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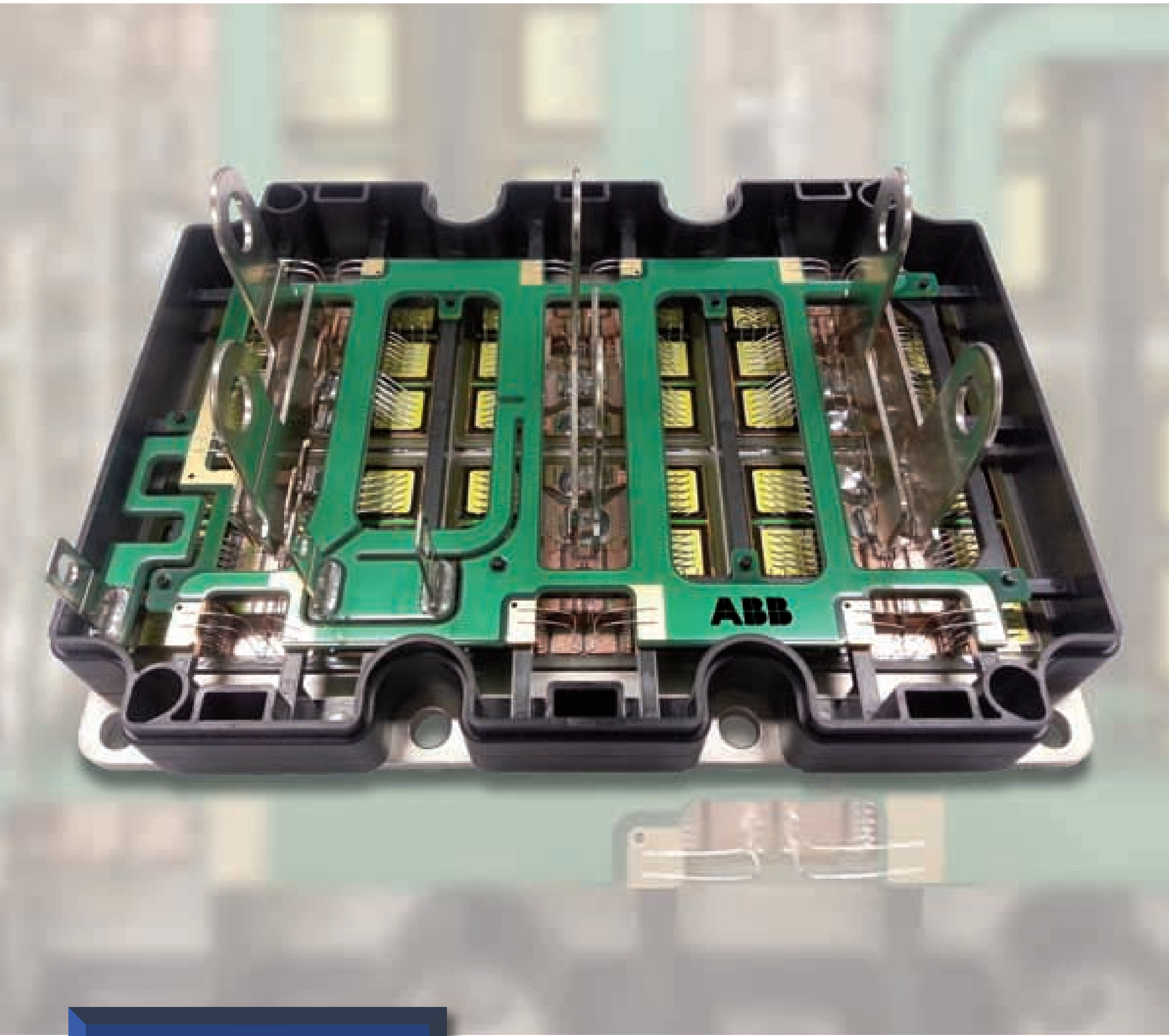
POWER MODULES

Improved HiPak Modules for Power Electronic Applications



THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

Also inside this issue

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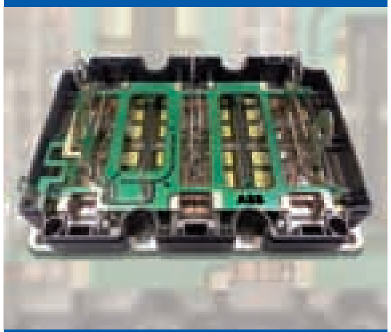
COVER STORY



Improved HiPak Modules for Power Electronic Applications

Today, IGBT based power electronic modules are the devices of choice for a vast range of applications from light-rail vehicles, heavy duty multi megawatts locomotives, to hundred megawatts HVDC installations. High reliability is the key element that needs to be addressed in all applications. ABB challenges the limits of both, the electrical and reliability specifications, by means of new, well-known and established technologies, and has developed an improved package. This package satisfies the increased reliability expectations without changing the electrical and thermal behavior, thus allowing the costumer for a one-to-one replacement without any need for requalification. This concept of improving well established processes and design elements and roll out on an existing product platformproves that substantial quality and reliability gain can be achieved without the need for the customer to redo a costly and time consuming design-in. Full story on page 24.

Cover supplied by ABB Semiconductors Switzerland

Bread and Butter in Power

Market researchers expects a return to steady growth for the IGBT market; specifically, from $3.6 billion in 2013 to $6 billion by 2018. Key applications such as motor drives, renewable energies (PV and wind) will fuel this growth. The need for efficient energy solutions is stronger than ever, and IGBT devices are still undergoing developments and improvements: thinner wafers, more efficient production, integration of functionalities, etc.

Since its introduction nearly two decades ago, high power IGBTs developed to be the device of choice for power electronics applications covering a wide range of voltage and current like light-rail vehicles and industrial drives in the hundred kilowatts to lower megawatt range, multi megawatt electric locomotives and industrial drives and even HVDC converters of up to several hundred megawatts. The need for energy efficient motor drive solutions and transportation together with the urge to explore alternative energy sources such as wind-power, further drive the demand of power-electronic converters. Since the up-time of such applications is crucial for the whole economics, reliability requirements are key.

As outlined in our feature on IGBTs in PV the trench-field-stop technology is the most common concept for modern IGBTs with blocking voltages in the range of 600 V to 1200 V. This technology allows implementing devices with low on-state voltages and soft switching on the one hand and low switching losses and a MOSFET-like switching performance for high-frequency applications on the other hand. Within this technology, the device performance is mainly controlled by design parameters like cell geometry, chip thickness, and doping profile. For instance, by adjusting these parameters, devices with a high carrier density in the drift region can be implemented. Such devices provide a low saturation voltage and achieve low static losses. During the turn-off, a high carrier density leads to a slower clear out of the device and the dynamic losses are increased. Therefore, the performance of an IGBT can be either optimized for high-frequency applications like solar inverters or boosters, which need devices with low dynamic losses, or for low-frequency applications, which benefit from low static losses.

An other approach is to use a MOSFET instead of a FWD. By replacing the reverse recovery diode with a smaller standard MOSFET than rated IGBT, the overall switching losses (both on and off) are further reduced. Since the MOSFET switches faster than the IGBT, it must be turned on before the IGBT and then delayed in turning it off after the IGBT. Additionally, IGBT drivers' area has never been so active, a bunch of start-up companies proposing solutions offering more design flexibility and/or higher performance.

IGBT is no longer the only high-end device solution. SiC devices are ready, and GaN devices are at sample stage. Adoption roadmaps are clearer now. The first full SiC PV inverters based on MOSFETs or JFETs have entered the market; it is more as a displacement. IGBT is slowly moving to medium and-low end solutions, allowing SiC to handle higher voltages, and GaN to capitalize on lower voltages – see our features in this issue.

Another hot topic is the local storage of electricity generated from renewable energies such as PV. The global photovoltaic capacity could increase by between 27 and 32 GW, 23 countries will increase their PV capacity by more than 100 MW this year. In addition to China and India, Japan, South America and many countries in the Middle East in particular will soon be expanding their PV capacities. The broad diversification of markets will lead to greater stability in the industry in the long term as development will cease relying on the subsidy policies of individual nations. Feed-in tariffs were the greatest incentive for investing in solar power. However, increasing electricity prices, tumbling feed-in tariffs and falling module prices are resulting in the on-site consumption of self-generated solar power becoming increasingly attractive. Thus the on-site consumption of solar power represents an attractive economic and reliable alternative to power generated using conventional methods. Thus higher demand for industrial batteries is anticipated. In 2012 a sum of almost $750 million was invested alone in the area of industrial LiIon batteries in Europe. The market volume will probably reach $1.7 billion by 2017. High figures are also being seen on the market for hybrid and electric vehicle batteries in Europe. Though several initiatives on LiIon technology have been implemented in Europe, the main players are still located in Japan and South Korea. Panasonic (recently acquired Sanyo), Samsung, LG Electronics and to a lesser extend Sony dominate the market by around 90 %. Regarding pricing per kWh a decline of 50 % can be expected, from $500 in 2010 down to $250 / kWh in the year 2020. And this will lead to an exceptionally increasing demand in battery and power management systems as well as charging solutions – again a huge potential for power electronic components.

All these trends and figures can be explored in this issue – enjoy reading.

Achim Scharf
PEE Editor

New Business Models for the Battery Industry

Energy storage is gaining more interest by various industries as recent events have shown. E-mobility including e-bikes, solar energy storage and last but not least all of the mobile devices require efficient electrical energy storage – mainly on LiIon technology along with associated battery management and charging solutions.

IMS Research is predicting that the global photovoltaic capacity will increase by between 27 and 32 GW, 23 countries will increase their PV capacity by more than 100 MW this year. In addition to China and India, Japan, South America and many countries in the Middle East in particular will soon be expanding their PV capacities. The broad diversification of markets will lead to greater stability in the industry in the long term as development will cease relying on the subsidy policies of individual nations.

The Asia-Pacific region is following the global trend by expanding renewable energies. Especially in industrial areas, it can therefore be assumed that energy storage projects will increase significantly in the near future. In particular, Japan, Australia and South Korea are paying close attention to new storage technologies in order to permanently maintain the stability of their energy supply. A study by the market research company Pike Research reveals the enormous potential of the market volume, which is expected to rise to $12 trillion by the year 2022. Experts predict that China and Japan will become the driving forces on the market in the next few years. India will also probably follow the trend: demand is now already increasing there due to lower costs.

Some industrial nations can only dream about this: last year the American government invested $120 million in energy storage technologies in the full knowledge that the energy storage market in its own country will break records in the next few years. According to the latest survey of Environmental Business International (EBI) on the American energy market, the market volume of the sector amounts to more than $3 trillion and is likely to pass the $5 trillion mark next year. The industrial sector of energy storage technologies in the USA has been driven, for example, by the expansion of the fleet of electric vehicles, but especially by the construction of large solar and wind parks all over the country.

Trends in energy storage

At Intersolar Europe 2013 from June 19–21 at Messe München, numerous exhibitors of the 1330 in total showcased a variety of new

The latest trend in solar power is on-site consumption backed by battery storage systems shown at Intersolar 2013 **Source: Intersolar**

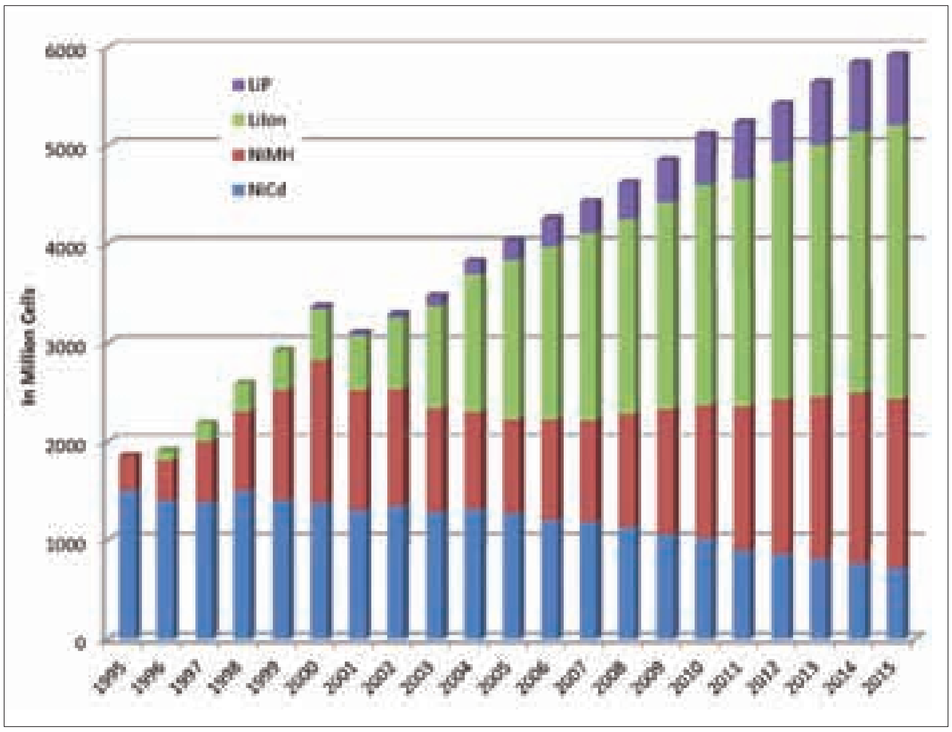
PV system solutions and investment opportunities due to the changing landscape.

Feed-in tariffs were the greatest incentive for investing in solar power. However, increasing electricity prices, tumbling feed-in tariffs and falling module prices are resulting in the on-site consumption of self-generated solar power becoming increasingly attractive. According to an electricity price analysis conducted by the German Association of Energy and Water Industries (BDEW), the electricity price paid by private householders has risen over the last five years from an average of 20.64 Euro cents per kWh in 2007 to 25.89 Euro cents per kWh in 2012, and a further price increase is expected. Small and medium businesses (SMEs) are also unable to escape the effects of rising electricity prices. Against this backdrop, the on-site consumption of solar power represents an attractive economic and reliable alternative to power generated using conventional methods.

Additionally, low PV system prices mean that solar power can already be generated in Germany for between 12 and 15 Euro cents per kWh. The desire for independence and electricity prices that remain calculable in the long term is exerting an ever greater influence on the purchasing decisions of private and commercial investors and companies. Sinking installation prices mean that more and more new medium-sized photovoltaics markets are emerging.

The recent decision by the German Federal Government to make a sum of €25 million available for the programme in connection with the market launch of electricity storage systems, will also greatly promote developments in the area of energy storage technologies in future. The European battery industry was therefore in favor of the EU initiatives regarding the promotion of renewable energies, sustainable mobility and resource efficiency which gave the industry additional impetus.

These changing demands are providing the photovoltaics industry with an opportunity to develop new business models, products and services. On-site consumption by private householders, industry and commerce has resulted in a trend emerging towards combining PV installations with other system components, such as energy storage systems and heat pumps that work alongside energy management systems. Energy storage systems allow surplus electricity to be stored for times at which it is needed, while solar power can be used to drive heat pumps, and intelligent control systems allow solar power production and consumption to be synchronized with the use of domestic appliances. Installation engineers, planners and developers are also benefiting from these developments, as the on-site consumption market requires specialist expert knowledge and greater levels of consultation in order to meet consumers' individual requirements. Thus a multitude of companies showcased complete solutions for the on-site consumption of solar power and 170 exhibitors were registered for energy storage systems alone.



Battery technology cell market worldwide **Source: Batteryuniversity/ BMZ**

Thus higher demand for industrial batteries is anticipated. In 2012 a sum of almost $750 million was invested alone in the area of industrial LiIon batteries in Europe. The market volume will probably reach $1.7 billion by 2017. High figures are also being seen on the market for hybrid and electric vehicle batteries in Europe: the market volume here will rise to €20 billion (A.T. Kearney Study "E-Drive Batteries 2025") by 2025.

Four players dominate the world market

At the sixth battery designer forum (June 26 – 27) in Aschaffenburg/Germany featuring 520 delegates Batteryuniversity's GM Seven Bauer gave a closer insight to the world market. Whereas in the year 2010 the world battery market was around $62 billion, this figure will increase up to $93 billion in the year 2015. Lead/acid will decline from over 53 % in 2010 to 45 % in 2015, NiCd with its 5 % share in 2010 will not survive and thus LiIon will increase its market share – from $10 billion in 2010 up to $16 billion in 2015.

Though several initiatives on LiIon technology have been implemented in Europe, the main players are still located in Japan and South Korea. Panasonic (recently acquired Sanyo), Samsung, LG Electronics and to a lesser extend Sony dominate the market by around 90 %. Regarding pricing per kWh a decline of 50 % can be expected, from $500 in 2010 down to $250 / kWh in the year 2020.

At this event several new technologies and improvements on LiIon batteries, battery management systems, chargers and power electronics have been introduced. Maxell works on Silicon-based nano hybrid electrodes leading to capacity improvements of 20 % at same voltage (2.75 V). Sony has reduced the DCR (resistance) of their next gen 18650 cell for e-bikes and power tools down to 25 mΩ leading to current capability of 30 A, compared to 10 A of the first generation. The Karlsruhe Institute of Technology works on Carbon Nanotubes for LiIon cathodes which promises to reduce the cathode weight by 15 % and increase efficiency by 5 %. The Fraunhofer IFAM Institute gave an outlook on rechargeable Zinc/Air batteries for range extender application. Additionally new efficient battery modules as well as charger and inverter topologies have been introduced.

Next in Stuttgart

The next event will be the BATTERY+STORAGE 2013 (30 Sept. to 2 Oct.) in Stuttgart/Germany. It addresses all players involved in the manufacturing of battery and energy storage systems for mobile and stationary implementations. The program features 140 presentations on a wide range of issues relating to the development, production, application and marketing of fuel cell and LiIon battery systems in various areas of application, examples of best-practices in the field of electromobility and approaches to the development of the necessary infrastructure.

www.intersolar.de
www.batteryuniversity.eu
www.battery-storage.de

IGBTs Back to Growth

After a few hiccups in 2011 and 2012, Yole Développement expects a return to steady growth for the IGBT market; specifically, from $3.6 billion in 2013 to $6 billion by 2018. Six key applications will fuel this growth. Motor drives is the largest one for IGBTs, renewable energies (PV and wind) are also trending well.

Since they rely on government investments, they can be unpredictable, but Japan and several developing countries will make up for Europe's slow-down. Mass transportation and UPS are based on infrastructure needs; thus, the need for greater efficiency is pushing these markets. As for hybrid and electric cars, question marks remain. Market growth will occur, but nobody can predict to what extent. Forecast is based on the latest Q1/2013 results and our understanding of technology adoption. Consumer and home appliances are now part of the equation. Home appliances increasingly require inverter-based motor drives, which provide better performance, comfort and efficiency - all "musts" for high-end products. Consumers are also using more advanced home solutions, like induction-based plates for rice cookers. These new applications will contribute to IGBT's growth in consumer applications.

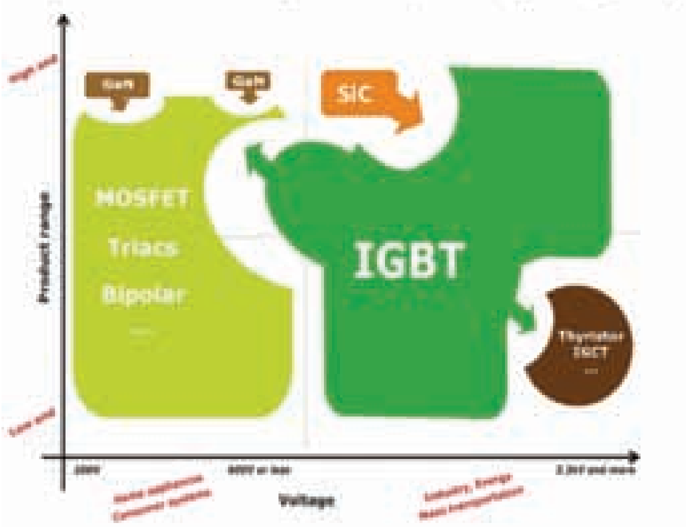
The IGBT market also faces competition from external, market-impacting trends. IGBT drivers' area has never been so active, a bunch of start-up companies proposing solutions offering more design flexibility and/or higher performance. Other companies are structuring offers at power stack level, and a lot of work has been put into power module packaging solutions. "IGBT is no longer the only high-end device solution. SiC devices are ready, and GaN devices are at sample stage. Adoption roadmaps are clearer now. We've seen the first full SiC PV inverters based on MOSFETs or JFETs; we see it more as a displacement. IGBT is slowly moving to medium and-low end solutions, allowing SiC to handle higher voltages, and GaN to capitalize on lower voltages," explains analyst Alexandre Avron.

The need for efficient energy solutions is stronger than ever, and IGBT devices are still undergoing developments and improvements: thinner wafers, more efficient production, integration of functionalities, etc. This is why Yole Développement believes that IGBT is not on its deathbed, nor even declining. The IGBT supply chain is not steady either, and we've observed a growing number of Asian companies involved or willing to be involved in this market. Among the biggest are CSR (who acquired Dynex), and of course BYD; both are moving towards a vertically integrated business model. Also, foundries and fabless companies are targeting opportunities in the low-voltage, low-end market. As a first step, Asian players will probably remain with standard technologies and focus on production for local use. On the other hand, European and US-based players are pushing for innovation. Some, such as ON Semiconductor (with its division Sanyo) and Alpha and Omega Semiconductor, are entering or reentering the IGBT market.

www.yole.fr

Power device technology positioning

(Source: IGBT Markets and Application Trends, Yole Développement, May 2013)



European Project on SiC/GaN Power Microelectronics

LAST POWER, the European Union-sponsored program aimed at developing a cost-effective and reliable technology for power electronics, announced mid of May its three-year program achievements that place Europe at the forefront of research and the commercialization of energy-efficient devices for industrial and automotive applications, consumer electronics, renewable-energy conversion systems, and telecommunications.

LAST POWER (Large Area silicon-carbide Substrates and heTeroepitaxial GaN for POWER device applications) was launched in April 2010 by the European Nanoelectronics Initiative Advisory Council (ENIAC) Joint Undertaking (JU), a public-private partnership in nanoelectronics. The initiative links private companies, universities and public research centers working in the field of wide bandgap semiconductors (SiC and GaN). The consortium members are STMicroelectronics (Italy), project coordinator, LPE/ETC (Italy), Institute for Microelectronics and Microsystems of the National Research Council –IMM-CNR (Italy), Foundation for Research & Technology-Hellas - FORTH (Greece), NOVASiC (France), Consorzio Catania Ricerche -CCR (Italy), Institute of High Pressure Physics - Unipress (Poland), Università della Calabria (Italy), SiCrystal (Germany), SEPS Technologies (Sweden), SenSiC (Sweden), Acreo (Sweden), Aristotle University of Thessaloniki - AUTH (Greece).

The main achievements in SiC-related efforts were based on the demonstration by SiCrystal of large-area 4H-SiC substrates, 150 mm in diameter, with a cut-off angle of 2°-off axis. The material quality, both in crystal structure and surface roughness, is comparable with the standard 100 mm 4°-off material available at the beginning of the project. At LPE/ETC, these substrates have been used for epitaxial growth of moderately doped epi-layers suitable for the fabrication of 600-1200 V JBS (Junction Barrier Schottky) diodes and MOSFETs, owing to the development of a novel CVD (Chemical Vapor Deposition) reactor for the growth on large-area (150 mm) 4H-SiC.

The quality of the epitaxial layer enabled the fabrication of JBS (Junction Barrier Schottky) diodes in the industrial production line at STMicroelectronics. The characterization of the first lots showed electrical performance comparable with the state-of-the-art 4°-off material. In this context, the fundamental technological step was the chemical mechanical polishing (CMP) process - StepSiC ® reclamation and planarization - implemented at NOVASiC, which is a key issue both for the preparation of the substrates before epitaxial growth and for the sub-nanometric control of the surface roughness of the device active layers. Within the project, the same company also developed epitaxial growth capability for both MOSFET and JFET devices. Additional research activities in SiO_2/SiC interfaces have been carried out in collaboration with ST and IMM-CNR to improve the channel mobility in 4H-SiC MOSFETs. Finally, novel technological modules for high-temperature 4H-SiC JFETs and MOSFETs have been developed in collaboration between Acreo and FORTH, with the support of CCR for the study of molding compounds and "lead-free" die-attach materials for reliable packaging solutions.

The LAST POWER project also researched the use of GaN-based devices in power-electronics applications. In particular, ST successfully obtained the development of AlGaN/GaN HEMTs epitaxial structures grown on 150 mm Si substrates, reaching a target of 3 µm thickness and 200 V breakdown. LAST POWER worked with IMM-CNR, Unipress, and ST to develop the technological steps for normally-off AlGaN/GaN HEMTs with a "gold-free" approach. The process modules are fully compatible with the device-fabrication flow-chart set in the ST production line and are being integrated for HEMTs fabrication. The interaction between the project partners working on material growth and device technology has enabled important steps towards monolithic integration of GaN-based and SiC-based devices, as both technologies have been successfully proven on 2°-off axis 4H-SiC substrates.

www.eniac-lastpower.org

Digi-Key Stocks GeneSiC 3300 V SiC Schottky Rectifiers

Digi-Key serves as exclusive distributor of SiC Schottky rectifiers from US-based GeneSiC Semiconductor. These rectifiers are specifically targeted towards voltage multiplier circuits and high voltage assemblies used in x-ray, laser, and particle generator power supplies. These 3300 V/0.3 A Schottky rectifiers feature zero reverse recovery current that does not change with temperature. This relatively high voltage in a single device allows a reduction in voltage multiplication stages required in typical high voltage generator circuits, through use of higher AC input voltages. The near-ideal switching characteristics allow the elimination/drastic reduction of voltage balancing networks and snubber circuits. "We believe the 3300 V rating is a key differentiator for the high voltage generator market, and will allow significant benefits to our customers," said Ranbir Singh, President of GeneSiC Semiconductor. All devices are tested to full voltage/current ratings and housed in halogen-free, RoHS-compliant, industry-standard TO-220FP (Full Pack) packages.

www.genesic.com, www.digikey.com

UK Power Electronics Technology Roadmap

NMI, the trade association for electronic systems, microelectronics and semiconductors, established a multi-annual innovation roadmap for the UK's power electronics industry.

The initiative is being undertaken in partnership with government and seeks to increase the UK industry's share of the global power electronics market. The roadmap is expected to identify key and disruptive technologies that can be exploited by UK industry and can be used to communicate to government the most effective, strategic funding opportunities. The Forum stems from the governmental report 'Power Electronics - A Strategy For Success' published in October 2011.

Facilitated by NMI and supported by IET, Gambica and the ESP Knowledge Transfer Network the Forum is an industry-led collaborative effort to have the UK recognized as a "world leader", bringing jobs and investment to the country.

www.power-electronics.org.uk

CWIEME Visitors Forecast Strong European Recovery

The majority of senior buyers and executives from the coil winding, insulation and electrical manufacturing sectors attending this year's (June 4-6) CWIEME in Berlin are forecasting strong business recovery over the next 12 months. The exhibition brought together over 750 international exhibitors and 6,000 visitors from over 100 countries - making this year's show the biggest on record.

The results from an exclusive survey commissioned by organisers i2i Events Group show that 49 % believe their business will perform better in the next 12 months. However, one of the biggest issues identified in the survey is the need for European manufacturers to confront growing competition from emerging economies, principally in areas such as price and speed of innovation and market entry. Speakers at CWIEME's workshop program also stated that Europe had the lead in the area of renewable energy where suppliers and manufacturers were developing world-leading technologies for wind turbines, tidal power and hydro-electricity. "Europe has being caught napping. For many years European sellers of electrical rotating machines and coil winding components have enjoyed sustained growth and secure markets", said Roger Schwander, Head of Expert Pool at SCO Consulting. "However, new market entrants from countries such as China, India and Brazil mean they are now facing much stiffer competition on price. Unless European manufacturers innovate quicker and bring products to market faster they will suffer in the

years to come."

Three of the strongest business areas identified by survey respondents are renewable energy, the automotive sector and consumer electronics. For those involved in these sectors, 86 % expected their level of business to increase over the next 3 years with 57 % of respondents predicting this will be by up to 10 %. But 19 % forecast that their business will grow by up to 20 % over the next 3 years. Some of the world's biggest suppliers of components are exhibiting including Shell, Waasner, Krempel, Trancerie Emiliane, Cogent Power (part of Tata Steel) ABB, Nynas, VonRoll and GKN. The 2013 CWIEME is the first under the ownership of i2i Events Group, which acquired the event and its sister shows in Bangalore and Chicago in September 2012. i2i Events is also launching a new CWIEME exhibition in Shanghai, China in 2014. "Europe in particular is seeing a major focus on renewable energy technology in order to meet the EU Renewable Energy Directive targets for 2020," commented Haf Cennydd, i2i Events Group's Portfolio Director.

www.coilwindingexpo.com/berlin

Power Electronics and Transport at EPE 2013

EPE '13-ECCE Europe, the 15th European Conference on Power Electronics and Applications (and Exhibition), will be held in Lille/France from September 3-5. The conference follows previous conferences held in major university cities across Europe since 1985, most recently Dresden, Aalborg, Barcelona and Birmingham. This time, EPE '13-ECCE Europe will take place in a city located at the crossroads of Paris, Brussels and London.

In the Lille EPE'13 - ECCE Europe conference, a wide range of topics will be broached with a particular focus on clean transportation systems: in 1983, Lille and its suburbs was the first area in the world equipped with a fully automated light metro named the "VAL", which was then exported to Seoul, Chicago and Torino. In 2013, to commemorate the 30th anniversary of this world first, special events will be proposed in collaboration with industrial and economic partners concerned by the VAL. Special attention is focused on Smart Grids, a special event within the conference will cover "Power Electronics Enabling the Grid of the Future". Also an "Aeronautic Day" will cover the various subjects of the all-electric aircraft. A "Automotive Day" will cover electric vehicles & infrastructure within various sessions and a panel discussion, and a "Railway Day" traction & infrastructure.

www.epe2013.com

GVA Implements Amantys IGBT Gate Drivers

The "Power Drive" family of drivers from UK-based Amantys offer improved creepage and clearance and isolation over alternative products in the market, with each drive configurable to operate different IGBT modules. This greatly simplifies the purchasing and logistics process in inverter designs for applications such as wind turbines, solar farm grid ties, and medium voltage motor drives.

These gate drives are available for operating voltages of 1.2 kV, 1.7 kV, 3.3 kV and 4.5 kV IGBTs with a current load rating up to 3600 A. They are compatible with all popular modules from ABB, Dynex, Fuji Electric, Hitachi, Infineon, Mitsubishi or Westcode/IXYS in case sizes 190x140 mm, 140x130 mm and PrimePack. In addition to the standard IGBT driver functionality, with "Amantys Power Insight" these products also receive IGBT performance data in real-time, allowing the system engineer to monitor and log operating conditions, make long-term measurements or control the module remotely. This approach to power electronics attracted the attention of GvA CEO, Werner Bresch. "With Amantys Power Insight we can receive real-time data about the performance of the system and initiate specific preventive actions if necessary, even when the system is remote and relatively inaccessible, such as in an offshore wind turbine," said Bresch. "This makes remote diagnosis and maintenance planning more cost efficient and far easier to manage."

Amantys demonstrated this monitoring capability in a live traction application at PCIM 2013. In the course of this development, Amantys collaborated with Dynex Semiconductor to integrate 4,500 V IGBT Modules in the EMEF "Lusogate" modular traction system, currently undergoing extensive system field trials in Portugal.

www.gva-leistungselektronik.de, www.amantys.com

Altera Acquires Enpirion

Mid May US-based FPGA company Altera announced it has signed a definitive merger agreement to acquire Enpirion, Inc., a provider of integrated power conversion products known as PowerSoCs (power system-on-chip).

"Power is increasingly a strategic choice for product differentiation in communications, computing and enterprise, and industrial applications," said Altera's CEO John Daane. "By adding a power group to Altera, we will bring even more value to system-level designs. Our FPGA roadmap will be enhanced significantly with the addition of Enpirion's power technologies." Enpirion's key enabling power technologies such as high-frequency switching, magnetics and packaging are engineered into complete power system-on-chip products.

www.altera.com

MOSFET Bridge Controller Minimizes Rectifier Voltage Loss

Linear Technology Corporation introduces the LT4320, an ideal diode bridge controller for 9 V to 72 V systems that replaces each of the four diodes in a full-wave bridge rectifier with a low loss N-channel MOSFET to significantly reduce the power dissipation and increase available voltage. Power supply size is reduced as the enhanced power efficiency eliminates bulky heat sinks. Low voltage applications benefit from the extra margin afforded by saving the two diode drops inherent in diode bridges. Compared to the traditional alternative, the MOSFET bridge enables a rectifier design that is highly space- and power-efficient.

Almost all of the electric power generated today is of the AC, while that demanded by electronic systems is of the DC kind. The conversion process from AC to DC is called rectification. While there are various rectification techniques, even electromechanical ones some decades ago, a simple electronic method involves a single diode (hence diodes are also called rectifiers). The diode allows the AC to pass through with a single polarity, blocking it when the voltage reverses (half-wave rectification as only half of the AC waveform passes through). To avail the complete power available in the AC waveform, a full-wave rectifier is used. It is constructed out of four diodes in the well-known bridge configuration.

However, in high power applications the diodes dissipate significant power and with low voltage inputs the two inherent diode drops take a significant bite out of the operating voltage. The diode bridge power dissipation can be calculated as 2 x 0.6 V (diode voltage dropp) x I_L, which yields 1.2 W at 1 A, 12 W at 10 A, and 120 W at 100 A. Rising power dissipation demands increasing amounts of heat sinking efforts to dissipate the heat and maintain the diode temperature within limits. At low power levels, spare circuit board area may suffice but at higher levels large and bulky heat sinks are required. The two diode drop voltage, roughly 1.2 V, is only 0.7 % of 170 V (peak voltage for 120 V AC), but 10 % of 12 V and 13.3 % of 9 V. A diode bridge rectifier on the auxiliary input with its two diode drops further exacerbates the wide range problem, especially at the lower end to 9.6 V (= 10.8 V – 1.2 V). Sometimes the minimum voltage is specified at 9 V, which after the diode bridge becomes 7.8 V.

MOSFETs replacing diodes

The LT4320 replaces each of the four diodes in a full-wave bridge rectifier with a low loss N-channel MOSFET to significantly reduce the power dissipation and increase available voltage. Low voltage applications benefit from the extra margin afforded by saving the two diode drops inherent in diode bridges. Compared to the traditional alternative, the MOSFET bridge enables a rectifier design that is highly space- and power-efficient. The controller operates for 9 V to 72 V systems at input frequencies from DC to 600 Hz.

The LT4320 switch control smoothly turns on the appropriate two MOSFETs, while keeping the other two off to prevent reverse currents. An integrated charge pump provides the gate drive for the external low on-resistance N-channel MOSFETs without requiring external flying capacitors. The choice of MOSFETs offers the greatest flexibility in power levels ranging from one to thousands of watts.

MOSFET selection

A good starting point is to reduce the power dissipation of the ideal bridge to 1/10 that of a diode rectifier bridge. Given the average output load current, I_{AVG}, select $R_{DS(ON)}$ to be:

$$R_{DS(ON)} = \frac{70\ mV}{I_{AVG}} \quad \text{for a DC power input}$$

or

$$R_{DS(ON)} = \frac{70\ mV}{3 \times I_{AVG}} \quad \text{for an AC power input}$$

In the AC power input calculation, 3 x I_{AVG} assumes the duration of current conduction occupies 1/3 of the AC period. The maximum allowable drain-source voltage, V_{DSS}, needs to be higher than the maximum input voltage.

Choose the lowest available total gate charge, Q_G, and correspondingly the lowest C_{ISS}, C_{OSS}, and C_{RSS}. Choosing a lower gate capacitance while meeting $R_{DS(ON)}$ speeds up the response time for full enhancement, regulation, turn-off, and input shorting events. $V_{GS(th)}$ must be a minimum of 2 V or higher. A gate threshold voltage lower than 2 V is not recommended since too much time is needed to discharge the gate below the threshold and halt current conduction during a hot plug or input short event.

Design example

For a 24 W, 12 V DC / 24 V AC application, IAVG = 2 A for 12 V DC. To cover the 12 V DC case:

$$R_{DS(ON)} = \frac{70\ mV}{2A} = 35m\Omega$$

For the 24 V AC operation, IAVG = 1A. To cover the 24 V AC case:

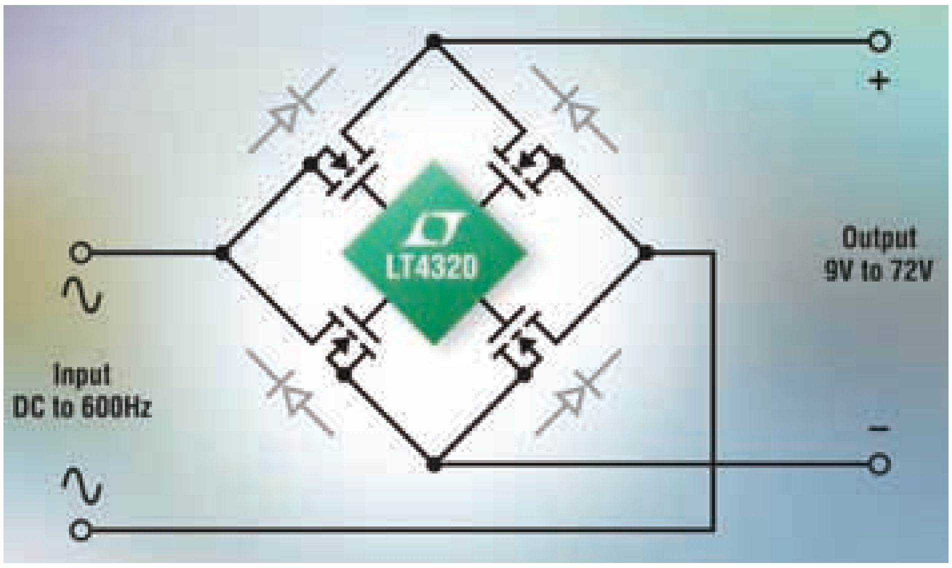
$$R_{DS(ON)} = \frac{70mV}{3 \times 1\ A} = 23m\Omega$$

This provides a starting range of $R_{DS(ON)}$ values to choose from.

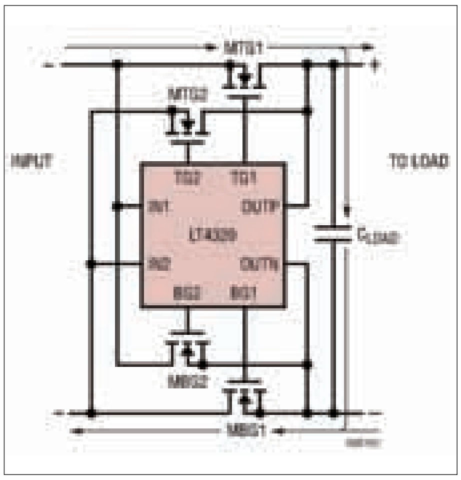
Ensure the MOSFET can handle a continuous current of 3 x I_{AVG} to cover the expected peak currents during AC rectification. That is, select ID ≥ 3A. Since a 24V AC waveform can reach 34 V peak, select a MOSFET with V_{DSS} >>34 V. A good choice of V_{DSS} is 60 V in a 24 V AC application.

Load capacitor selection

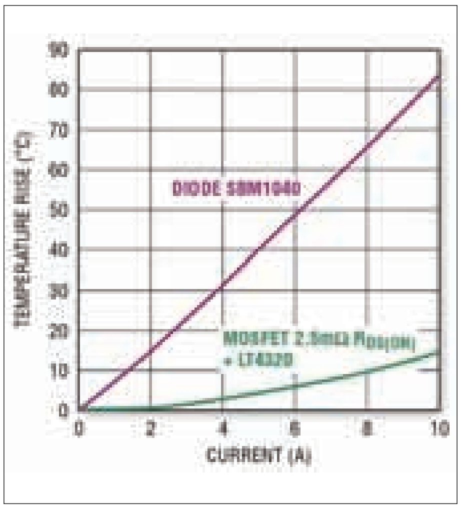
A 1 µF ceramic and a 10 µF minimum electrolytic capacitor must be placed across the OUTP and



LEFT: The LT4320 diode bridge controller replaces the conventional rectifiers with MOSFETS



Current flow when input IN1 of LT4320 sees a positive waveform



Temperature rise of diode vs MOSFET bridge

OUTN pins with the 1 µF ceramic placed as close to the LT4320 as possible. Downstream power needs and voltage ripple tolerance determine how much additional capacitance between OUTP and OUTN is required. C_{LOAD} in the hundreds to thousands of microfarads is common.

A good starting point is selecting C_{LOAD} such that:

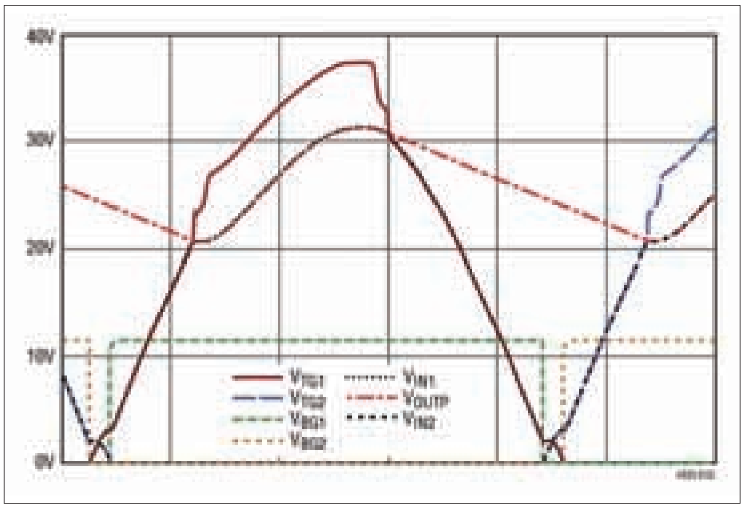
$C_{LOAD} \geq I_{AVG}/(V_{RIPPLE} \times 2 \times Freq)$

where I_{AVG} is the average output load current, V_{RIPPLE} is the maximum tolerable output ripple voltage, and Freq is the frequency of the input AC source. For example, in a 60 Hz, 24 V AC application where the load current is 1A and the tolerable ripple is 15 V, choose

$C_{LOAD} \geq 1\ A/(15\ V \times 2 \times 60\ Hz) = 556\ \mu F$.

C_{LOAD} must also be selected so that the rectified output voltage, OUTP-OUTN, must be within the LT4320/LT4320-1 specified OUTP voltage range.

For applications that may encounter brief over-voltage events higher than the absolute maximum rating, install a unidirectional transient voltage suppressor (TVS) between the OUTP and OUTN pins as close as possible to the LT4320.



24 V AC sample waveforms

Application benefits

Replacing diodes with MOSFETs reduces the voltage drop and consequently the power dissipation by a factor of 10. This drastic reduction in heat dissipation eliminates heat sinks from low power applications while simplifying thermal design in high power ones. With a 9 V input, two diode drops (1.2 V) eat up 13 % of the available voltage. With MOSFETs this wastage can be reduced by 10x making the end application much more feasible.

The integrated charge-pump facilitates an all N-channel MOSFET design, simplifying the Bill of Materials (BOM) as opposed to a design using a mix of N- and P- channel MOSFETs. N-channel MOSFETs are smaller, economical and offer a wider selection than P-channel ones. Being external to the controller, the MOSFETs can be easily sized for a wide range of application power levels.

The charge pump provides at least 425µA of pull-up current to turn on the top-side N-channel MOSFET gate. No external flying capacitors are required. The strong pull-up current enables rectification for high frequency inputs and high power applications employing large gate charge MOSFETs.

The LT4320 input frequency range encompasses DC, common AC line frequencies of 50 Hz and 60 Hz, and airborne AC generation at 400 Hz. Higher frequencies of operation are possible depending on MOSFET size. Designing with the LT4320 primarily involves selection of one component - the external N-channel MOSFET. Reduced heat greatly eases board thermal design while the increased operating voltage simplifies downstream power supply design.

www.linear.com/LT4320

Highly Integrated Driver ICs for Low-Power LED Bulbs

Power Integration's new LYTSwitch-0 is optimized to achieve a simple and cost effective LED driver with good line and temperature regulation

Power Integration's new LYTSwitch-0 ICs are designed for cost-sensitive, non-isolated, non-dimmable GU10 bulbs and other space-constrained bulb applications. The devices feature efficiencies of more than 90 % and deliver constant current with better than +/- 5 % regulation in typical applications. Power factor is greater than 0.8 at 115 VAC and 0.55 at 230 V AC, meeting ENERGYSTAR™ V1 draft 3 consumer lighting standards for North America and Ecodesign Directive Lot 19 part 2 for Europe.

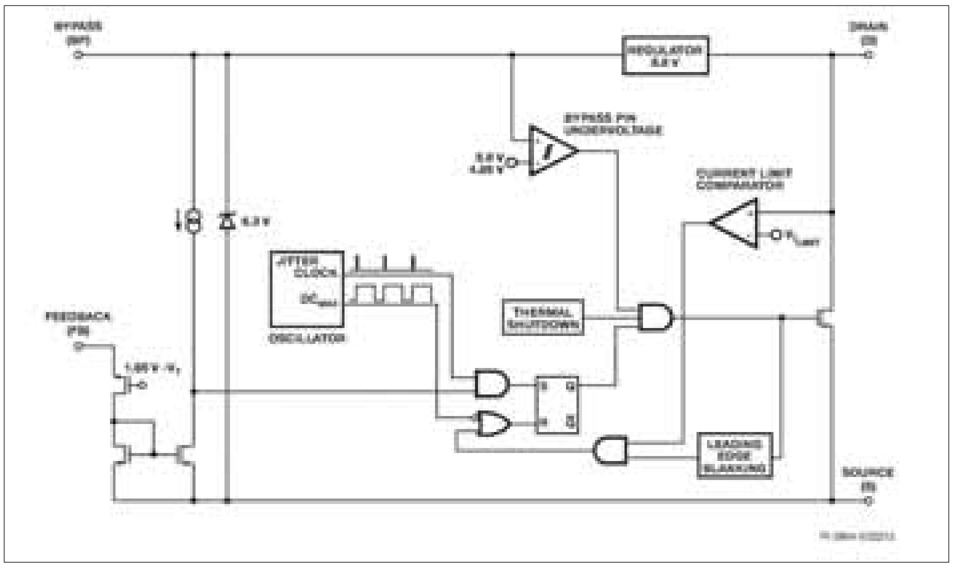
LYTSwitch-0 is optimized to achieve a simple and cost effective LED driver with good line and temperature regulation from 0 to 100°C (LYTSwitch-0 case temperature). The LYTSwitch-0 family has built-in thermal limit to protect the power supply in case the bulb is subjected to an excessive operating temperature.

LYTSwitch-0 combines a high-voltage power MOSFET switch with a power supply controller in one device. Unlike conventional PWM controllers, it uses a simple ON/OFF control to regulate the output voltage. The controller consists of an oscillator, feedback (sense and logic) circuit, 5.8 V regulator, BYPASS pin undervoltage circuit, over-temperature protection, frequency jittering, current limit circuit, blanking and a 700 V power MOSFET. The device incorporates additional circuitry for auto-restart.

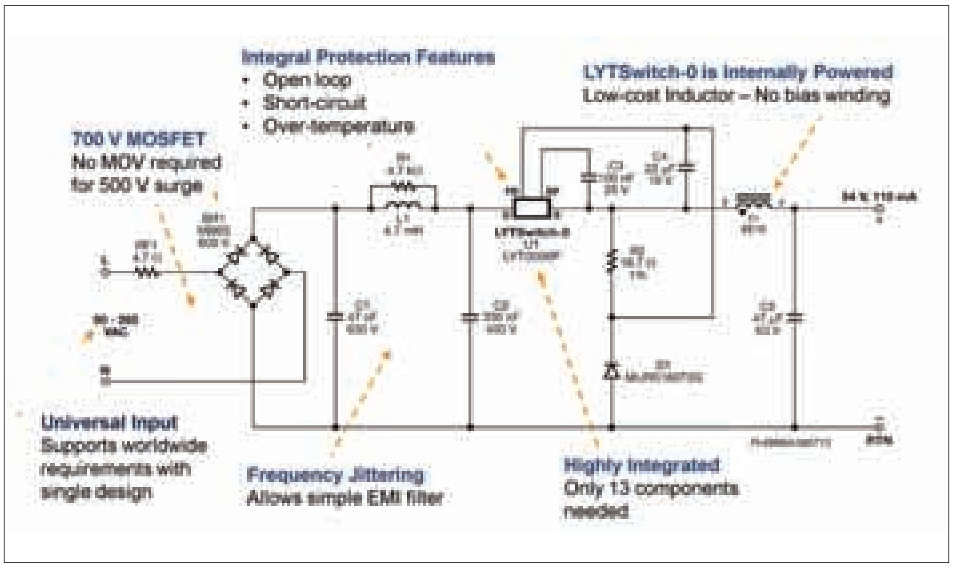
The start-up and operating power are derived directly from the voltage on the DRAIN pin, eliminating the need for a bias supply and associated circuitry. The fully integrated auto-restart circuit safely limits output power during fault conditions such as short-circuit or open-loop.

LYTSwitch-0 reference design

To assist designers a cost effective power supply utilizing the LYTSwitchTM-0 family (LYT0006P) in a



Functional block diagram LYTSwitch-0002



Power supply schematic. T1 can be replaced by a drum core inductor if final casing/housing has sufficient room to avoid shorting the magnetic flux

highly compact buck topology has been developed. This power supply operates over an input voltage range of 90 V AC to 264 V AC. The DC bus voltage is high enough to support a 54 V output when using a buck topology. In a buck converter the output voltage must always be lower than the input voltage. The output voltage is also limited by the maximum duty cycle of the LYTSwitch-0, which also requires the input voltage to be larger than the output voltage.

The power supply uses the LYT0006P (U1) in a high-side buck configuration to deliver a constant 110 mA current at an output voltage of 54 V DC. The power supply is designed for driving LEDs, which should always be driven with a constant current (CC).

Fuse RF1 provides short circuit protection. Bridge BR1 provides full wave rectification for good power factor. Capacitor C1, C2 and common-mode choke L1 form a Pi (π) filter in order to meet conducted EMI standards. Capacitor C1 and C2 are also used for energy storage reducing line noise and protecting against line surge.

The buck converter stage is consists of the integrated power MOSFET switch within LYT0006P (U1), a freewheeling diode (D1), sense resistor (R2), power inductor L2 and output capacitor (C5). The converter is operating mostly in DCM in order to limit the cycles of reverse current. A fast freewheeling diode was selected to minimize the switching losses.

Inductor L2 is a standard EE10 which will constrain the flux path and ensure the right inductance in any casing. It can be replaced by a lower cost drum-core inductor once positioned in a specific enclosure that has a known effect on the magnetic flux of the inductor.

Fast output diode (D1) was used to achieve good efficiency and for thermal management. Normally for LED applications, the ambient temperature is above 70°C. A device with low t_{RR} (<35 nS) is recommended.

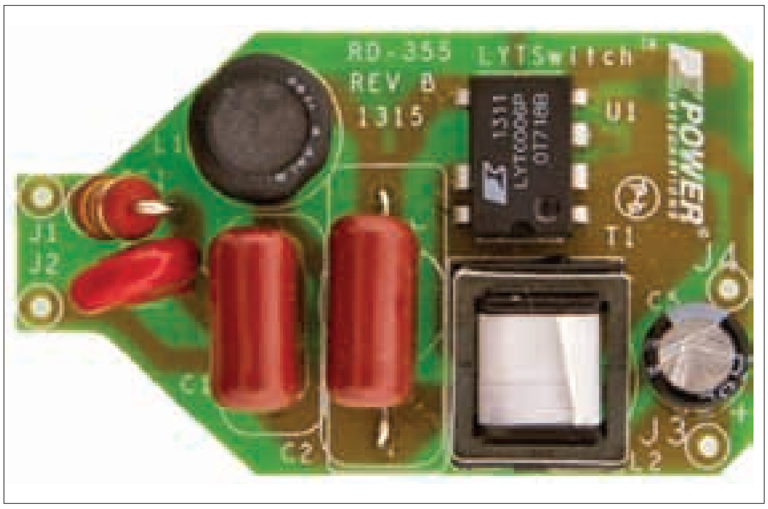
Regulation is maintained by skipping switching cycles. As the output current rises, the voltage into the FB pin will rise. If this exceeds V_{FB} then subsequent cycles will be skipped until the voltage reduces below V_{FB}. Current is sensed from R2 and filtered by C4, then fed to the FB pin for accurate regulation. The key to achieving good line regulation is in balancing the power inductor and sense resistor values after the minimum inductance has been calculated.

The bypass capacitor (C4) is connected between the FEEDBACK pin and the SOURCE pin and helps reduce power loss during output current sensing. The capacitor acts to sample-and-hold the feedback current information for the FB pin. No limiting resistor is required between the FB pin and C4, because the peak voltage will not exceed the maximum rating of the device.

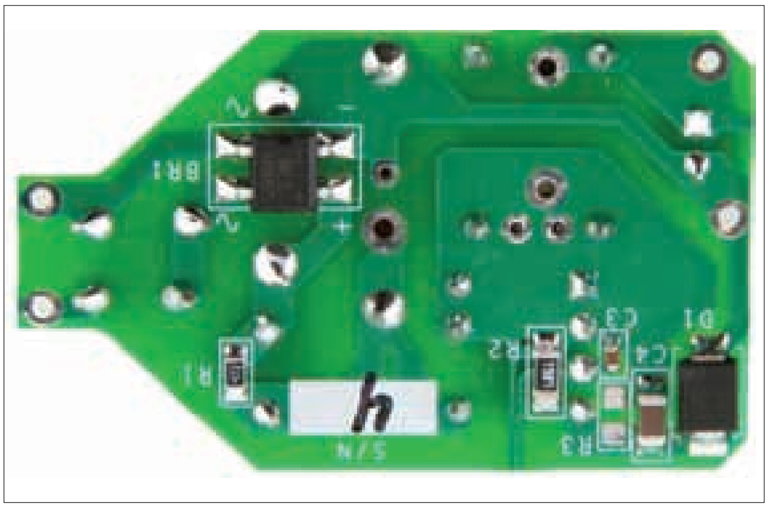
Optional, one shot, no-load protection circuit is incorporated in this design. In case of accidental no-load operation, the output capacitor is protected by VR1. Zener diode VR1 would need to be replaced after a failure.

In operation (LED retrofit lamp), the load is always connected, so VR1 can be removed to save cost. To protect during board level testing (in manufacturing) 40 V AC can be applied to the input; if no output current is measured then the load is not connected. This test will allow safe, non-destructive initial power up of the board, without the need of an O V protection circuit.

Samples of LYTSwitch-0in SO-8 and DIP packages are available now, priced at $0.29 each in 10,000-piece quantities. Datasheet and introduction video are available at **www.powerint.com/en/products/lytswitch-family/lytswitch-0**



Populated PCB reference design top side



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GaN Switching for Efficient Converters

GaN transistor switching speeds of 50 V per nanosecond and two orders of magnitude improvement in specific on-resistance over Silicon devices improve volumetric and conversion efficiency in any power systems and has particular relevance to solar boost converters. GaN Systems novel switch topology maximizes these advantages whilst reducing cost of manufacture. By designing CMOS integrated driver solutions upon which the GaN die is mounted directly in a stacked chip assembly – combining the switch, its driver, sensors and customized interface circuitry – helps to ease design-in these new devices.

Girvan Patterson, CEO GaN Systems Inc., Ottawa, Canada

GaN Systems novel switch is formed from a sea of source and drain islands with a common gate region running between them (see Figure 1). This results in up to four times reduction in the die area occupied by a transistor of given on-resistance and simplifies the semiconductor processing required, thereby minimizing manufacturing cost. In addition high breakdown voltages, in excess of 1200 V, can be achieved with this topology. The current in each source island flows directly from the die through a copper post into the interconnect pattern on the surface to which the die is mounted. Initially produced using GaN on SiC processes, these devices are now migrating to GaN on Silicon.

Each drain island is connected by a through-substrate-via to a common connection pad on the back of the die. In this way no large current flows in on-chip metallization allowing high currents to be switched without danger of electro-migration. The construction allows flip chip assembly of the die eliminating the need for bond wires (see Figure 2). Conventional bonds represent significant inductance that contribute to high frequency switching transients and power loss in designs that take maximum benefit from switching speeds of the order of 50 V/ns.

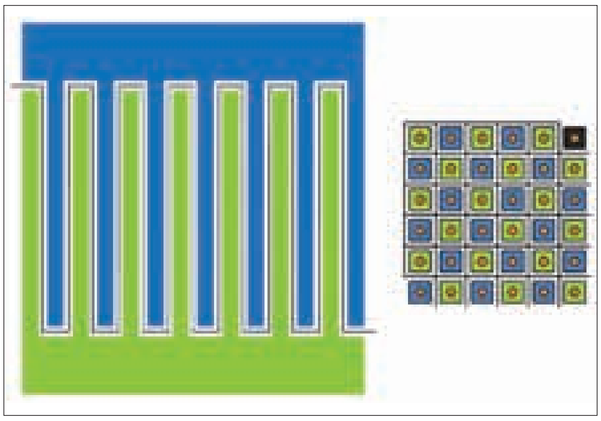


Figure 1: Compared to the traditional FET finger structure the GaN Systems switch is formed from a sea of source and drain islands with a common gate region running between them

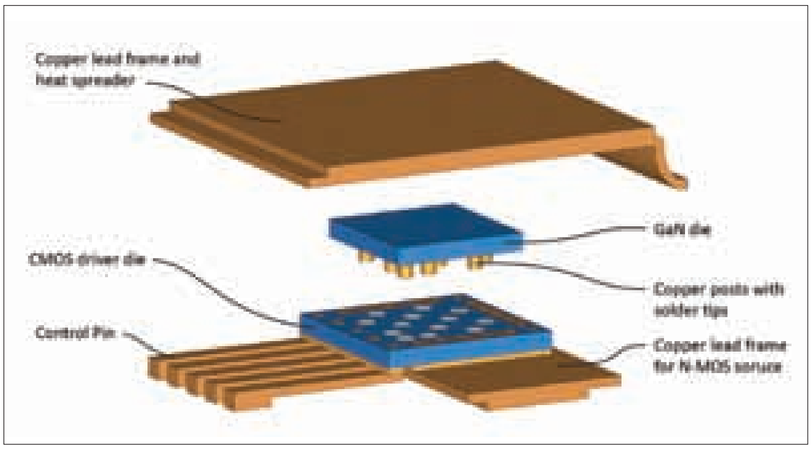


Figure 2: Flip-chip assembly eliminating the need for bond wires

Normally-off via cascode

Whilst processes are emerging that allow normally-off switching action using Island designs, the resulting degradation of on-resistance of these devices over equivalent normally-on solutions favors the adoption of the latter in high power applications.

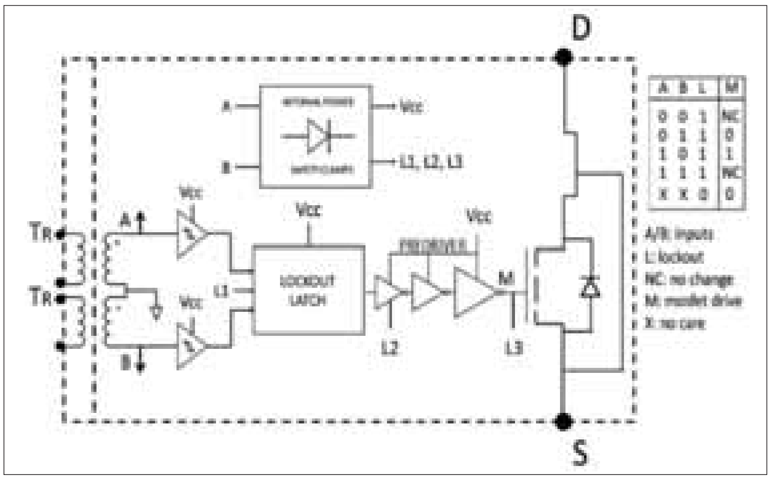
The inclusion of a cascode connected low voltage MOSFET switch in the source connection of the GaN device provides an equivalent normally-off switching action. To facilitate simple application of the switch in practical applications, the GaN switch can be directly mounted onto the drain pad of a low on resistance, low voltage NMOS transistor forming a chip-on-chip CMOS / GaN stack that represents a normally-off structure.

The NMOS transistor is integral to a CMOS driver chip that provides sensing of gate voltage and temperature of the switch and is able to control the slew rate of the GaN switch. First iterations of this switch and driver combination include differential inputs, and a Schmitt trigger. The circuit can be driven by a logic input or even a pulse transformer to facilitate galvanic isolation (Figure 3).

Future developments are planned that will include high voltage isolation within the driver chip using a SOS process. Adding multiple GaN switches then offers the prospect of forming complete half and full bridge isolated switch configurations (Figure 4).

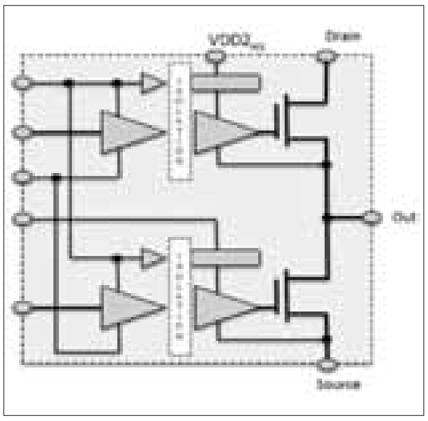
Thermal issues to be solved

Although the GaN die is thinned to 100 microns, thermal resistance remains a concern. Heat removal from the GaN die is



A	B	L	M
0	0	1	NC
0	1	1	0
1	0	1	1
1	1	1	NC
X	X	0	0

ABOVE Figure 3: **Block diagram of integrated driver / GaN switch**



ABOVE Figure 4: **A future isolated half bridge function using multiple GaN switch die and a SOS driver stack**

achieved separately from the heat that is generated by the MOSFET. This approach is needed to allow the MOSFET to remain within its temperature range. Therefore packaging issues were a prime concern during the design process.

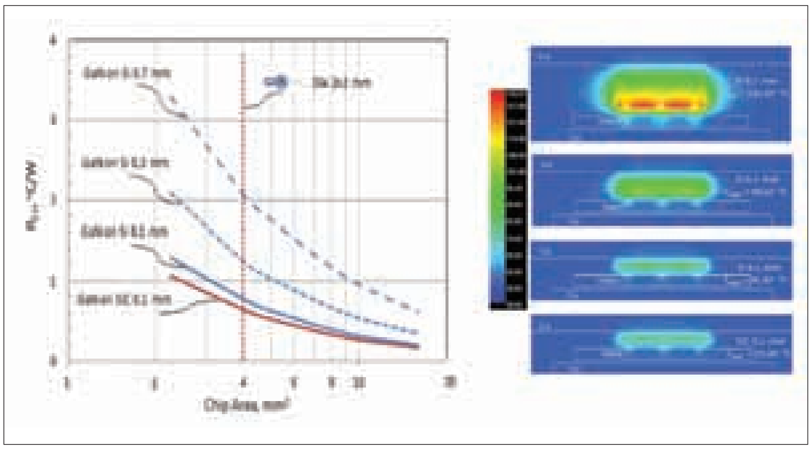
Because the GaN transistor has ten times the on-resistance of the low voltage MOSFET it is vital to achieve effective heat removal from the surface of the GaN device. Although there are 12 plus 1 copper posts mounted on the surface of the GaN transistor, more than 90 % of the heat is actually dissipated via the substructure of the GaN transistor. Currently most GaN transistors produced are built on SiC or Si substrates. GaN on Si devices produced using thick Si substrates are less prone to warp issues but the thermal resistance is problematic. However, if the Si substrates can be thinned to 0.1 mm, the thermal resistance of the SiC and the Si substrates are similar. The graphs shown in Figure 5 were drawn for the example where the GaN device dissipates 40 W and CMOS device dissipates 4 W. The upper and lower heat spreaders are held at 50°C. The combined devices (2 mm x 2 mm GaN and 4 mm x4 mm CMOS) are mounted in an equivalent PQFN structure outlined in the thermal cross section.

Electrical performance

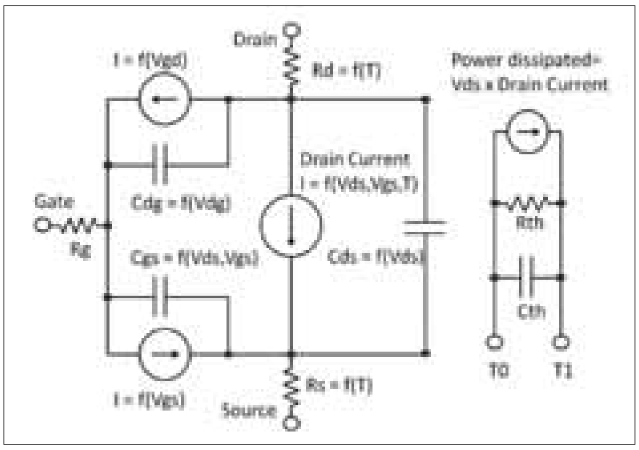
The CMOS circuit was designed to conform to the design rules of a conventional 1 micron CMOS fabrication foundry. SPICE models were supplied by the CMOS foundry and a SPICE model was developed for the GaN transistor. Particular care was taken to include within the GaN model a thermal network that includes several elements that enable the on-resistance and saturation current to dynamically track active area temperature. The model includes the thermal resistance of the GaN transistor and it also allows the user to include the package thermal resistance (Figure 6).

Keeping the model compact, and restricting it to a small number of nodes, allows for quick convergence in highly non-linear simulations such as power switching transients. In order to populate the model parameters with appropriate values, the GaN device has been characterized using pulsed IV and CV measurements over bias and temperature.

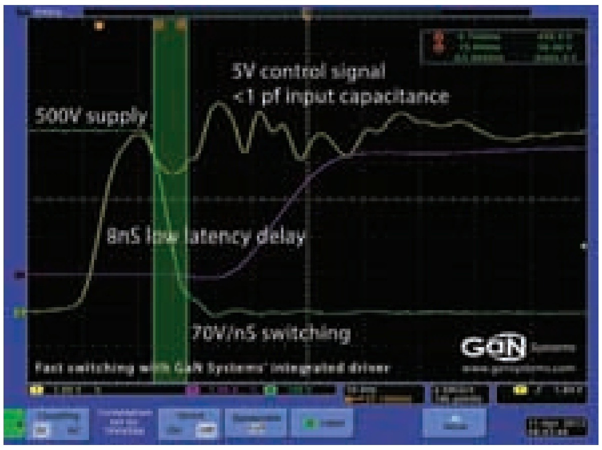
Consideration was given to process corners and statistical variations. Systematic verification of the device behavior under various modes of operation, including power switching load lines, completes the modeling process. Co-simulating the transient response of the GaN transistor with the CMOS driver and the package parasitics provides a realistic prediction of the electrical and thermal performance of the device in a power switching application. The CMOS / GaN hybrid was designed to be capable of being driven by an isolating pulse transformer. Galvanic isolation allows for the device to be used in the upper section of a half bridge. This isolation, if

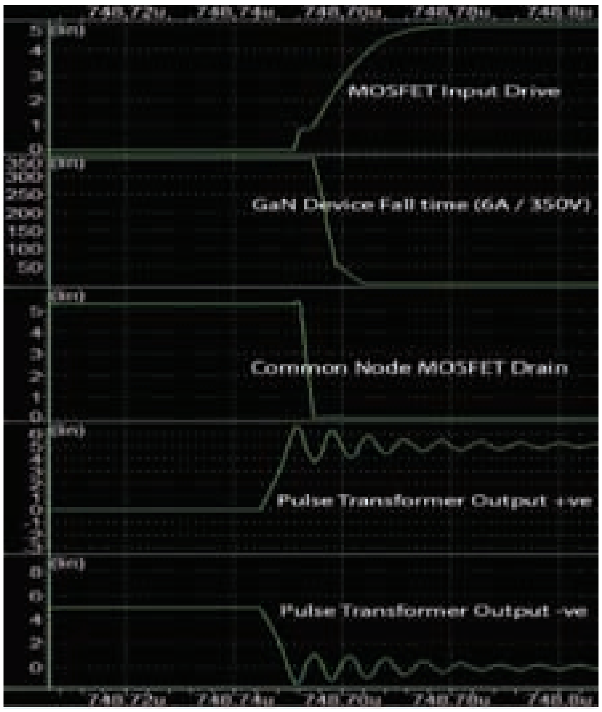


ABOVE Figure 5: **Thermal resistance and surface temperature of GaN devices**



LEFT Figure 6: **Block diagram illustrating the elements used in the electro-thermal non-linear model developed for the GaN HEMT**

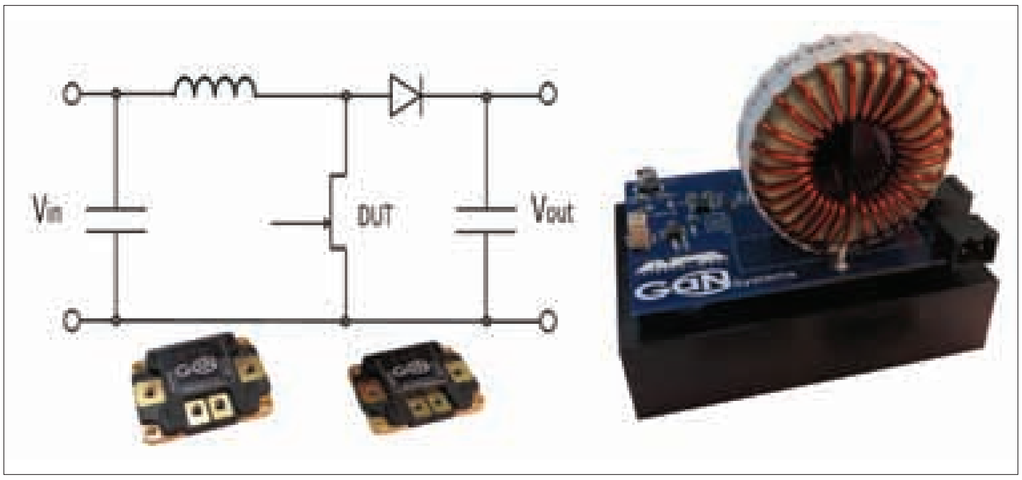




achieved at low cost can also be used to alleviate ground loop problems that may occur when driving the lower section. The simulated results include the pulse transformer SPICE model.

The delay from the rise of the input to the Schmitt circuit to the MOSFET turning-on is less than 5 ns. The GaN transistor is

ABOVE & RIGHT Figure 7: Simulated and measured results including an isolation pulse transformer (above), CMOS circuit and GaN transistor



LEFT Figure 8: Basic schematic, PQFN GaN semiconductors, and realized PV boost converter

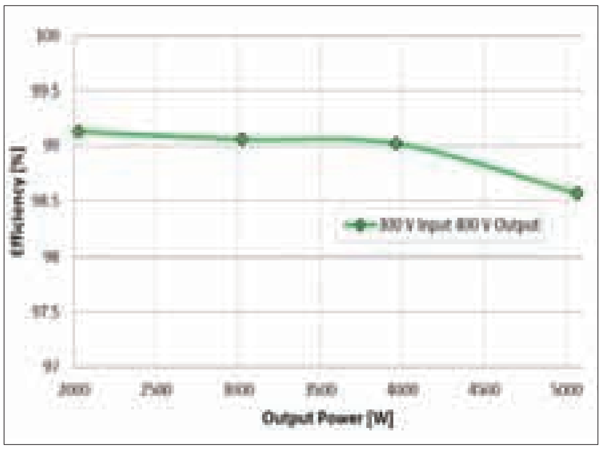
fully on within 15 ns of the input signals reaching the trigger levels of the Schmitt circuits. The input capacitance of the Schmitt circuits is less than 1 pf (Figure 7).

The GaN transistor and CMOS circuit were assembled in a prototype PQFN package. Given a resistive load of 60 Ω the 1200 V GaN transistor cascoded with the CMOS / MOSFET is able to achieve a 350 V transition within 10 ns. The delay from the pre-driver transition to the completed output swing is less than 15 ns. The overall delay time from the output of the isolating pulse transformer is approximately 20 ns – the CMOS circuit having added 5 ns as shown in the screen shot of Figure 7 (right).

PV boost converter performance

The typical operating points for the Photo Voltaic (PV) string using central maximum power point (MPP) tracking can be between 150 and 350V. A simplified schematic of the test circuit used to evaluate the performance of the GaN transistor, the PQFN GaN transistor and CMOS circuit, and the realized converter are shown in Figure 8.

The converter was tested under two operating voltage conditions. First, a 200 V input was applied and a 400 V output was established. The output power was then swept from 750 W to 2 kW. The system maintained an efficiency of greater than 98.2 % over the entire operating range. Since there is so little loss in the converter power stage, only passive air cooling is necessary. Another series of tests were conducted where a 300 V input was applied and a 400 V output was established. Here, the output power was



LEFT Figure 9: Boost converter efficiency from 2 kW to 5 kW output power

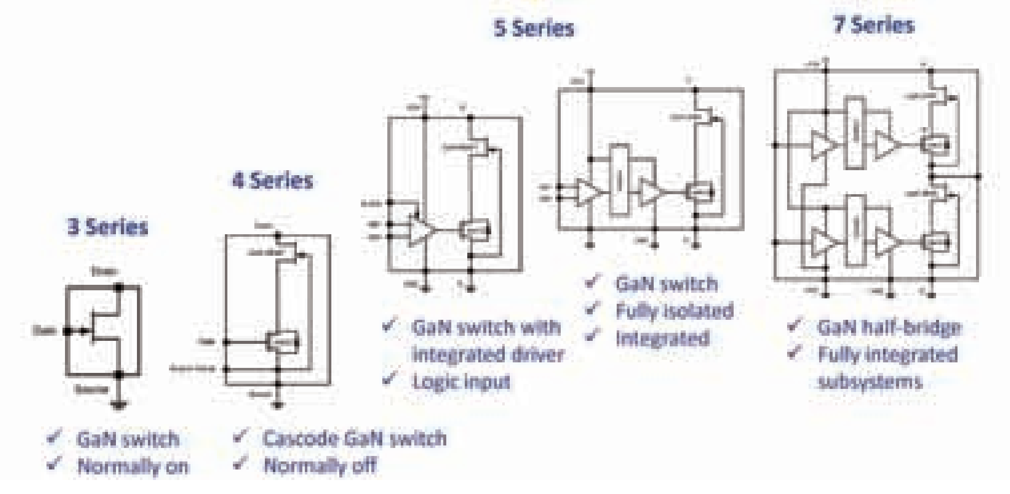


Figure 10: GaN Systems roadmap

swept from 2 kW to 5 kW. The system maintains over 99 % efficiency from 2 kW to 4 kW, and then dips slightly to 98.5 % at 5 kW (Figure 9). The converter has an approximate mass of 487 grams which equates to a gravimetric power density of approximately 10 kW/kg.

Figure 10 shows the roadmap, from individual GaN switches to fully integrated subsystems.

Conclusion

The described combinations of GaN switches and CMOS or SOS custom driver devices serve to accelerate the adoption of the advantages of GaN switches into power conversion and control systems by providing the system designer with a single device that is easily driven from logic signals. The inclusion of feedback from on-chip sensors and the ability to control switching slew rate open the prospect of tailoring the switch performance for given applications. In solar applications the high voltage operation, embedded galvanic isolation and high speed operation of these devices offer the prospect of higher switching speeds with improved conversion efficiency, lower component count, smaller size and reduced conversion loss.

Literature

"Development of Gallium Nitride Switches for Efficient Converters", PEE Special Session Power GaN for Highly Efficient Converters, PCIM Europe 2013, Nuremberg

High Voltage Gallium Nitride Devices for Inverters

Gallium Nitride (GaN) devices now demonstrate higher efficiency in inverter circuits for both solar and motor drive systems and in power supply building blocks such as the DC/DC LLC and the PFC. The article investigates how GaN is making such rapid performance progress and uses test results to illustrate what is now possible using GaN compared to recent SiC transistor performance. It then predicts future improvements that will continue to make GaN a more attractive alternative to either Si or SiC for high efficiency systems. **Umesh Mishra and Yifeng Wu, Transphorm Inc., Goleta, USA**

For the past four decades, the Silicon MOSFET designers have accomplished great results in density by converting from planar designs to trench and then decreasing the size of the trenches which reduces the specific on-resistance while increasing the capacitance.

At high voltage the super junction devices were created to reduce the EPI portion of the conduction losses of high voltage devices while again increasing the capacitance and changing its characteristics in the circuit. Subsequent generations of super junction devices minimized this capacitance problem in hard switched applications. Subsequent generations focused on either hard switched or soft switched in order to optimize the performance trade-offs specifically for that application. While recent improvements in super junction silicon devices reduce the output capacitance by 20 % and the reverse recovery charge Q_{rr} of the intrinsic body diode by 25 %, that is a far distance behind the effective Q_{rr} of the new GaN transistors which reduce Q_{rr} by 95 %. While GaN was behind SiC for power devices, its pace of progress has been rapid, overtaking that of SiC in many applications and thereby capturing the interest of systems manufacturers.

Rejecting some of the myths

When discussing the latest trends in HV GaN products is best to begin by rejecting some of the myths. First, dynamic on-resistance or current collapse has been eliminated for 600 V products back in 2009. Second there were many people who believed that it was not possible to make and qualify 600 V GaN on Silicon. With the recent JEDEC qualification of Transphorm's first generation of GaN-on-Si devices, we believe that has also been laid to rest as well as the issue that dislocations would prevent such an accomplishment.

The initial 600 V products include both diodes and GaN high electron mobility transistors (HEMT). The TPH3006PS HEMT combines low switching and conduction losses to reduce energy loss by 50 percent compared to conventional Silicon-based power conversion designs. The TO-220-packaged GaN transistor features low on-state resistance of 150 mΩ, low reverse-recovery charge of 54 nC and thus high-frequency switching capability. As illustrated in Figure 1, the HEMT is capable of switching 400 V in 3.5 ns. It is this fast switching that makes the higher performance achievable. While fast switching is expected with GaN devices, the low capacitance of the GaN HEMT improves the performance in resonant switching more than expected.

Also available in industry-standard TO-

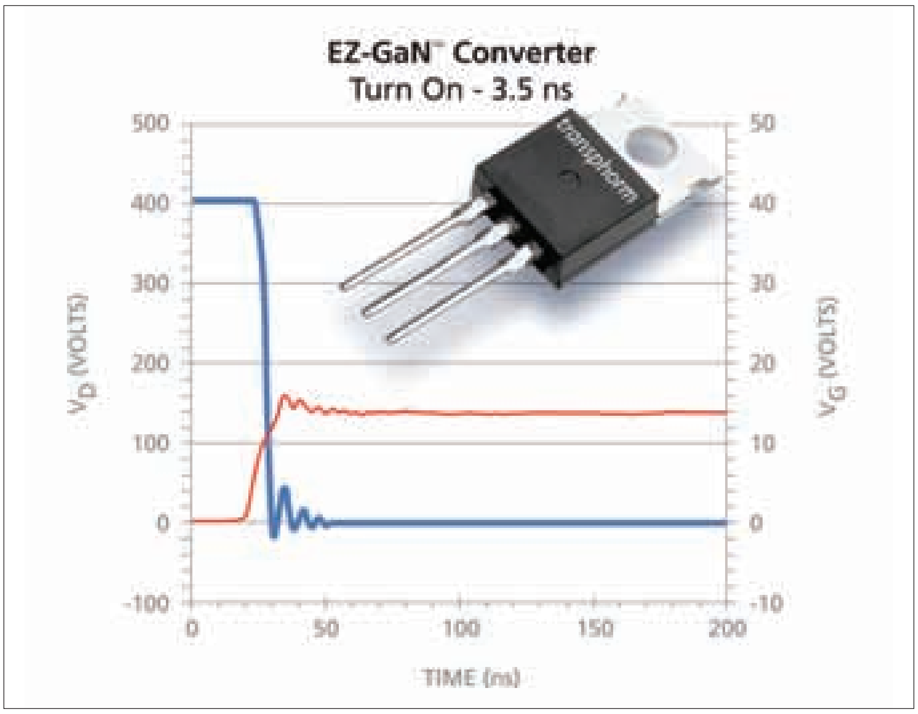


Figure 1: Switching characteristics of the TPH3006PS HEMT

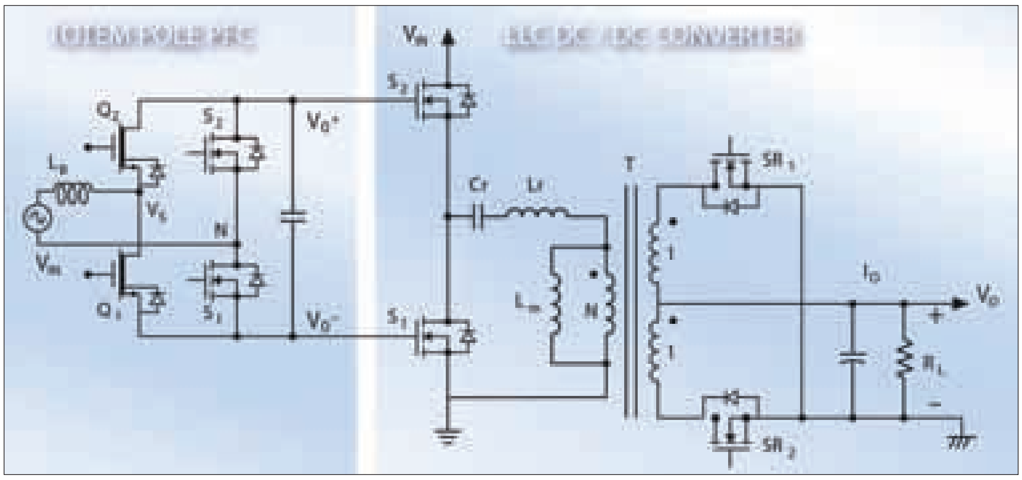


Figure 2: Off-line 1 kW 48 V power supply reaches a peak efficiency of 97.5 percent utilizing GaN devices

220 packages, the TPS3410PK and TPS3411PK GaN diodes offer 6 A and 4 A operating currents, respectively, with a forward voltage of 1.3 V. In addition, three application kits – PFC (TDPS400E1A7), Daughter Board (TDPS500E0A) and Motor Drive (TDMC4000E0I) – are available for rapidly benchmarking the in-circuit performance.

High-efficiency applications

With the implementation of a high efficiency off-line 1 kW 48 V power supply a peak efficiency of 97.5 percent has been demonstrated . The power supply design utilizes a 99 % efficient totem pole power factor correction (PFC) front end, combined with a 98.6 % efficiency LLC converter (Figure 2). A prototype circuit has been displayed at the PCIM Europe Conference and Exhibition.

Conclusion

GaN devices for high voltage have now moved out of the lab and into systems providing designers new tools with which to continue enabling greater systems performance. The completion of qualification of GaN at 600 volts clearly dispels several myths that were previously repeated in order to predict a very limited opportunity for GaN.

Literature

"Latest High Voltage GaN Devices for Inverters", PEE Special Session Power GaN for Highly Efficient Converters, PCIM Europe 2013, Nuremberg

Improved HiPak Modules for Power Electronic Applications

Today, IGBT based power electronic modules are the devices of choice for a vast range of applications from light-rail vehicles, heavy duty multi megawatts locomotives, to hundred megawatts HVDC installations. High reliability is the key element that needs to be addressed in all applications. ABB challenges the limits of both, the electrical and reliability specifications, by means of new, well-known and established technologies.

Gontran Pâques and Raffael Schnell, ABB Semiconductors, Lenzburg, Switzerland

Since its introduction nearly two decades ago, high power IGBTs developed to be the device of choice for power electronics applications covering a wide range of voltage and current. The ABB HiPak line-up suits the needs of applications like light-rail vehicles and industrial drives in the hundred kilowatts to lower megawatt range, multi megawatt electric locomotives and industrial drives and even HVDC converters of up to several hundred megawatts. The need for energy efficient motor drive solutions and transportation together with the urge to explore alternative energy sources such as wind-power, further drive the demand of power-electronic converters. Since the up-time of such applications is crucial for the whole economics, reliability requirements are key.

Improved HiPak platform

ABB is introducing an improved package for the complete HiPak module product portfolio (Figure 1) starting with the voltage range from 1700 V up to 3300 V. This improved platform is a one-to-one replacement of the actual products and there is no change neither in the electrical nor the thermal characteristics of the module. Its improved reliability is based on established technologies and designs that where developed and tested in the past few years. This new improved HiPak platform ensures that the HiPak standard fits also for the applications of tomorrow.

Figure1: Improved HiPak 2 module

Past designs of power modules often used a hard mold, usually epoxy. For the use in modern power modules epoxy has more and more issues to fulfill the large number of requirements such as high operating temperature range (-50 to 150°C), international fire and smoke standards and a high comparative tracking index (CTI) for short creepage distance. Moreover, the expoxy's thermal expansion coefficient does not match to the corresponding coefficients of the other materials in the module. This is needed, however, to fulfill the temperature cycling requirements. Furthermore, hard molds like expoxy contain elements that may cause electro-chemical reactions inside the module. Therefore, new designs usually

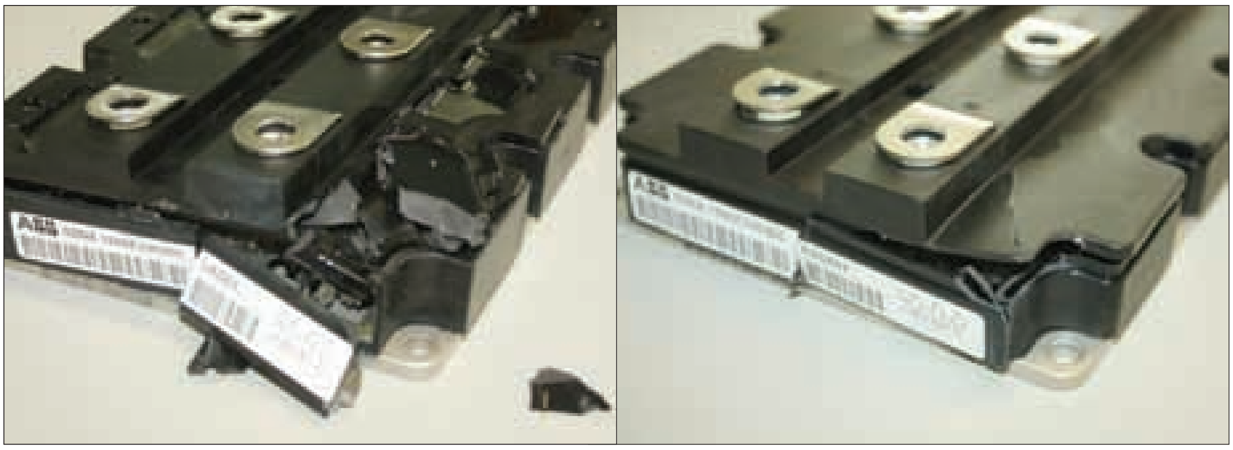


Figure 2: Old HiPak 2 module after destructive short-circuit test (left) and improved HiPak 2 module after same test

hold back from using epoxy.

With the help of a new housing material together with a reliable epoxy-less package design, the case temperature range for the improved HiPak is increased from -40°C to 125°C now from -50°C to 150°C. Moreover, the improved package now complies with the latest fire and smoke requirements that are needed for traction applications: NFF 16-101/102 I3 – F2 and CEN TS 45545 HL2 cat. R23. The epoxy-less module is designed such that all electric potentials are internally separated by gel and/or the housing. The mechanical robustness is guaranteed by a balanced distribution of the external mechanical load on all supporting parts. This measure also results in less damaging explosion behavior of the overall module. Figure 2 show a standard HiPak module (left) versus an improved one (right) after the destructive short circuit test. Both modules were exposed to exactly the same electrical overstress. It can clearly be seen that the improved module is less fractured.

Improved internal auxiliary connection

Internally, the formerly soldered auxiliary connections between gate-print and substrate are replaced by standard bonded aluminum wires. This well established technology allows for higher reliability and offers a redundant double wire connection (Figure 3). For an optimal bonding process, the supporting structure of the gate-print was redesigned, bringing a maximum stiffness and stability to the gate-print. The main advantage of the bonded connection is the in-line process control of the bond-joint quality by the bonding tool which measures the bond-foot deformation and thus can detect non-conformance. The soldering process on the other hand only allows a post process quality control which is usually an automated visual inspection. Nevertheless such a post process control does not guarantee a 100 % accurate inspection for instance of cold solder joints. In addition, the new design allows for a more stable gate-print assembly, improving the overall mechanical reliability of the module.

Improved power terminals

To improve the temperature cycling performance and the process reliability of the soldered terminal connection, an improved solder foot was designed for the main terminals. Specifically designed spacers guarantee a homogenous solder layer thickness. A similar concept with spacers was already successfully introduced a couple of years ago for soldering the substrate to the baseplate. In addition, the main terminal foot size and shape are designed in order to allow for a nice and reproducible solder meniscus (Figure 4). Moreover, the coating of the terminal has been changed. Meticulous analyses of the intermetallic layer have led to the conclusion, not to use nickel plated terminal feet. Nickel can lead to micro cavities in the intermetallic phase, resulting in a more sensitive solder interface with respect to cracking or delamination.

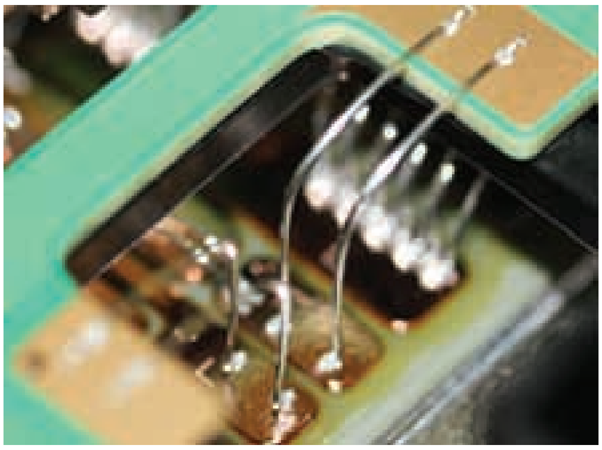


Figure 3: Improved auxiliary connection

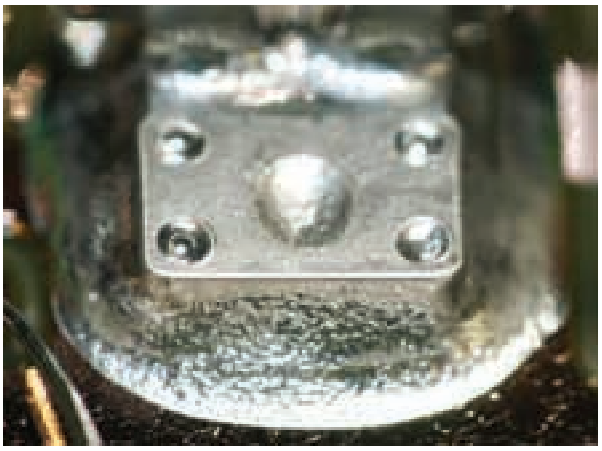


Figure 4: Improved main terminal foot

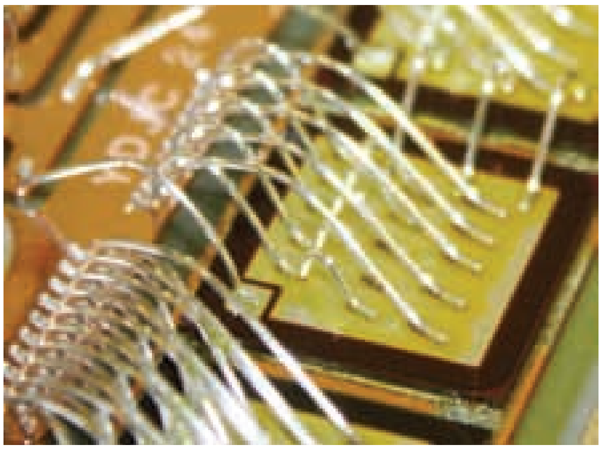


Figure 5: Improved wire-bonding layout

Improved wire-bonding

To improve the power cycling capability the emitter side wire-bonding parameters have been improved and optimized by using the latest in-process control options offered by new bonder generations. In addition, so called stich-bonds (Figure 5) are used. This design is a trade-off between utility (better fatigue behavior) and the needed bond area. The result is a boosted power cycling capability of about a factor 4 (Figure 6). The targeted 10 % capability is 2 million cycles for $\Delta T = 60$ K and at T_{vj}, max = 150°C. Our actual achievement indicates even better results.

Many small improvements

Besides the main technological and design improvements, many small improvements have been realized to ensure both, a reliable and producible fabrication process. Boosting the overall quality of our fabrication processes we achieved a major overall module quality increase. Some of these small improvements are for example

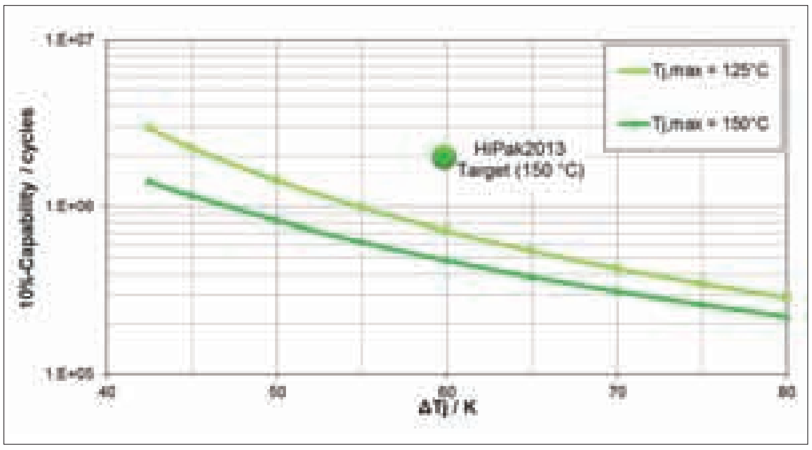


Figure 6: **Improved power cycling capability**

the solder-stop-free substrates allowing for a cleaner soldering process, the improved gate-print contact metallization for a better auxiliary terminal lead-free soldering process and a reliable bonding connection.

Qualification of the improved platform

The qualification of the improved HiPak platform is on-going and close to completion. Of course, all the relevant tests are performed. These include shock and vibration, temperature cycling, power cycling and temperature humidity bias. All incorporated technologies and design elements have successfully passed the verification tests and the final product already passed most of the qualification tests. The results are better or at least equal for every test compared to the current package.

The roll out will start with the 3300 V 1500 A HiPak2 SPT+ module and will be followed by the 1700 V SPT+ modules. In a first step, all low-voltage housings (E, N and M) will be replaced. In a second step, the improvements will be made available for the high-voltage housings (G, J and P). The roll out of the first module type will start in the third quarter 2013.

Conclusion

In the scope of improving the overall reliability performance of the HiPak module platform, ABB has developed an improved package based on well-known and established technologies. This package satisfies the increased reliability expectations without changing the electrical and thermal behavior, thus allowing the costumer for a one-to-one replacement without any need for requalification. This concept of improving well established processes and design elements and roll out on an existing product platform proves that substantial quality and reliability gain can be achieved without the need for the customer to redo a costly and time consuming design-in.

Parallel Switch Increases Efficiency of Power Module for PV Inverters

As the solar market matures, electronic power designers are faced with new challenges in inverter designs. The older less efficient two level designs will simply not meet next generation requirements, nor compete successfully in the marketplace. Increasing the efficiency and using a higher switching frequency is becoming the norm. To add to the complexity, customers are also requesting a higher DC input voltage to the inverter. **Mark Steinmetz, Field Applications Engineer, Vincotech, Unterhaching, Germany**

Many customers are looking at ways to reduce overall systems cost, not only in the inverter, but the number of panels and connections used. By increasing the panel array voltage to the system, it lowers the total DC current while increasing the rated power for solar inverter. This can result in significantly lower costs for the DC infrastructure as well as the overall balance of system costs. Since the power of the solar inverter system is limited mainly by the current, the power can be substantially increased by increasing the operating voltage, resulting in additional cost savings. This system configuration simplifies the inverter design since a DC boost is not required, lowering the cost to the inverter. That's why the panel and inverter voltage is set to increase to 1000 V and even 1500 V [1, 2].

The focus on the technological side of the inverter market has been to increase efficiencies up to 98 % or higher, that's becoming increasingly important to engineering, procurement and construction firms (EPCs) as they're looking to price projects [3]. Efficiencies are improving for two main reasons - the power semiconductor components and the topologies of inverter have gotten better, leading to overall improvements in inverter technology. The race is on for higher inverter efficiencies, voltages, controls and standards [4].

As the market changes from a lower efficiency of 95 % to a goal of 99 % using increasing panel voltage, inverter designers must look into innovative ways to achieve this while keeping costs in check. Thus Vincotech has introduced several new power modules that address increased efficiency at high power ranges.

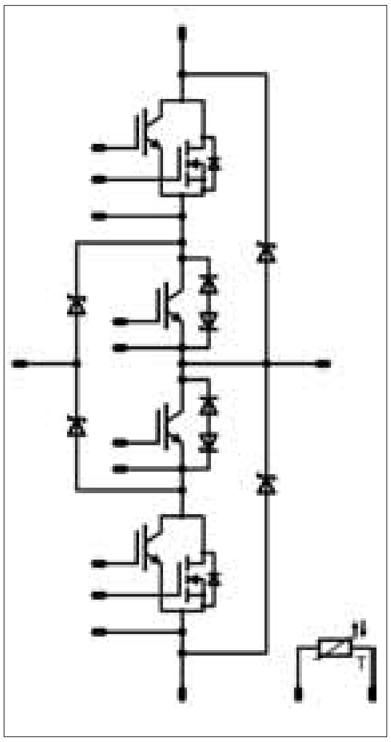


Figure 1: **The Parallel Switch is realized by replacing the reverse recovery diode with a smaller standard MOSFET than rated IGBT**

The parallel switch – a cost effective solution

The next generation inverter designs now use a three-level Neutral Point Converter (NPC) approach. This topology is a proven and reliable design approach which has been used by UPS manufactures. Its advantages have also been published in a number of white papers. The outer switches are primarily MOSFETS, needed for their high switching characteristics. Low saturation IGBTs are selected for the inner switches, which switch at line speed. This switch combination is well suited in

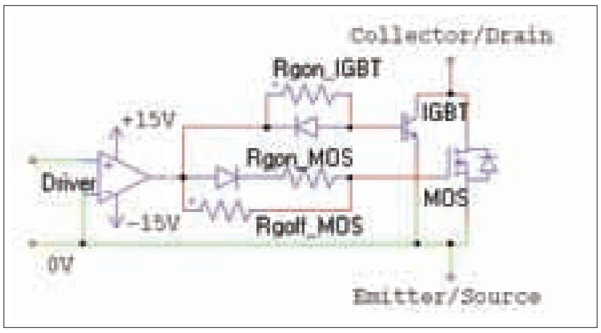


Figure 2: **Example of driver with separate gate control for MOSFET**

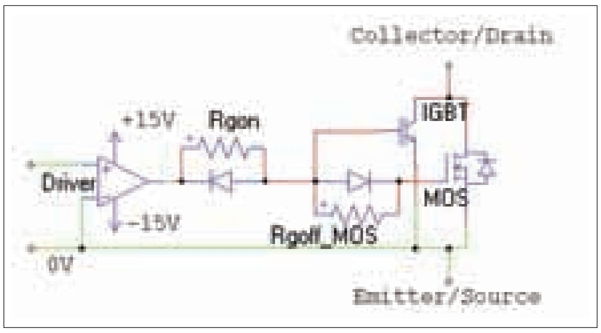


Figure 3: **Single Gate control using a simple circuit with a fixed delay**

Input Voltage = 1200V	Power Out @ 12kHz	T junction avg.@ 12kHz	Power Out @ 16kHz	T junction avg.@ 16kHz	Power Out @ 20kHz	T junction avg.@ 20kHz
OutBuck Switch	20.84	89.48	22.45	90.21	24.07	90.95
OutBuck Diode	15.2	88.19	15.22	88.2	15.24	88.22
OutBoost Inv D.	0	80	0	80	0	80
OutBoost Switch	20.39	90.54	20.39	90.54	20.39	90.54
Out Boost Diode	0	80	0	80	0	80
Stage Losses	112.85 W		116.11 W		119.39 W	
Efficiency	98.780%		98.746%		98.711%	

Table 1: Efficiencies of the Parallel Switch at higher switching speeds

low to medium low power rated inverters – 5 kW to 15 kW.

However, as the size in the inverter is increased (i.e. above 15 kW), the MOSFET starts to lose its benefits due to its on-resistance (R_{DSON}). Thus, an IGBT with good high switching frequency characteristics such as Fairchild Semiconductor's FGL40N120ANDT is now selected. Although a good alternative, this too has its limitations. The losses and overall efficiency starts to fall off at higher frequencies. As the cost of copper has significantly increased affecting inductors and filters, along with the higher cost of electrolytic capacitors, designers are looking to use higher switching frequencies to reduce these components in size and the number used.

To address this higher frequency requirement, Vincotech has developed a novel switch – the Parallel Switch (see Figure 1). By replacing the reverse recovery diode with a smaller standard MOSFET than rated IGBT, the overall switching losses (both on and off) are further reduced to the IGBT. In addition, the Parallel Switch also aids in efficiency in light through high load ranges.

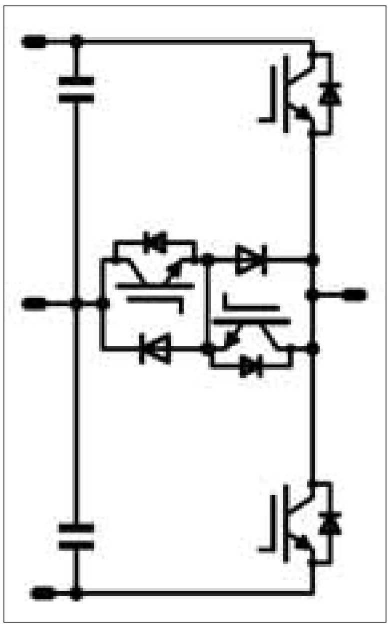


Figure 4: Single-phase Mixed Neutral Point Converter

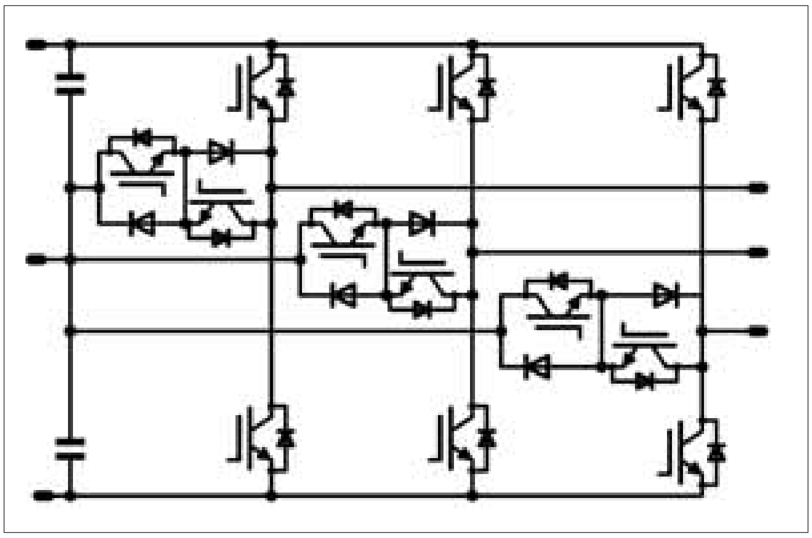


Figure 5: Integrated three-phase Mixed Neutral Point Converter

Gate control

The designer must take into account the relationship between turning on and off the MOSFET in conjunction with the IGBT. Since the MOSFET switches faster than the IGBT, it must be turned on before the IGBT and then delayed in turning it off after the IGBT. Typically, this is in the range of 100 ns to 200 ns. The following solutions are examples to accomplish this:

1. Separate gate signals by two independent drivers. This allows the designer to fine tune the Parallel Switch in an optimum fashion while reducing complexity and design time.
2. Driver with separate gate control for MOSFET. This will allow the designer to control the operation between the two switches. Figure 2 is an example of this type of circuit.
3. Single Gate control using a simple circuit with a fixed delay. If the designer can determine the best delay between the two switches, he can implement this in a discrete fashion. Figure 3 is a typical circuit to accomplish this.

This topology has been implemented in several standard NPC modules including FZ-P96706NPA045FP – 1200 V (600 V x 2), 50 A, reactive power rated and FZ06NPA070FP01-P969 – 1200 V (600 V x 2), 70 A, reactive power rated.

Efficiency at higher voltages

The Parallel Switch concept can be further extended by using 1200 V components. Although 1200V components have higher losses in comparison to 600 V rated types, using a small Silicon Carbide MOSFET in parallel with the IGBT increases the switching efficiency of the outer switches. Selecting two 1200 V low saturation IGBT's for the inner switches, the stack now can withstand high voltage inputs (> 1500 V). This is a much lower cost solution versus using larger Silicon Carbide MOSFETS in the buck switch section. Using Vincotech's flowSOL simulator along with its highly accurate database of components, the efficiency for this advanced technology at higher switching speeds can be increased to 98.7 % and higher (see Table 1). Although the switching frequency increases, the total efficiency of the module remains practically the same from 12 kHz (98.78 %) to 20 kHz (98.711 %).

Vincotech is addressing the need to increase efficiency at a high power range – Mixed Neutral Point Converter -

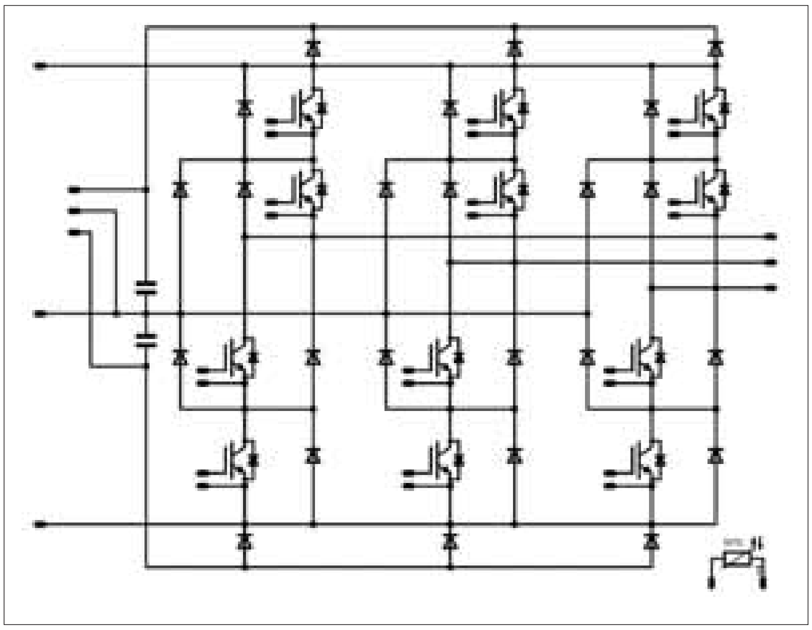


Figure 6: High Voltage module capable of 2400 V at 400 A

flowMNPC4w, i.e. "Wide Body." These new lines of modules offer the benefits of [5] high efficiency (>99 % at 8 kHz), supports up to 250 kW output power, reducing output filter sizes and losses by >50 %, reduced electromagnet noise by >50 %, and feature low inductance (typ 5nH), allowing switching frequencies of 20 kHZ or higher.

This new line of advanced topology modules offer the designer a wide range of both power and configurations including both single phase (Figure 4) and integrated three-phase types (Figure 5):

Single Phase (1X flowscrew4w) [6] include the types 70-212NMA300SCM208P (1200V/300A), 70-212NMA400SCM209P (1200V/400A), and 70-212NMA600SCM200P (1200V/600A).

The unique packaging design used in these modules offer a low inductive interface for integration into a three phase system while allowing a flexible assembly for better thermal spreading [7]. Three-phase can be realized (3X flowscrew4w) offering the designer an integrated approach with a high power screw interface. In addition to this product line, Vincotech is also introducing an Ultra Fast High Voltage module 70-W624N3A320SH-M400F capable of 2400 V at 400 A, i.e. 260 kVA, (see Figure 6).

Utilizing Vincotech's packaging technology (Figure 7) – a very low inductance (5 nH) complete 3-phase inverter power module offers the designer flexibility, ease of use, less design time, and tested reliability.

Literature

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[5., 6., 7] Frisch, Michael. "Product Overview and Roadmap, NPC." November 14, 2011

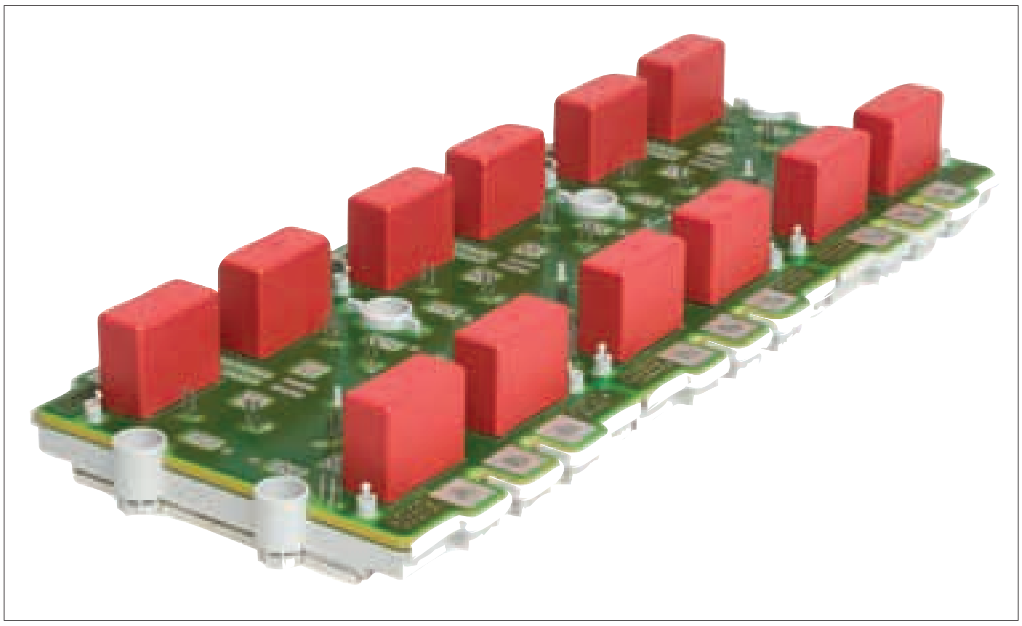

Figure 7: Very low inductance complete 3-phase inverter power module

EI 3" Modular Bobbin Range

Miles-Platts, the premier manufacturer of precision plastic injected coil bobbins and technical moldings, has recently launched a new concept in bobbin technology which combines the availability of standard-off-the-shelf product with the flexibility of custom options. Available through Dexter Magnetic Technologies, the Miles-Platts modular single phase EI 3" lamination bobbin is the latest in thermoplastic coil bobbin design. Sold as two units, bobbin combinations are available in nine standard sizes allowing design engineers to choose stack heights ranging from 2.00 inches to 6.00 inches in ½" increments. Tongue and groove construction around the join lines facilitate easy bobbin assembly and provides extended creepage distances. Available as standard in Zytel or Rynite to meet Class F 155c or Class N 200c insulation systems. Other engineering polymers available on request.

The EI 3" Modular Bobbin Range offers a robust design for large wire gauges and winding. Further details can be found at www.dextermag.com or by downloading the datasheet at:

www.dextermag.com/upload/Dexter_Miles-Platts_ Modular-Bobbin-Range_2013.pdf

1 MHz Buck Converter GaN Demonstration Board

EPC's EPC9107 is a fully functional buck power conversion demonstration circuit featuring 9 -28 V input to 3.3 V, 15 A maximum output current. It uses the EPC2015 eGaN FET in conjunction with the TI LM5113 100 V half-bridge gate driver. The EPC9107 demonstrates the reduced size and performance capabilities of high switching frequency eGaN FETs when coupled with this dedicated eGaN driver. The complete power stage including eGaN FETs, driver, inductor and input/output caps comes in 0.5" × 0.5" layout. To assist the design engineer, the EPC9107 demonstration board is easy to set up and contains various probe points to facilitate simple waveform measurement and efficiency calculation.

www.epc-co.com

MiniSKiiP Dual Module Ranges Up to 90 kW

Semikron's MiniSKiiP is now available for power ranges up to 90 kW. The portfolio of the new MiniSKiiP Dual covers 150-300 A/650 V, 150-300 A/1200 V and 100-200 A/1700 V. Thus Spring Technology is available for power ratings higher than 40 kW. The benefits: lower material costs as compared to traditional inverter designs because the expensive bus-baring of the load connectors can be replaced by a cost-efficient PCB connection. The spring contacts make the layout of the PCB simpler and more flexible because the PCB does not need holes for soldering pins. Also, the springs allow for a more flexible connection between the PCB and the module than a soldered joint, which adds extra benefits particularly under thermal and mechanical stress. The MiniSKiiP Dual's output of up to 90 kW requires higher current-carrying capability of the PCB, which e. g. can be achieved by using a 210 µm standard metal coating on the PCB. This allows for load currents up to 180 A RMS, which used to be reserved for modules with screw mounted busbars.

www.semikron.com

Safety Disc Capacitors

KEMET offers new radial through hole ceramic safety disc capacitors. Safety Certified Capacitors are classified as either X and/or Y capacitors. Class X capacitors are primarily used in line-to-line (across-the-line) applications. In this application there is no danger of electric shock to humans should the capacitor fail, but could result in a risk of fire. The class Y capacitor is primarily used in line-to-ground (line by-pass) applications. In this application, failure of the capacitor could lead to danger of electric shock. Typical applications include alternative energy, industrial/lighting, medical, and telecommunications. These 900 Series ceramic disc capacitors are specifically designed for interference-suppression in AC- line filtering applications. Having internationally recognized safety certifications, they are well-suited for applications that require keeping potentially disruptive or damaging line transients and EMI out of susceptible equipment. They are also a solution for suppressing line disturbances in motors, relays and switching power supplies.

www.kemet.com

650 V/105 A Power MOSFETs

Vishay added 650 V power MOSFETs to its E Series family of devices. These 22 new devices in eight different packages offer an extended on-resistance range from 30 mΩ to 600 mΩ at 10 V and broaden the maximum current ratings from 6 A to 105 A. Based on Siliconix' Superjunction Technology, the 650 V E Series MOSFETs offer extended headroom for applications that require additional input-voltage safety margin such as renewable energies, industrial, lighting, telecommunications, consumer, and computing. On-resistance varies by type from 600 to 30 mΩ and gate charge from 21 to 405 nC resepectively.

www.vishay.com

Enhanced Gate MOSFETs

ST's new STripFET™ VII DeepGATE™ MOSFETs are available for 80 and 100 V breakdown voltage. They feature an enhanced MOSFET gate structure, which lowers on-resistance while also reducing internal capacitances and gate charge. The devices also have high avalanche ruggedness to survive potentially damaging hard conditions, which makes them a strong choice for automotive applications. STripFET VII DeepGATE technology is suited for systems operating at DC voltages such as 48V, which is widely used in telecom applications; devices with 80 V or 100 V rating have adequate 'safety margin' to withstand typical over-voltage surges in a 48 V system and are also chosen for highly rugged performance in 12 V or 24 V automotive applications. Other technologies, such as Mdmesh Superjunction, are needed for higher voltage ratings such as 600 or 650 V. MDmesh devices provide suitable safety margin for applications such as AC/DC power supplies, lighting ballasts and display panels. ST recently announced a new high-efficiency MDmesh family featuring low gate charge for use in resonant converters.

www.st.com/pmos

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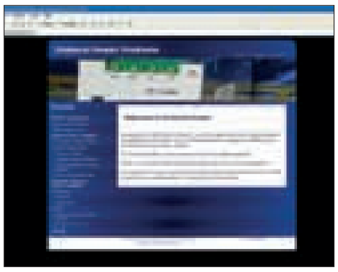

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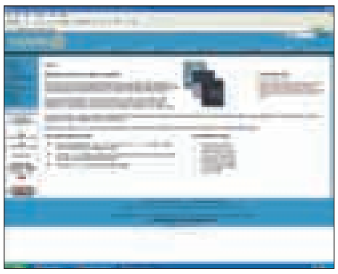

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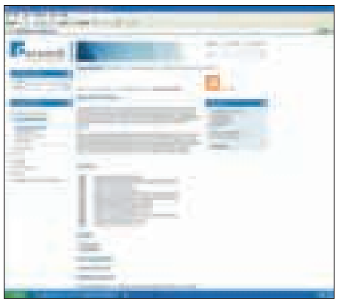

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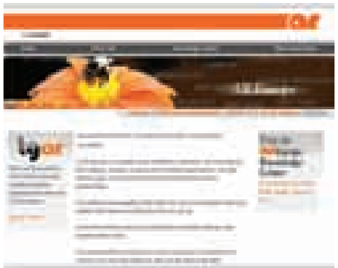

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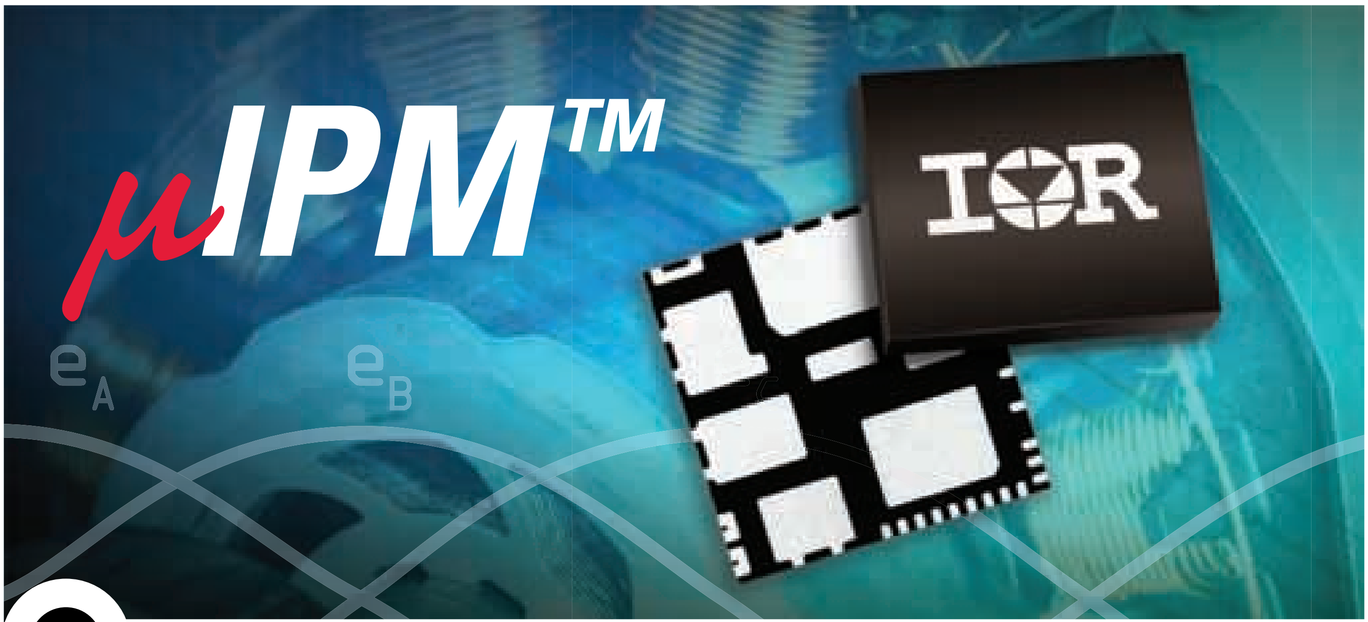


Innovative Power Module Reduces System Size

μIPM™ Power Modules Deliver up to 60% Smaller Footprint

Specifications:

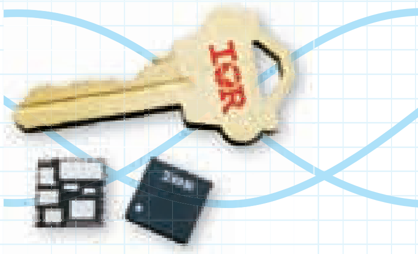
Part Number	Size (mm)	Voltage	IO (DC@ 25°C)	Motor Current**		Motor Power VO=150/75VRMS	Topology
				w/o HS	w/HS		
IRSM836-024MA	12x12	250V	2A	470mA	550mA	60W/72W	3P Open Source
IRSM836-044MA	12x12	250V	4A	750mA	850mA	95W/110W	3P Open Source
IRSM836-025MA	12x12	500V	2A	360mA	440mA	93W/114W	3P Open Source
IRSM836-035MB	12x12	500V	3A	420mA	510mA	108W/135W	3P Common Source
IRSM836-035MA	12x12	500V	3A	420mA	510mA	100W/130W	3P Open Source
IRSM836-045MA	12x12	500V	4A	550mA	750mA	145W/195W	3P Open Source

Features:

- 3-phase motor control IC
- 12x12x0.9mm PQFN package offers up to 60% smaller footprint
- Eliminates the need for heat sink
- DC current ratings from 2A to 4A
- Voltage range of 250V – 500V

μIPM™ Advantages:

- Shortens design time
- Shrinks board space requirements
- Simplicity - Eliminates Heat Sink
- Replaces more than 20 discrete parts to deliver a complete motor drive stage
- Slashes assembly time and cost
- Simplifies procurement and inventory management
- Reference design kits available for quick evaluation on any 3-phase motor



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THE POWER MANAGEMENT LEADER

* IR's iMOTION™ (ai mo shan), representing the intelligent motion control, is a trademark of International Rectifier
** RMS, Fc=16kHz, 2-phase PWM, ΔTCA=70°C, TA ≈ 25°C