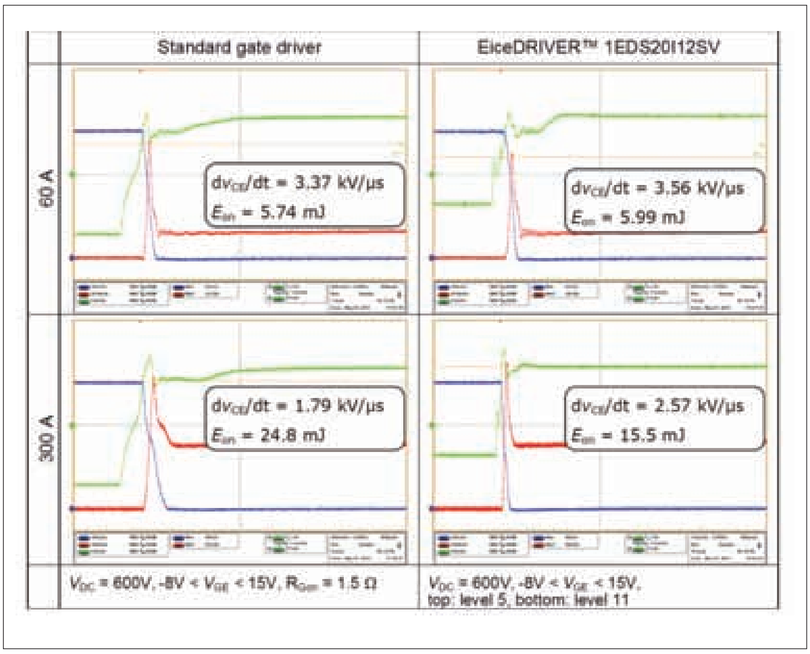

Figure 4: Large advantage of more than 40% with 1EDS0I12SV regarding turn-on energy compared to standard gate driver in a gate driver design example showing the collector-emitter voltage (blue), the collector current (red), and the gate-emitter voltage (green)

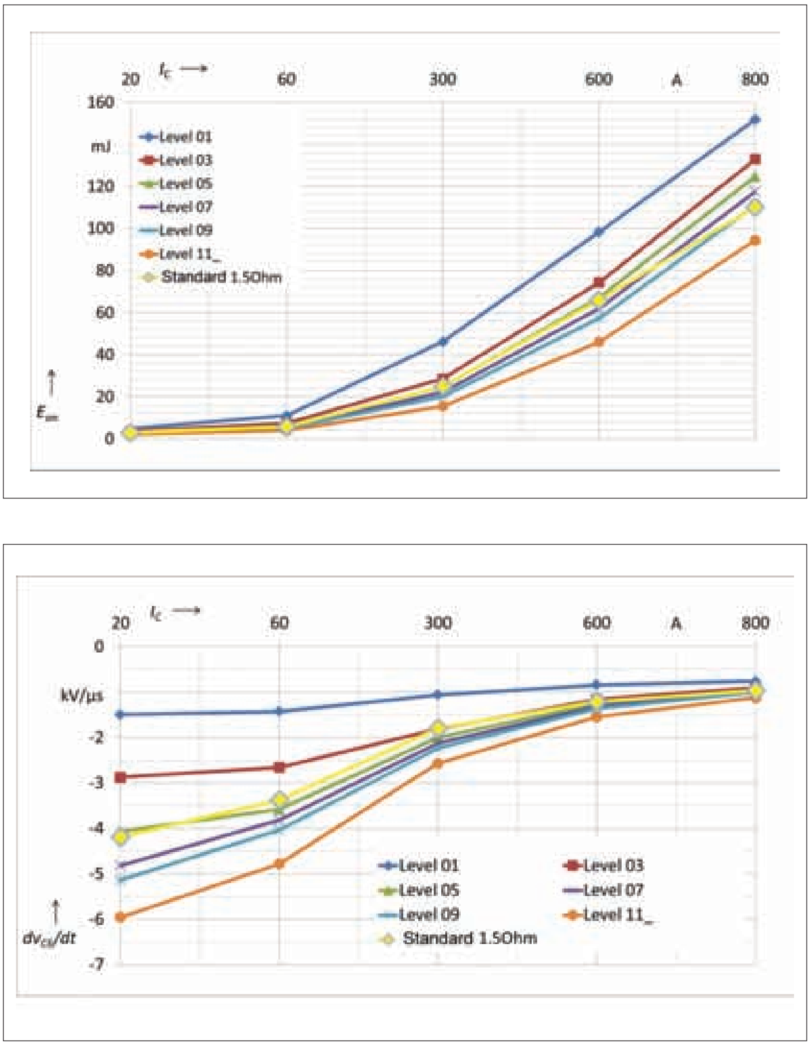

Figure 5: Example of dv_{CE}/dt range (bottom) and turn-on energy E_{on} of 1EDS-SRC gate current control IC for speed level 1, 3, 5, 7, 9 and 11 compare to standard driver at IGBT junction temperature of 25°C

the turn-on phase. This solution is more cost efficient than a similar setup using bipolar transistors. Additionally, the p-channel MOSFET provides a rail-to-rail capability, which is not possible with bipolar transistors. The Driver IC can control in total up to three p-channel MOSFETs (BSD314SPE) in parallel, which covers a range of current classes of up to 900 A of 1200 V modules.

Effect of gate current control IC on transient collector-emitter voltage at turn-on

The adjustability of the controlled gate current of the EiceDRIVER 1EDS20I12SV allows the design engineer to change paradigms concerning the switching speed of the diode. An excellent EMI at low load condition of a frequency inverter can now be combined with a high efficiency at high load conditions, which is given in Figure 4. Another advantage is the turn-on propagation delay, which is more predictable compared to a pure resistive turn-on.

The standard gate driver uses the gate resistor value of the module datasheet. This is 1.5 Ω for FF600R12ME4 from Infineon Technologies. The selected 1.5 Ω leads to a turn-on energy of E_{on} = 24.5 mJ at 50% of nominal current. On the other side the 1EDS20I12SV shows similar switching behavior at low currents. The turn-on energy as well as the turn-on voltage transient dv_{CE}/dt are almost the same. The tremendous advantage is visible at high currents. A smaller turn-on energy of E_{on} = 15.5 mJ is achieved. This value is 40 % lower than the turn-on energy of the standard gate driver. Thus, the usage of the new gate driver IC results in a considerable improvement of the overall efficiency.

The example of a gate driver design was developed to investigate more detailed the relation of the various speed levels of the EiceDRIVER as a function of the collector current. Since the gate current control loop allows for several degrees of freedom, there are even greater advantages for 1EDS20I12 possible.

The bottom part of Figure 5 shows the range of dv_{CE}/dt rate over various speed settings and collector amplitudes. It can be seen, that the control range of the gate current control IC is sufficient to cover the same range as with a common fixed gate resistor control, while enabling the advantage to change the dv_{CE}/dt rate pulse-by-pulse during operation. For this reason the commutation speed is not limited to a single curve. In fact, it can now cover even a full area of possible dv_{CE}/dt values. The dv_{CE}/dt area can be above or below the "nominal" dv_{CE}/dt line which is

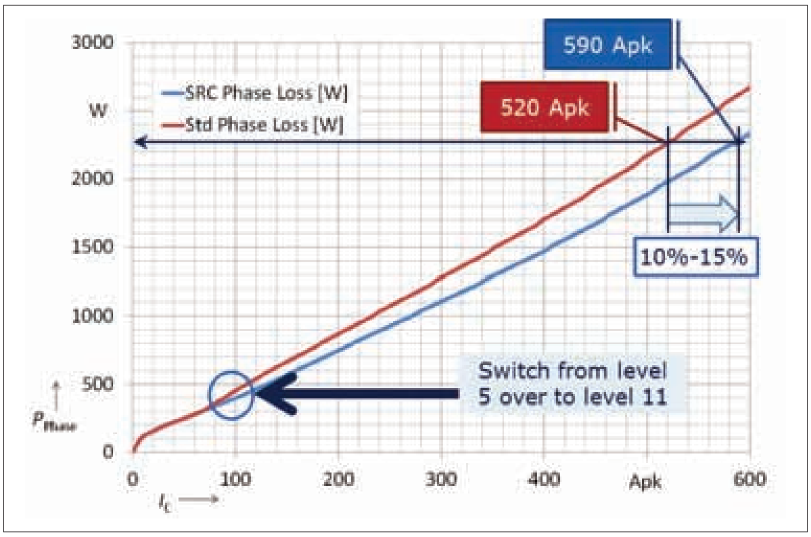

Figure 6: Calculated power losses per phase show a gain of 10 % - 15 % in respect to output current with slew rate control (blue) over a standard driver (red) (V_{DC} = 600 V, -8 V < V_{GE} < 15 V, f_P = 15 kHz)

achieved with the nominal gate resistor of 1.5 Ω. Figure 5 proves that it is now possible to stay below the critical values of dv_{CE}/dt in the application by setting the commutation speed according to the instantaneous electrical conditions of the application.

Figure 6 shows the improved calculated power loss of an EconoDUAL3 type FF600R07ME4 when using the EiceDRIVER 1EDS20I12SV only with level 5 for currents below 100 A peak and with level 11 for the instantaneous currents above 100 A peak according to Figure 5.

It can easily be seen that the slew rate control EiceDRIVER IC can gain approximately 10 % - 15 % more current using the same module compared with a standard driver circuit. The IC 1EDS20I12SV can therefore help to lower system cost by reducing e.g. the heatsink size. Aiming at higher power density, the new driver IC is obviously also supporting this goal.

Conclusion

This paper discusses the advantages of a novel and innovative EiceDRIVER™ 1EDS20I12SV gate current control IC, which uses a closed loop gate current control for turn-on. The advantages compared to dv/dt or sine wave filters are discussed. The turn-on properties can be adjusted pulse-by-pulse in real-time during operation of the application. It is shown by a switching test example, that the gate driver IC can control a wide range of collector-emitter transient voltage dv_{CE}/dt. In the discussed example, values from 1.5 kV/µs up to 6 kV/µs at small collector currents are achieved, which is superior over only 1 trade-off line when using a common gate resistor control. This helps to reduce the size of motor and EMI filters or even makes them superfluous. With this, system costs are significantly reduced, while at the same time system efficiency is increased.

The calculation of inverter losses shows an extension of output current by approximately 10 % - 15 % when using the EiceDRIVER™ 1EDS20I12SV. This advantage can be used to increase the output power of an inverter as well as improving the power density of the application.

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Fast Thyristors for Induction Heating Solutions

Induction heating is one of the key metal industry applications using high-power resonant converters. The power range of such converters goes up to 10 MW and there is no more efficient alternative as switching device than the bipolar fast thyristor. ABB provides for years fast switching thyristors and further expands its portfolio for high-power resonant inverters. **Ladislav Radvan, ABB s.r.o. – Semiconductors, Switzerland**

Induction heating is based on three basic effects: electromagnetic induction, skin effect and heat transfer. Electromagnetic induction was first discovered by Michael Faraday in 1831. An electrically conducting object (usually a metal) can be heated when placed in an inductor that is part of a resonant circuit. An alternating current flowing through the inductor's coil generates an oscillating magnetic field. This in turn induces Eddy currents (also called Foucault currents) in the object which, by means of resistive (Joule) heating, heats up the object. According to Lentz's law the direction of the inductive current is opposite that current that generated the magnetic field which induced the inductive current.

In addition to this, the high frequency used in induction heating applications gives rise to a phenomenon called skin effect. This skin effect forces the alternating current to flow in a thin layer close to the surface of the object. The effective resistance of the object is increased which greatly increases the heating effect. As the skin effect is frequency dependent, the frequency can be used to specify the heating depth. Although the heating due to Eddy currents is desirable in this application, it is interesting to note that transformer manufacturers need to avoid this phenomenon in their transformers. Laminated transformer cores, powdered iron cores and ferrites are all used to prevent Eddy currents from flowing inside transformer cores.

The effects described above render induction heating many advantages compared to other heating methods. Induction heating is cost effective due to the lower energy consumption. Heat is generated directly in the heated object without any interfaces. Heating is contactless and therefore very clean. Induction heating is a fast process offering improved productivity with higher volumes. The heating energy can be easily and precisely regulated and the whole object or just parts of it can be heated by frequency adjustments. Figure 1 shows the typical converter power requirements and operating frequency as a function of induction heating furnace capacities.

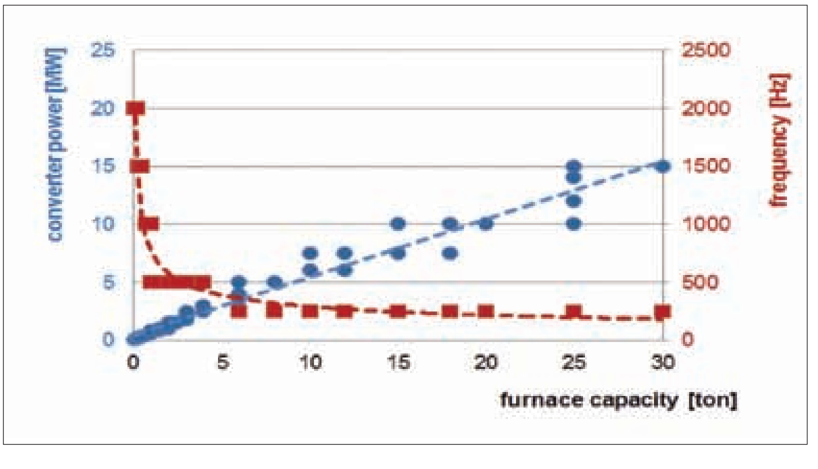


Figure 1: Typical converter power and operating frequency as a function of induction heating furnace capacities

Switching Techniques for Resonant Inverters

The most efficient way to feed induction coils with an alternating current is by integrating it into a resonant circuit, forming a resonant inverter.

Generally, semiconductor switches are operated in the hard-switching mode in various types of pulse width modulated (PWM) DC/DC converter and DC/AC inverter topologies. One disadvantage of PWM schemes is that the exact time at which the power is switched on or off is given and cannot be controlled and optimized to reduce losses.

A way to improve the efficiency of power inverters is to reduce the switching losses. One big advantage of resonant inverter topologies is that they make use of soft-switching techniques which allow to minimize switching losses. There are two different modes at which active switches as transistors are operated, depending on the device type.

Zero Voltage Switching (ZVS) technique means that the transistor is switching at the moment when the voltage is close to zero. This method eliminates turn-on losses caused by parasitic capacitance $C_{Gate\text{-}Source}$ and is often used for MOSFETs.

Zero Current Switch (ZCS) is the more preferred method for IGBT modules and even necessary when using fast thyristors (circuit commutation). This technique reduces turn-off losses as the current does not flow through the device before or at the moment of switching and the tail current – typical for bipolar devices – is eliminated. Benefits of soft switching techniques are not only the loss reduction and highly efficient energy conversion, but also the limitation of electro-magnetic interference (EMI) (less di/dt and dv/dt is generated in the switching process).

Circuit Topologies for Resonant Inverters

Figure 2 depicts a quite popular topology: the voltage source inverter (VSI) in the ZVS mode using a medium frequency (10 – 25 kHz) IGBT switch. The LCL resonant tank allows to easily adapt to variable loads without the need for a transformer. R1

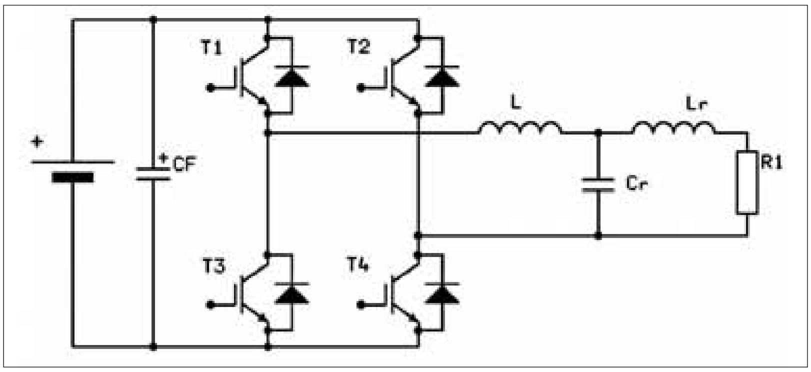


Figure 2: **Voltage source inverter with inductive coupling (ZVS mode) and parallel resonant circuit**

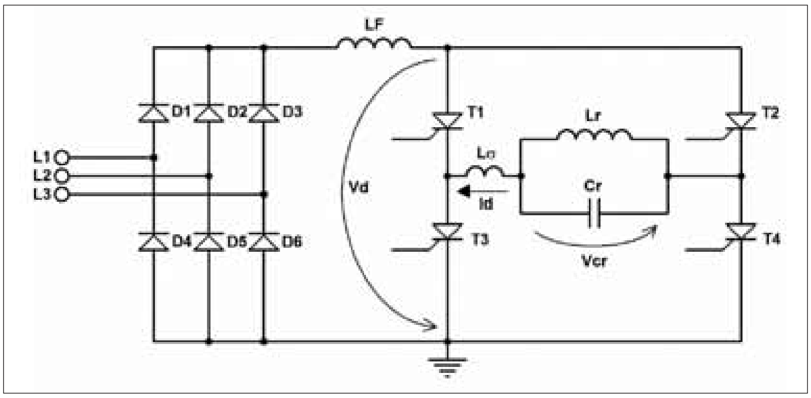


Figure 3: **Current source inverter (ZCS mode) and parallel resonant circuit**

represents the heated object. Typical applications applying such circuits are surface hardening, bending or welding. ABB offers a wide range of IGBT modules in different industrial standard housings and topologies for this application.

Induction melting systems in the 10 MW range traditionally and exclusively use current source inverters with fast switching thyristors in presspack housings. A frequently used circuit topology is shown in Figure 3, with a standard input 3-phase controlled (or uncontrolled) rectifier, a big serial inductance and an H-bridge in the inverter part. The LF choke is for current stabilization and filtering purposes. A control unit must enable a capacitive phase shift between the inverter output current I_d and the resonant load voltage V_{Cr} (basic operation condition necessary for the thyristor recover process).

Only the positive half-wave of the AC voltage is applied to the thyristors, after the minimal turn-off time has elapsed. L_r at the same time enables the commutation process of T_x. The inverter output current id has a rectangular shape changing its polarity by activating T1/T4 or T2/T3 (diagonally). The energy is thus periodically pumped into the parallel resonant circuit and the inverter output voltage V_{σ} has a sine waveform at the resonance frequency and di/dt is limited by the parasitic inductance $L\sigma$ and by the voltage V_d. Higher output power converters need higher power thyristors or usually use several discrete thyristors connected in series.

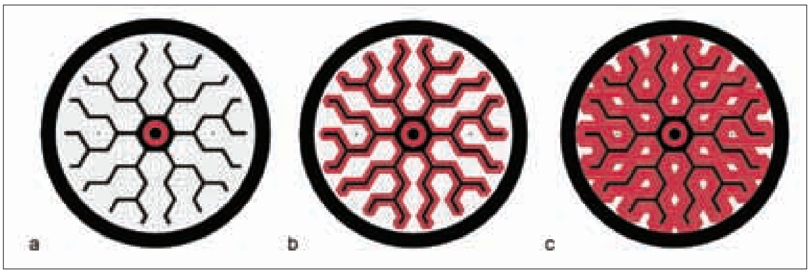
Device Features

ABB Semiconductors offers a wide range of fast thyristors with a total of 21 different types, optimized for different operation frequencies. The fast thyristor portfolio comprises standard fast thyristors (up to 1 kHz) and medium frequency thyristors (up to 10 kHz). Common to all fast thyristors are

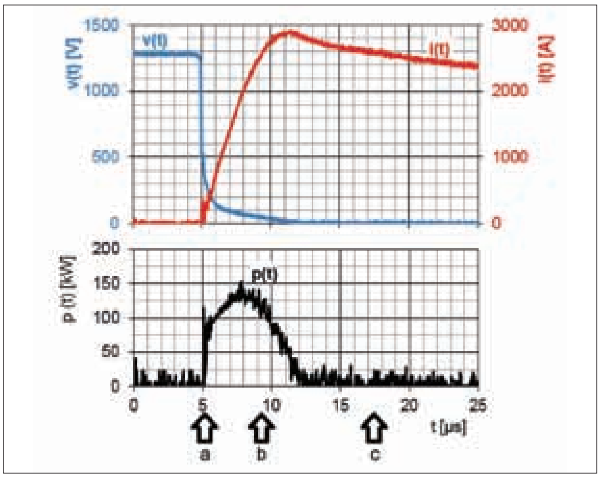
- amplifiying & distributed gate structure
- carrier lifetime control technology
- optimized carrier concentration profile for maximum current rating
- special cathode-gate design for faster on-state current spreading and effective operation in the specified frequency range.

All thyristors feature the alloyed technology where the Silicon wafer is directly alloyed to the molybdenum disc which renders the device more robust against surge and peak powers generated at occasional hard-switching conditions. Moreover, the alloyed molybdenum disc helps to stabilize the junction temperature and acts as an energy buffer.

The latest product is the 2 kV fast thyristor based on a 3-inch Silicon wafer. It is offered in two options: the 5STF 28H2060 and the 5STF 23H2040. The first one has an average on-state current I_{TAV} of 2.8 kA and a turn-off time t_q of 60 µs. The latter has an average I_{TAV} of 2.3 kA and a t_q of 40 µs. These thyristors feature a very efficient cathode area usage. Figure 4 shows how the current spreads in the cathode during turn-on. Thanks to the massively distributed gate structure over all the whole cathode area the turn-on losses are nearly eliminated. The central auxiliary thyristor serves as a gate signal for the distributed gate electrode of the main thyristor. The large cathode area around the distributed gate is immediately activated and switching losses are efficiently reduced.



ABOVE Figure 4: **On-state carrier spreading during thyristor switching**



RIGHT Figure 5: **Waveforms related to the three carrier spreading stages of Figure 4**

Figure 5 shows thw waveforms during thyristor turn-on (600 A/µs) and calculated power loss (arrows below relate to Figure 4), $T_i = T_{jmax}$.

Further design features implemented in these two new fast thyristors are

- minority carrier life-time reduction
- cathode shunt network to protect the thyristor against parasitic turn-on at high dv/dt
- concentration profile optimization to achieve low on-state losses.

Figure 6 shows thyristor turn-off and blocking voltage measurement curves at different turn-off times t_q. Parasitic turn-on occurs at turn-off times equal or below 21 µs, which is well below the specified value of 60 µs, thus demonstrating a good datasheet value margin. State-of-the-art fast thyristors feature an optimal balance between fast spreading of the carrier distribution over the whole cathode area at turn-on and a thyristor immunity against high dv/dt. In the event of an applied blocking voltage the remaining charge in the device as well as the additional capacitive current must be extracted by the shunt network and must not act as an internal or false gate signal. Such a current amplitude at high dv/dt can be as high as several tens of amperes. The high power resonant inverter is exactly the type of system where the inverter requirement naturally meets the fast thyristors' properties.

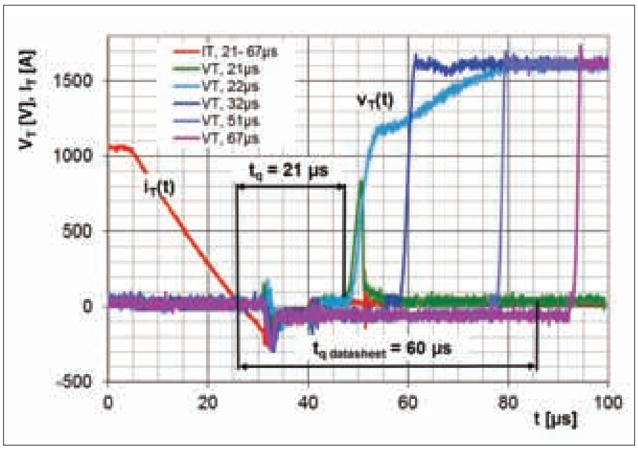


Figure 6: Turn-off and blocking voltage measurement curves at different turn-off times, 500 V/µs, $T_j = T_{jmax}$

Application Examples

It has been proven for years that the heavy metal industry relies on the reliability and performance of fast thyristors. And as in many other market segments also in the heavy metal industry there is a general trend towards increased power and power density, higher efficiency and productivity. Fast thyristors are one of the key enablers to follow these trends. The most powerful applications are melting and pouring in the heavy metal industry with furnace capacities of up to 50 tons and inverter powers of up to 50 MW.

Some applications in the medium power range are surface hardening or quenching for the production of cogwheels, arbors, valves, rails, etc. Further examples are preheating for material forming or before welding, induction welding, stress revealing after welding, steel tempering or annealing. Also induction bending (800 kW level) to shape big tubes for power plants or "I-shape" steal support forming are frequent applications.

Powering IGBT Gate Drives with DC/DC Converters

IGBTs can now be found in high power devices with effective gate capacitances measured in hundreds of nanofarads. Although this capacitance has simply to be charged and discharged to turn the IGBT on and off, the circulating current to do so causes significant power dissipation in voltage drops in the gate driver circuit and within the IGBT. An emerging trend is to use a DC/DC converter to provide optimum power rails for driving IGBTs .**Paul Lee – Director of Business Development, Murata Power Solutions, UK**

At high power, inverters or converters typically use 'bridge' configurations to generate line-frequency AC or to provide bi-directional PWM drive to motors, transformers or other loads. Bridge circuits include IGBTs whose emitters are switching nodes at high voltage and high frequency so the gate drive PWM signal and associated drive power rails, which use the emitter as a reference, have to be 'floating' with respect to system ground, so called 'high side' drives. Additional requirements are that the drive circuit should be immune to the high 'dV/dt' of the switch node and have a very low coupling capacitance. An emerging trend is to use a DC/DC converter to provide optimum power rails for these 'floating' drive circuits using an IGBT.

Typical Example

An initial consideration is to set the on and off-state gate voltages. For example, a typical IGBT is the FZ400R12KE4 from Infineon. It has a minimum turn-on threshold of 5.2 V at 25°C, in practice to ensure full saturation and rated collector current of 400 A, at least 10 V must be applied. The part has a maximum gate voltage of ± 20 V so +15 V is a good value with some margin. Higher values produce unnecessary dissipation in the gate drive circuit. For the off-state, 0 V on the gate can be adequate. However, a negative voltage typically between -5 and -10 V enables rapid switching controlled by a gate resistor. A consideration also is that any emitter inductance between the IGBT and the driver reference, (point x in Figure 1), causes an opposing gate-emitter voltage when the IGBT is turning off. While the inductance may be small, just 5 nH would produce 5 V at a di/dt of 1000 A/µs which is not unusual. This inductance of 5 nH is just a few millimeters of wired connection (the FZ400R12KE4 has a stray package inductance of 16 nH). An appropriate negative drive ensures that the gate-emitter off-voltage is always zero or less.

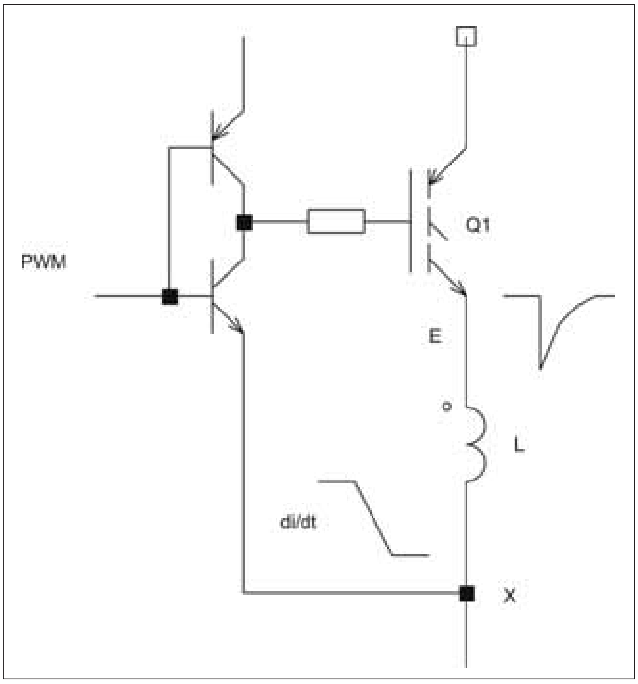


Figure 1: Switch-off with stray inductance L, negative di/dt produces a negative voltage on the emitter, opposing the turn-off voltage

A negative gate drive also helps to overcome the effect of collector-gate 'Miller' capacitance on device turn-off which works to inject current into the gate drive circuit. When an IGBT is driven off, the collector-gate voltage rises and current flows through the Miller capacitance of value C_m. d_{Vce}/d_t into the gate emitter capacitance C_{ge} and through the gate resistor to the driver circuit, see Figure 2. The resulting voltage V_{ge} on the gate can be sufficient to turn the IGBT on again with possible shoot-through and damage. Driving the gate to a negative voltage mitigates this effect.

A DC/DC converter with +15/-9V outputs conveniently provides the optimum voltages for the gate driver.

The gate of an IGBT must be charged and discharged through R_g in each switching cycle. If the IGBT data sheet provides a gate charge curve then the relationship is $P = Q_g$ x F xV_s where P is gate drive power, Q_g is data sheet charge for a chosen gate voltage swing, positive to negative, of value V_s.

If the data sheet does not provide a charge curve but just a Q_g value at specific gate voltages, the value of Q_g at other gate voltage swings can be approximated by multiplying by the ratio of the actual versus data sheet voltage swings. For example the FZ400R12KE4 has a Q_g value of 3.7 µC with ±15 V gate voltage swing (30 V total). For a swing of +15/-9 V (24 V total) gate charge approximates to $Q_g = 3.7e^{-6}$ x 24/30 ≈ 3 µC. At 10 kHz this requires gate drive power of $P_g = 3e^{-6}$ x $10e^{3}$ x 24 ≈ 0.72 W.

With derating and allowing for other incidental losses, a 2 W DC/DC converter would be suitable. In our example, with 24 V total gate voltage swing, the charge and discharge energy must be the same in each cycle, so the average charge and discharge current must be the same, at 30 mA given by P_g/V_s. The peak current I_{pk}, required to charge and discharge the gate

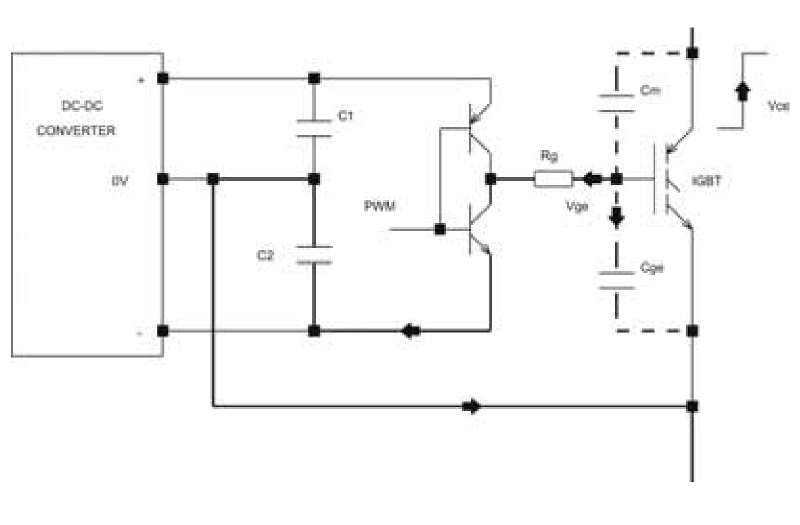


Figure 2: Current through 'Miller' capacitance C_m works to turn on the IGBT

is a function of V_s, gate resistance of the IGBT R_{int} and external resistance R_g. Thus $I_{pk} = V_s / (R_{int} + R_g)$.

The FZ400R12KE4 has $R_{int} = 1.9\ \Omega$ so with a typical external resistor of 2 Ω and a swing of 24 V, a peak current of over 6 A results. This peak current must be supplied by 'bulk' capacitors on the driver supply rails as the DC/DC converter is unlikely to have sufficient value of output capacitors to supply this current without significant 'droop'. Of course the gate driver itself must be rated for these peak current values as must the gate resistors. For our example, total gate drive energy E per cycle is given by $E = Q_g \times V_s = 72\ \mu J$.

The bulk capacitors on the +15 and -9 V rails supply this energy in proportion to their voltages so the +15 V rail supplies 45 µJ. If we assume that the bulk capacitor on the +15 V rail should not drop more than say 0.5 V each cycle then we can calculate minimum capacitance C by equating the energy supplied with the difference between the capacitor energies at its start and finish voltages, that is $45\ \mu J = \frac{1}{2} C (V_{init}^2 - V_{final}^2)$ and $C = (45e^{-6} \times 2)/(15^2 - 14.5^2) \approx 6.1\ \mu F$.

Although the -9 V rail supplies about a third of the energy, it requires the same capacitor value for 0.5 V drop as this is a larger percentage of the initial value.

Converter Considerations

It is advisable to place the IGBT driver and its DC/DC converter (Figure 3) as close as possible to the IGBT to minimize noise pick up and volt drops. This places the components in a potentially high temperature environment where reliability and lifetime reduces. DC/DC converters should be chosen with appropriate ratings and without internal components that suffer significantly with temperature such as electrolytic capacitors and opto-couplers. Data sheet MTTF values will typically be quoted at 25 or 40°C and should be extrapolated for actual operating temperatures.

The absolute values of gate drive voltages are not very critical as long as they are above the minimum, comfortably below breakdown levels and dissipation is acceptable. The DC/DC converters supplying the drive power therefore may be unregulated types if the input to the DC/DCs is nominally constant. Unlike most applications for DC/DCs however, the load is quite constant when the IGBT is switching at any duty cycle. Alternatively the load is close to zero when the IGBT is not switching. Simple DC/DCs often need a minimum load otherwise their output voltages can dramatically increase, possibly up to the gate breakdown level. This high voltage is stored on the positive bulk capacitor so that when the IGBT starts to switch, it could see a gate over-voltage until the level drops under normal load. A DC/DC should be chosen therefore that has clamped output voltages or zero minimum load requirements.

IGBTs should not be actively driven by PWM signals until the drive circuit voltage rails are at correct values. However, as gate drive DC/DCs are powered up or down, a transient condition might exist where IGBTs could be driven on, even with the PWM signal inactive, leading to shoot-through and damage. The DC/DC should therefore be well behaved with short and monotonic rise and fall times. A primary referenced on-off control can enable sequencing of power-up of the DC/DCs in a bridge reducing the risk of shoot-through.

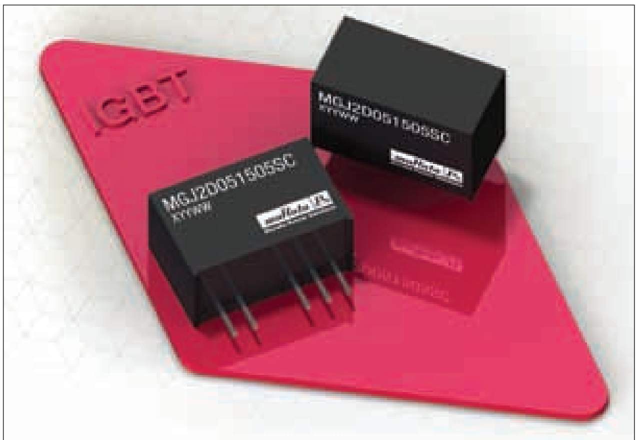


Figure 3. Typical 2 W IGBT driver DC/DC converter, the MGJ2 from Murata Power Solutions

Driving High-Speed Devices

DC/DCs for 'high side' IGBT drives see the switched 'DC-link' voltage across their barrier. This voltage can be kilovolts with very fast switching edges from 10 kV/µs upwards. Latest GaN devices may switch at 100 kV/µs or more. This high 'dV/dt' causes displacement current through the capacitance of the DC/DC isolation barrier of value $I = C \times dV/dt$.

So for just 20 pF and 10 kV/µs, 200 mA is induced. This current finds an indeterminate return route through the controller circuitry back to the bridge causing voltage spikes across connection resistances and inductances potentially disrupting operation of the controller and the DC/DC converter itself. Low coupling capacitance is therefore desirable, ideally less than 15 pF.

When the IGBT driver is powered by an isolated DC/DC converter, the barrier in the converter will be expected to withstand the switched voltage applied to the IGBTs which may be kilovolts at tens of kHz. Because the voltage is switched, the barrier will degrade over time faster than with just DC by electrochemical and partial discharge effects in the barrier material. The DC/DC converter must therefore have robust insulation and generous creepage and clearance distances. If the converter barrier also forms part of a safety isolation system, the relevant agency regulations apply for the level of isolation required (basic, supplementary, reinforced), operating voltage, pollution degree, over-voltage category and altitude.

High-Voltage Switcher Achieves 5 Percent Current Regulation Accuracy

In chargers it is often necessary to adjust the output current in addition to the output voltage. In recent years primary side regulation (PSR) methods without optical coupler are gaining popularity. Such methods pose challenges on the accuracy that we can obtain because of the indirect sensing of the output current and voltage. The UCC28910 is the first TI high-voltage switcher that achieves output current regulation accuracy within 5% – without external components. **Rosario Davide Stracquadaini, System Engineer, Texas Instruments, Catania, Italy**

The UCC28910 is the first TI high-voltage switcher that incorporates a controller. This 700-V Power FET has a 700 V current source for start-up and is dedicated to off-line isolated flyback power converters. It uses primary-side regulation and senses all the needed quantities to perform output voltage and current regulation, from auxiliary winding, without the need for an optical coupler.

Operation principle

The device's working mode is forced into discontinuous conduction mode (DCM) with valley-switching to reduce switching losses. Figure 1 shows a typical offline converter schematic where a minimal component count is visible.

The output voltage is sensed sampling the transformer auxiliary winding voltage through pin VS. The device's internal circuitry can detect when the ringing amplitude on the auxiliary waveform goes below an acceptable value and closes the sampler switch. The ringing here is the ringing that follows resetting of the leakage inductance. The same circuitry also can sense the knee of the auxiliary waveform at the end of the demagnetization time when the sampler switch is closed.

The sampled value of the auxiliary winding waveform gives information about the output voltage level, which is used when the converter regulates the output voltage. The length of the transformer demagnetization time is used when the converter regulates the output current.

The output-current regulation level on this switcher is established by setting the peak value of the primary current and the transformer turn ratio according to equation 1;

$$I_{OUT}=\frac{1}{2}\cdot N_{PS}\cdot I_{PK}\cdot f_{SW}\cdot T_{DEMAG} \quad (1)$$

where N_{PS} is the transformer primary to the secondary turn ratio; I_{PK} is the primary peak current which is equal to the UCC28910 internal MOSFET peak current; T_{DEMAG} is the transformer demagnetization time; f_{SW} is the switching frequency that is modulated to keep constant the product $F_{SW}\cdot T_{DEMAG}$ The peak value of the internal MOSFET is set selecting the value of the resistance connected between the device's IPK and GND pins.

Because of the MOSFET switch-off delay (t_d in Figure 3 and in equation 2), the primary peak current depends on the slope of the primary current (S_{IP}) in equation 2:

$$I_{PK}=I_{PK_{TARGET}}+S_{IP}\cdot t_d=I_{PK_{TARGET}}+\frac{V_{in}}{L_P}\cdot t_d \quad (2)$$

Here the slope of the current depends on the converter's input voltage (V_{IN}) and the value of the transformer's primary inductance (LP). As the input voltage changes, the primary peak current also changes. According to equation 1 the output current also changes.

The previous consideration states that the output current regulation level will not be accurate, if the effect of the switch-off delay is not properly compensated.

In state-of-the-art ICs dedicated to this

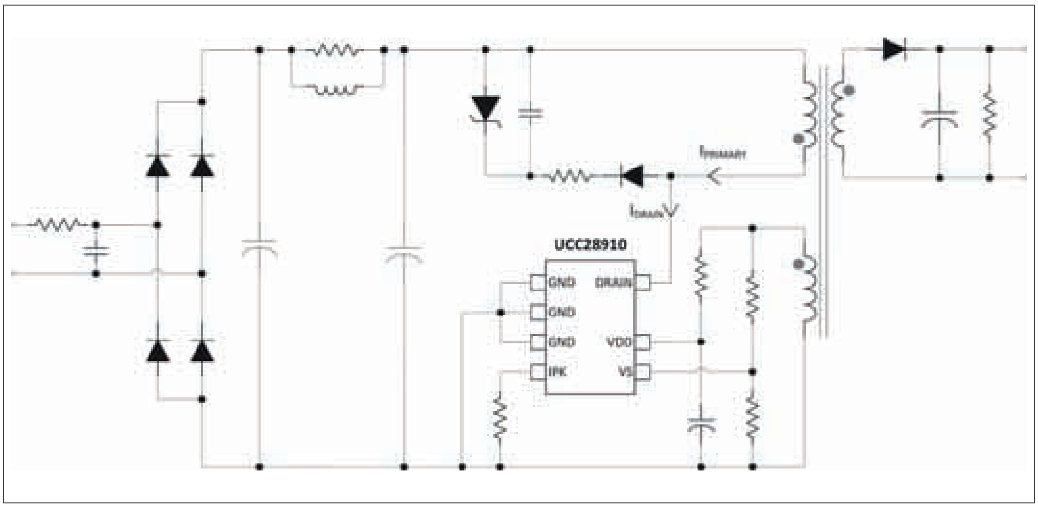
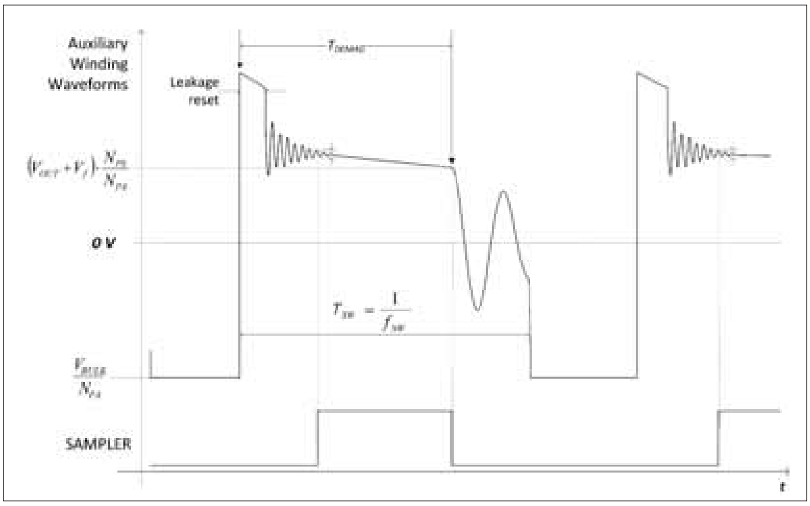
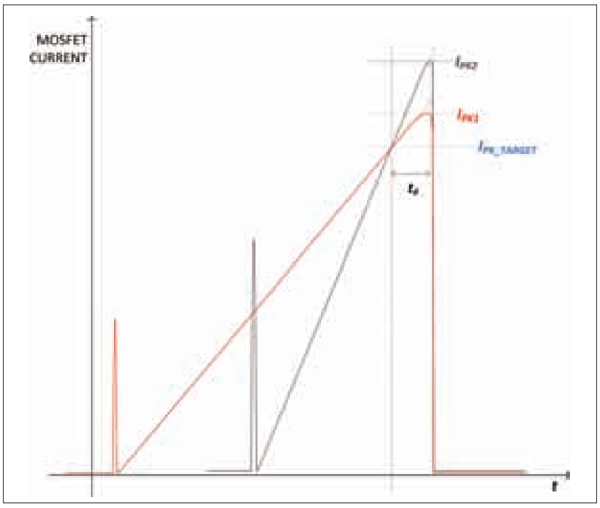


Figure 1: A typical application schematic for the UCC28910 switcher





ABOVE Figure 2: Auxiliary winding waveforms

LEFT Figure 3: MOSFET current at different converter input voltage

kind of converter, this compensation is performed sensing the input voltage and adjusting the pulse-width modulation (PWM) comparator level, or the switching frequency according to the sensed input voltage value. In doing so, the inductance voltage spread is not compensated. You may need additional components to sense the converter input voltage. At a minimum, you will need to tune one or more external components to adjust the compensation amount to obtain almost constant output current on the entire input voltage range.

The UCC28910 uses a fully integrated proprietary, solution to compensate for the converter's input voltage and primary inductance variations, achieving accuracy within ±5% in output-current regulation. The solution compensates the IPK variation adjusting the switching frequency to satisfy equation 3:

$$I_{PK}\cdot f_{SW_{adj}}\cdot T_{DEMAG}=I_{PK_{TARGET}}\cdot f_{SW}\cdot T_{DEMAG}\,(3)$$

Here IPK is the primary peak current; fSW_adj is the value of the switching frequency after compensation;

IPK_TARGET is the target value of the primary peak current that is the value of the primary peak current, if td is zero (see Figure 3). With this device, equation 1 becomes equation 4:

$$I_{OUT}=\frac{1}{2}\cdot N_{PS}\cdot I_{PK}\cdot f_{SW_{adj}}\cdot T_{DEMAG}=\frac{1}{2}\cdot N_{PS}\cdot I_{PK_{TARGET}}\cdot f_{SW}\cdot T_{DEMAG}\,(4)$$

The peak-current variation caused by the primary inductance spread, and by the input voltage variation, is almost perfectly compensated by the UCC28910 internal circuitry. It is mandatory to say "almost" because the compensation method is based on equation 2, which supposes that the primary current is a perfectly triangular waveform. Looking at the top of the waveform in Figure 3 we see that the peak of the current is rounded. This implies an amount of error in respect to equation 4. The device takes this error into account, even if it cannot compensate for it 100 %. What is important is that all the necessary quantities that this device needs to sense are internal to the device. This means that there is no need for additional external components. Moreover, there is no need to tune the amount of compensation because it is already exactly what it needs to be. Ultimately, the user just need to set up the output current value by setting the transformer turn ratio and the MOSFET peak-current value.

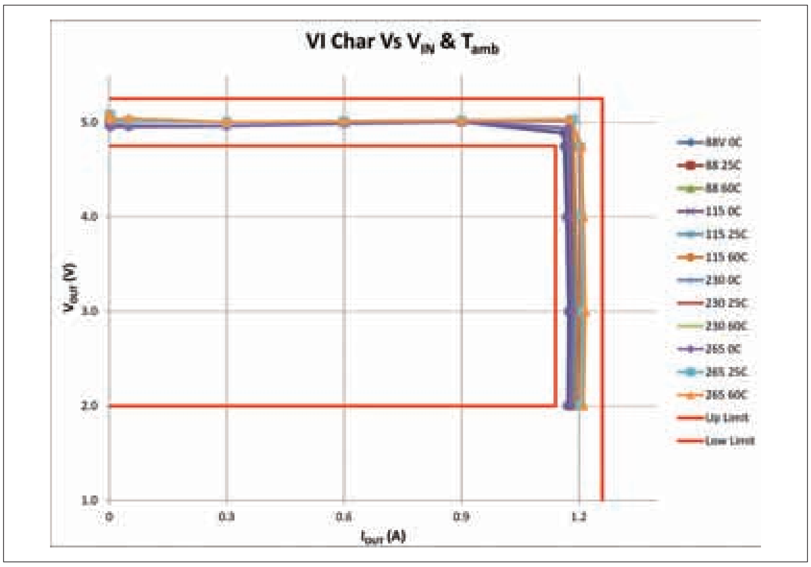
Figure 4 shows the results of experimental tests performed on a demo-board with input voltages ranging from 88 V AC to 265 V AC. The ambient temperature ranges from 0°C to 60°C. The target regulation level for the output current is 1.2 A and 5 V for the output voltage. As is evident, the output current is within the ±5% limits (see red lines) with some margin.

Conclusion

Once the transformer turn ratio is fixed, we have only to fix the value of the MOSFET current-peak proper by selecting and tuning the resistance connected on the device's I_{PK} pin, which fixes the output current regulation level. No other components are needed to achieve a fine-working compensation, thus eliminating the need to turn off the delay effect.

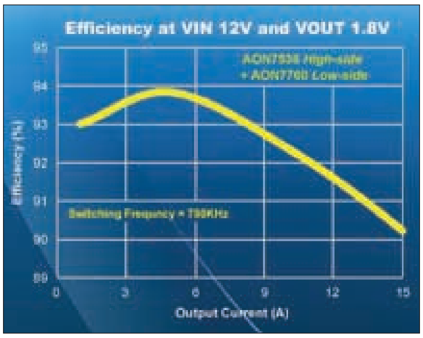
Literature

UCC28910 datasheet



RIGHT Figure 4: Converter voltage / current output curves

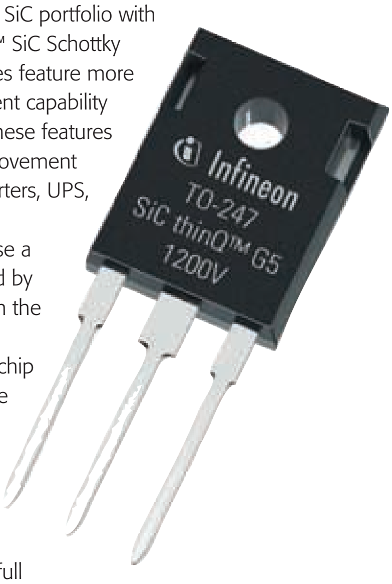
25 V / 30 V MOSFETs in 3 mm x 3 mm Footprint



Alpha and Omega Semiconductor released six 25 V and 30 V MOSFETs (AON7760, AON7510, AON7758, AON7764, AON7536, and AON7538) in compact 3 x 3 mm DFN packages. These devices are suited for a variety of DC/DC step-down conversion solutions. The proprietary power trench MOSFET technology accomplishes a low figure-of-merit for fast switching applications such as DC/DC converters that operate over 600 kHz. The AON7536 is optimized for high-side switching by minimizing Q_g and C_{rss}, thus, lowering the switching power losses. When paired with the AON7760, AON7536 can achieve 90 % efficiency at 15 A for a 12 V input and 1.8 V output. This new 3x3 DFN family has a 20 % figure-of-merit improvement from the previous generation. In addition to the DC/DC applications, the AON7510's low on-resitance of 1.3mΩ (max) @ 10 V is ideal for conduction loss critical applications such as those with a high current system switch, load switch, or motor drive.

www.aosmd.com

Fifth Generation 1200 V SiC Schottky Diodes



Infineon Technologies expands its SiC portfolio with the 5th generation1200 V thinQ!™ SiC Schottky diodes. The new 1200V SiC diodes feature more than 100 % improved surge current capability and excellent thermal behavior. These features result in significant efficiency improvement and robust operation in solar inverters, UPS, 3-phase SMPS and motor drives.

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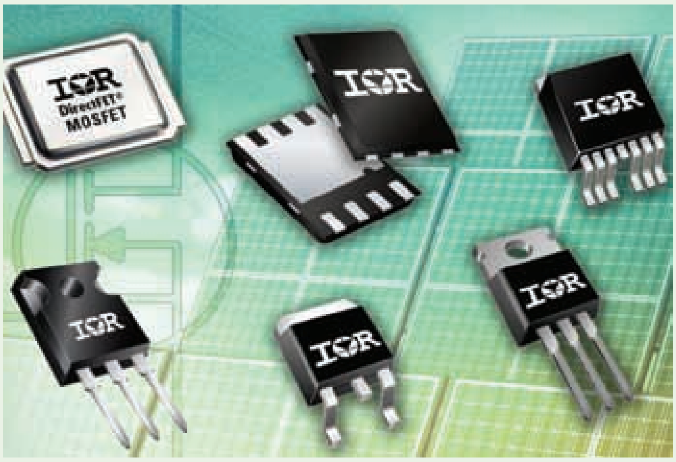
www.infineon.com/sicdiodes1200V

60 V Power MOSFETs



International Rectifier expanded its portfolio of 60 V and up to 240 A StrongIRFET™ power MOSFETs available in various standard and performance power packages. The new MOSFETs are designed for a wide range of industrial applications including power tools, Light Electric Vehicle (LEV) inverters, DC motor drives, Li-Ion battery pack protection, and SMPS secondary-side synchronous rectification. Available in through-hole and surface mount packages, the expanded 60 V family includes the IRF7580M. Housed in a low profile, compact Medium Can (ME) DirectFET® package that delivers high current density while reducing overall system size and cost, the device is well suited for space constrained high power industrial designs. As with the entire DirectFET® family, this device has wire bond free construction for improving reliability performance. The family of 19 MOSFETs offers low on-resistance for improved performance in low frequency applications, very high-current carrying capability, soft body diode, and 3 V typical threshold voltage to improve noise immunity. Each device in the family is 100 % avalanche tested at industry highest avalanche current levels to ensure the most robust solution for demanding industrial applications. Pricing for IRF7580M begins at $0.78 each in 10,000 unit quantities.

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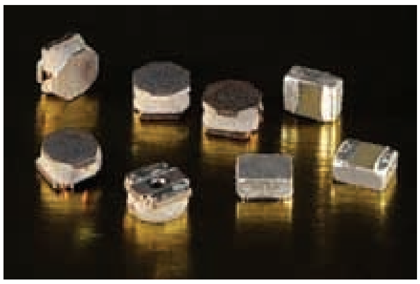
SMT Power Inductors



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www.tfc.co.uk

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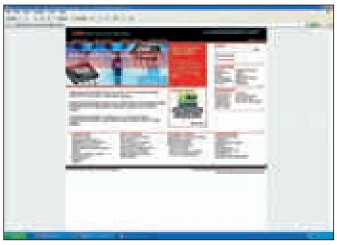

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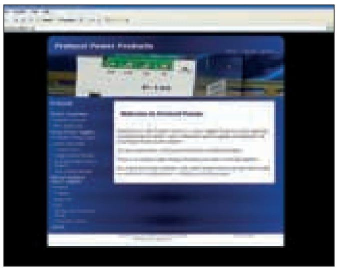

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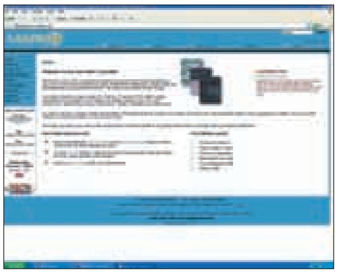

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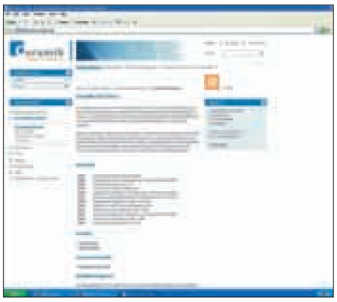

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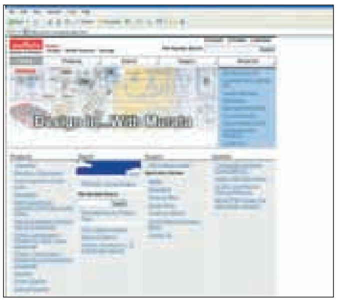

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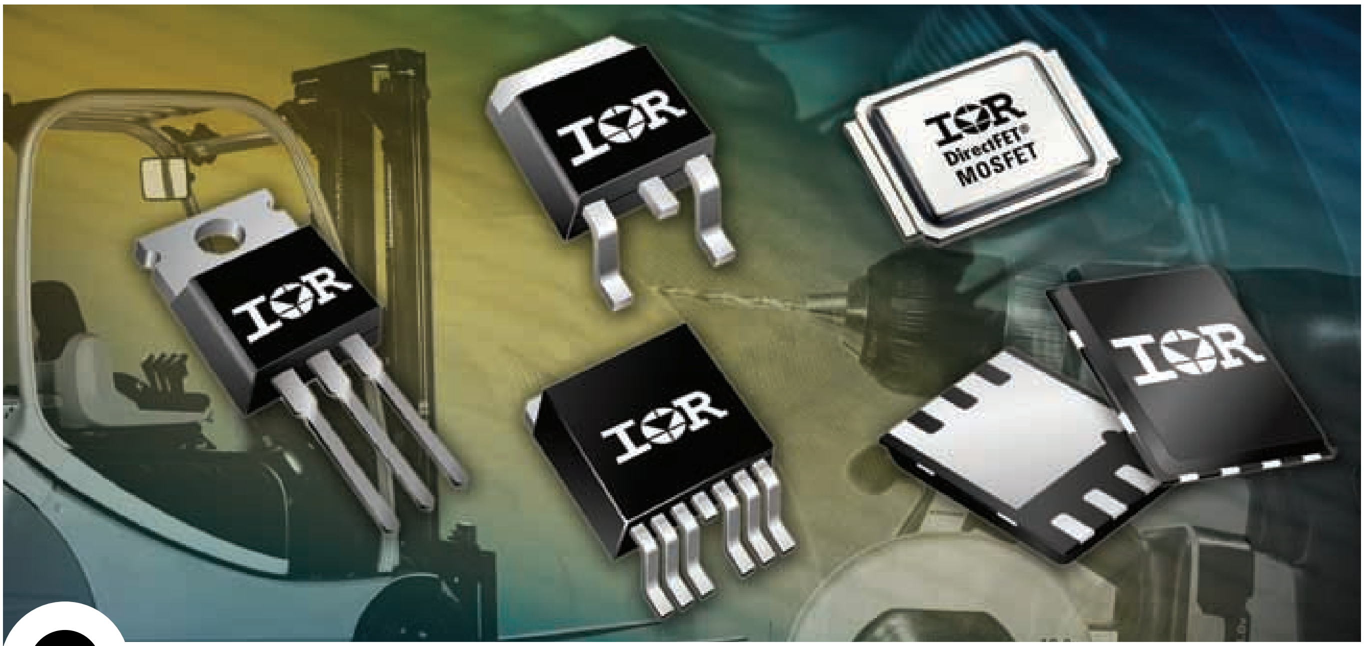

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Specifications

Package	B_{VDSS} (V)	ID @25°C (A)	$R_{DS(on)}$ max @Vgs = 10V (mΩ)	Qg@ Vgs = 10V (nC)	Part Number
PQFN 5x6	25	100	0.95	56	IRFH8201TRPbF
	25	100	1.05	52	IRFH8202TRPbF
	30	100	1.1	58	IRFH8303TRPbF
	30	100	1.3	50	IRFH8307TRPbF
	40	100	1.4	134	IRFH7004TRPbF
	40	85	2.4	92	IRFH7440TRPbF
	40	85	3.3	65	IRFH7446TRPbF
DirectFET Med.Can	30	192	1.3	51	IRF8301MTRPbF
	40	90	1.4	141	IRF7946TRPbF
	60	114	3.6	120	IRF7580MTRPBF
D^2-Pak	40	195	1.8	150	IRFS7437TRLPbF
	40	120	2.8	90	IRFS7440TRLPbF
	60	120	5.34	86	IRFS7540TRLPbF
D^2-Pak 7pin	40	195	1.5	150	IRFS7437TRL7PP
	60	240	1.4	236	IRFS7530-7PP
D-Pak	40	90	2.5	89	IRFR7440TRPbF
	60	90	4	86	IRFR7540TRPbF
TO-220AB	40	195	1.3	300	IRFB7430PbF
	40	195	1.6	216	IRFB7434PbF
	40	195	2	150	IRFB7437PbF
	40	120	2.5	90	IRFB7440PbF
	40	118	3.3	62	IRFB7446PbF
	60	195	2.0	274	IRFB7530PbF
TO-247	40	195	1.3	300	IRFP7430PbF

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