# POWER ELECTRONICS EUROPE

ISSUE 8 – December 2014 www.power-mag.com


## DC/DC POWER MODULES

### Power Modules to the Rescue


## Hit the Road!

### with Micrel Power Modules


THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY


**Also inside this issue**

**Editor** Achim Scharf
Tel: +49 (0)892865 9794
Fax: +49 (0)892800 132
Email: achimscharf@aol.com

**Production Editor** Chris Davis
Tel: +44 (0)1732 370340

**Financial Manager** Clare Jackson
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034

**Reader/Circulation Enquiries**
Perception-MPS Ltd.
Tel: +44 (0) 1825 749900
Email: dfamedia@pmps.info

**INTERNATIONAL SALES OFFICES**
Mainland Europe:
Victoria Hufmann, Norbert Hufmann
Tel: +49 911 9397 643 Fax: +49 911 9397 6459
Email: pee@hufmann.info

Armin Wezel
phone: +49 (0)30 52689192
mobile: +49 (0)172 767 8499
Email: armin@eurokom-media.d

Eastern US
Karen C Smith-Kernc
email: KarenKCS@aol.com
Western US and Canada
Alan A Kernc
Tel: +1 717 397 7100
Fax: +1 717 397 7800
email: AlanKCS@aol.com

Italy
Ferruccio Silvera
Tel: +39 022 846 716 Email: ferruccio@silvera.it

Japan:
Yoshinori Ikeda,
Pacific Business Inc
Tel: 81-(0)3-3661-6138
Fax: 81-(0)3-3661-6139
Email: pbi2010@gol.com

Taiwan
Prisco Ind. Service Corp.
Tel: 886 2 2322 5266 Fax: 886 2 2322 2205

**Publisher & UK Sales** Ian Atkinson
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034
Email: ian@dfamedia.co.uk
www.power-mag.com

Circulation and subscription: **Power Electronics Europe** is available for the following subscription charges. **Power Electronics Europe**: annual charge UK/NI £60, overseas $130, EUR 120; single copies UK/NI £10, overseas US$32, EUR 25.
Contact: DFA Media, 192 The High Street, Tonbridge, Kent TN9 1BE Great Britain.
Tel: +44 (0)1732 370340.
Fax: +44 (0)1732 360034. Refunds on cancelled subscriptions will only be provided at the Publisher's discretion, unless specifically guaranteed within the terms of subscription offer.

Editorial information should be sent to The Editor, **Power Electronics Europe**, PO Box 340131, 80098 Munich, Germany.



Printed by: Garnett Dickinson.

ISSN 1748-3530



## COVER STORY


## Power Modules to the Rescue

The requirements for higher density boards and reducing system size are driving the need for smaller DC/DC solutions, resulting with the evolution of power modules. It took many years for the power module technology to arrive to the mass market. In the early days, it was very difficult to design power converters. At the time, they were entirely designed with discrete and leaded components or taken from a tap off a transformer. The reality was that designing power converters was considered a black art. There were very few experts in this field who had a great understanding of all aspects of power conversion. The design cycles took more than a year because of multiple design iterations were needed due to stability issues, component failure, or EMI issues caused by high di/dt or dv/dt and improper or constrained layouts that increased the amount of radiated EMI. Today there are an increasing number of suppliers offering power modules due to improvement in technology on many fronts. It is now time to take advantage of this new generation of power modules. The process of selecting a DC/DC power module is important and designers need to select the best solution in terms of value (performance and size) versus cost effectiveness. Full text on page 18.

Cover supplied by Micrel Inc.

# Power Semiconductors Superdeal in Final Stage

Late August Infineon Technologies and International Rectifier Corporation announced that they have signed a definitive agreement under which Infineon will acquire International Rectifier for $40 per share (a premium of more than 50 percent over the closing share price in August) in an all-cash transaction valued at approximately $3 billion. Infineon will fund the transaction using cash-on-hand and fully underwritten credit facilities of Euro 1.5 billion in total. Infineon's and International Rectifier's product portfolios are highly complementary, both companies underline. International Rectifier's expertise in low-power, energy-efficient IGBTs and Intelligent Power Modules, Power MOSFETs and Digital Power Management ICs will integrate well with Infineon's offering in power devices and modules. With International Rectifier, Infineon acquires an advanced manufacturer in Gallium Nitride on Silicon (GaN) based power semiconductors. This combination will accelerate and solidify Infineon's position in GaN discretes and GaN system solutions, improving its ability to pursue this strategically important technology platform with significant future growth potential. The transaction will result in a broad range of products creating a comprehensive provider in the market for Silicon-, Silicon Carbide- and Gallium Nitride-based power devices and ICs. The integration of International Rectifier will generate economies of scale through optimization of the combined entity's operating expense structure and through the acceleration of the ramp-up of Infineon's 300-millimetre thin wafer manufacturing capability. Infineon will also have a much broader and stronger regional scope. International Rectifier has a strong presence in the US, the important center of innovation especially in the Connected World, and will also help to improve Infineon's position in Asia. The increase in exposure to the distribution channel will allow Infineon to meet the needs of a broader range of customers. According to Oleg Khaykin, currently President and CEO of International Rectifier, this transaction provides significant value to our stockholders and opens new strategic opportunities for both our customers and employees. By combining two complementary providers in power management solutions, International Rectifier will benefit from Infineon's products and technologies, manufacturing and operational excellence and greater R&D scale.

End of October the waiting period under the Hart-Scott-Rodino Antitrust Improvements Act has been expired. Expiration of the HSR Act waiting period satisfies one of the conditions required to finalize the acquisition. The transaction remains subject to other closing conditions, including the receipt of additional regulatory clearances, and approval of the transaction by International Rectifier Corporation stockholders, the latter has been agreed in November.

Since Infineon holds the pole position in power semiconductors for a couple of years, the acquisition will give them the undisputed leadership with approximately 20 + percent market share. According to market researcher IHS, the global power semiconductor market (discretes and modules) in 2013 was valued at more than $15 billion. In 2012 International Rectifier hold the No. 1 position in the $6 billion power MOSFET market, followed by Renesas, Toshiba, Infineon, Fairchild and Vishay. In the $1.04 billion market for discrete IGBTs Infineon hold No. 1, followed by Fuji, Mitsubishi, Fairchild and Renesas. For the IGBT modules ($3 billion) Mitsubishi hold the pole position, followed by Infineon, Fuji, Semikron and Hitachi. Thus the combined revenues of both companies will give a push particularly in power MOSFETs which are well suited to be transferred to Infineon's 300-mm production lines.

Infineon's revenue in fiscal year (September end) rose to 4.320 billion Euros – an increase of 12 percent. For the whole of the 2015 fiscal year, revenue growth of 8 percent is expected. Regarding productivity, Infineon performs much better than the US-based fabs of IR. In particular 300 millimetre wafers translate into 30 percent less investment in relation to revenues. But IR, a $1.05 billion company, also runs a 200-mm fab in Newport/UK, here Infineon's CEO Reinhard Ploss refused to comment on closing or keeping this activity on occasion of the annual press conference end of November. IR Newport/South Wales focuses on analog and mixed signal markets and currently operates CMOS and power MOSFET processes. With a cleanroom area of 3,000 $m^2$, the 200-mm fab supports wafers at 0.35 µm feature size. IR already announced plans to restructure a number of its facilities across the world and its Newport facility was to be resized – better downsized - in several phases in 2015. Though IR's production will be continued but partially transferred to Infineon's fabs and the IR's organization will be integrated, the roughly 5,000 IR employees will face a phase of uncertainty – as Electronica has shown. And on the other hand – one of the major inventors in power semiconductors such as the first hexagonal MOSFET (HEXFET) in 1979 or the GaN-based power device platform in 2008 – will disappear while perhaps keeping the well-known brand. Consolidation or concentration of industry will be the name of the game in 2015!

We will not disappear – though the commercial conditions are not so favorable. Since this is the final issue in 2014, I wish all our readers a very merry Christmas and a good jump into 2015.

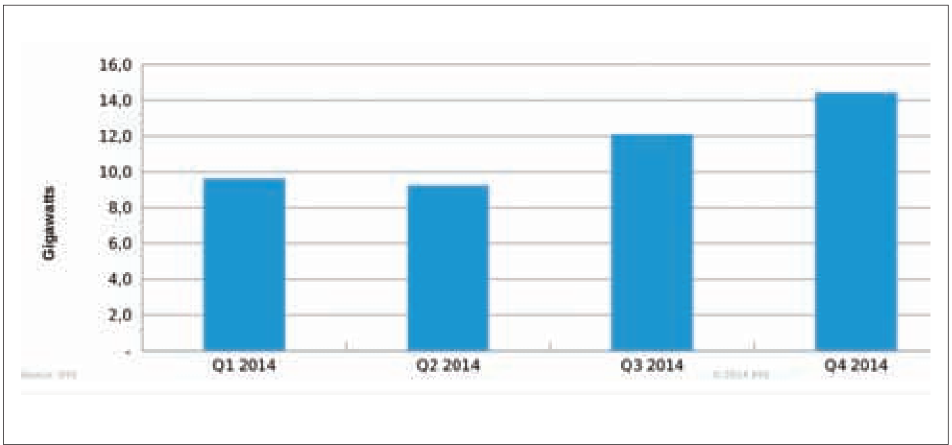
**Achim Scharf**
**PEE Editor**

# Solar Installations to Rise 20 % in 2014

Global PV solar installations will rise to 45.4 GW in 2014, with 32 % of this total, or 14.4 GW, coming in the fourth quarter, a 20 percent increase in installations from 37.8 GW in 2013.

Driven by strong demand in China and the United States, the final quarter of the year will again be the largest in terms of new installations. Market researcher IHS predicts that these two countries alone will account for more than half of all global demand in the final quarter of 2014. “Following a first half that saw declines in several key countries, the global PV solar market is undergoing a major acceleration in the final quarter of the year,” said Ash Sharma, senior director of solar research at IHS. “China and the United States will propel global growth. With China installing more than 5 GW and the United States installing 2.3 GW in the fourth quarter of 2014, these two countries will account for more than 50 percent of global installations during this period. The huge final quarter in China is expected to be only slightly higher than what was achieved in the same quarter of 2013—a figure that surprised many in the industry”. Unless new policy or targets are raised further, IHS predicts China’s annual growth to slow to 10 percent in 2015 - but still sufficient for the country to remain the largest end market globally. But several other countries achieved strong installations in the first half of the year, including the United Kingdom and Japan. However, there were also declines in Europe and in countries that typically undertake more installations toward the end of the year. This set the stage for a major rebound in installations during the second half of the year. However, Germany and Italy will see another year of market decline with only 2.1 GW and 0.8 GW of new installations in 2014, respectively, down from 3.3 GW and 1.7 GW in 2013.

www.ihs.com




**Global PV installations in 2014** **Source: IHS**

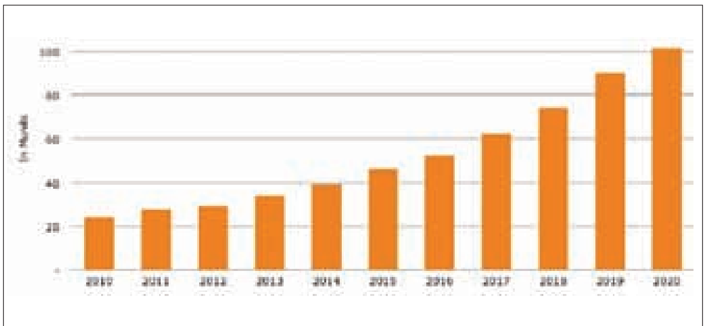
# Change in Inverter Industry

**The $65 billion inverter market by 2020 will be driven by multiple applications - electrification trends in transportation, the need for power conversion optimization for CO2 emission reduction, and the development of clean electricity sources. Such strong and sustainable drivers will make the inverter market grow.**

**“The largest markets in 2020 will be represented by motor drives, UPS, and PV”, explains Yole’s analyst Pierric Gueguen. “The strongest market growth will be featured by EV/HEV, with 18.3 % CAGR between 2013 and wind and UPS markets remaining almost flat”. The inverter market is heavily application dependent. However, there are some cross-market trends, companies with a good position within one inverter market segment are researching entry into other segments.**

**Companies like Alstom, ABB, Ingeteam, Siemens, and General Electric already offer products for two or more inverter segments. Some players have chosen vertical integration to optimize**

**their internal cost structure better target commodity-like markets, as well as to meet the severe cost requirements of the automotive industry. Other players have bet on horizontal integration to offer complete solutions to customers.**



**Overall inverter market 2010-2020 (million units)** **Source: Yole Développement**

**The inverter supply chain is changing to align with new customers’ requirements. This was first learned in the PV industry when the first SiC inverters were introduced several years ago by SMA and REFUsol (now AEI), since then the highest customer priority has changed from high efficiency to low cost. The reshaping of the inverter supply chain is the most pronounced when analyzing the local market drivers and players. Chinese players heavily impact the overall market in most inverter applications.**

**Understanding the characteristics of a local market is important in identifying the most promising market sectors and also helps in choosing the right product mix and the optimal sales strategy.**

**Companies which can anticipate regional market changes are on the best path to conquering new markets, and will lose less in weakened markets. China and Japan remain the markets with relatively difficult access for foreign players, and thus are dominated by local companies, except for the rail and UPS application markets. Many European and US companies are working to improve their position within the huge growth potential markets such as PV, wind, and electric vehicles.**

**www.yole.fr**

# Infineon Outperformes the Market

"Fiscal year 2014 was a successful year for Infineon, revenue rose to 4.320 billion Euros – an increase of 12 percent", said Infineon's CEO Reinhard Ploss at the annual press conference end of November. "The fiscal year itself followed the typical pattern, with a seasonal decline in revenue in the first quarter, followed by three quarters of growth. Compared to the respective quarters of the previous year, revenue in all four quarters of the 2014 fiscal year was significantly higher, mostly with two-digit growth rates.

Two factors contributed primarily to this success. Firstly, we had already geared the company at a very early stage towards growth in demand. And thanks to progress in cycle management, our manufacturing facilities responded quickly and flexibly, and were able to deliver on time. We thus seized the opportunities presented by the growing market".

The automotive business, Infineon's largest sector, benefited from various developments. Firstly, growth in the global automotive market. This was supported by the market in North America with a revival in spring, the continuing growth in demand in China, and market recovery in Western Europe. Secondly, the above-average sales successes of the three German premium manufacturers. Audi, BMW and Mercedes using a particularly large number of semiconductors into their models, i. e. the new BMW i8 is equipped with 75 Infineon devices particularly in the drive train. Thirdly, an increasing demand for functions that make driving safer and more convenient – especially in mid-range vehicles. And fourthly, the growing demand for solutions that reduce CO2 emissions. In numbers – revenues increased by 15 % from €1.714 billion in fiscal 2013 to €1.965 billion in 2014. Business in the Industrial Power Control segment (Power Modules) has recovered significantly, mainly due to the sharp rise in demand in the renewable energy and rail transport sectors accompanied by a slow but steady revival in industrial drives. Compared to difficult 2013 fiscal year, revenues increased from €651 million by as much as 20 % to reach a total of €783 million. The Power Management & Multimarket segment grew from €987 million in 2013 to €1.061 billion due to a greater demand for semiconductors in mobile devices. Secondly, the introduction of digital control concepts for DC/DC power supply in servers showed a very pleasing development. Controller and driver ICs and low-voltage MOSFETs benefited from this. Finally, the Chip Card & Security segment grew by 7 % from €463 million to €494 million in 2014.

"We are confident that this overall growth trend will continue. For the whole of the 2015 fiscal year, we expect revenue growth of 8 percent", Ploss forecasts.

One of the most interesting items is of course the planned $3 billion acquisition of International Rectifier. Infineon has already secured credit lines and is of good hope to close this transaction early in fiscal 2015. "The product portfolios of Infineon and International Rectifier complement each other perfectly. The strengths of International Rectifier lie in its energy-efficient IGBTs, IGBT driver ICs and intelligent power modules for low-power applications, as well as its power MOSFETs and digital power management ICs. We can combine this portfolio very well with our range of discrete IGBTs and modules. By taking over International Rectifier, Infineon is acquiring a technology leader in gallium nitride-based power semiconductors. This will allow us to accelerate and consolidate our roadmap with regard to GaN discrete products and GaN system solutions. The gallium nitride technology platform promises significant growth potential", Ploss underlined.

Regarding productivity, Infineon performs much better than the US-based fabs of IR. "In particular 300 millimeter wafers translate into 30 percent less investment in relation to revenues. Capacity loading is currently 80 percent", Ploss stated. But IR also runs a 200-mm fab in Newport/UK, here Ploss refused to comment on closing or keeping this activity. **AS**

**www.infineon.com**


**Infineon's CEO Reinhard Ploss is proud to announce that BMW uses 75 semiconductors in its new i8 model**

# More Power for Electronics


**More than 73,000 visitors from over 80 countries and 2,737 exhibitors from 50 countries made Electronica from November 11 – 14 in Munich the most successful event ever**

More than 73,000 visitors from over 80 countries and 2,737 exhibitors from 50 countries made Electronica from November 11 – 14 in Munich the most successful event ever. Supporting activities such as the Automotive Conference also attracted 160 participants from 20 countries. The focus here was on sensor fusion, connectivity and LED lighting plus associated power electronics. The next electronica takes place in Munich from November 8-11, 2016.

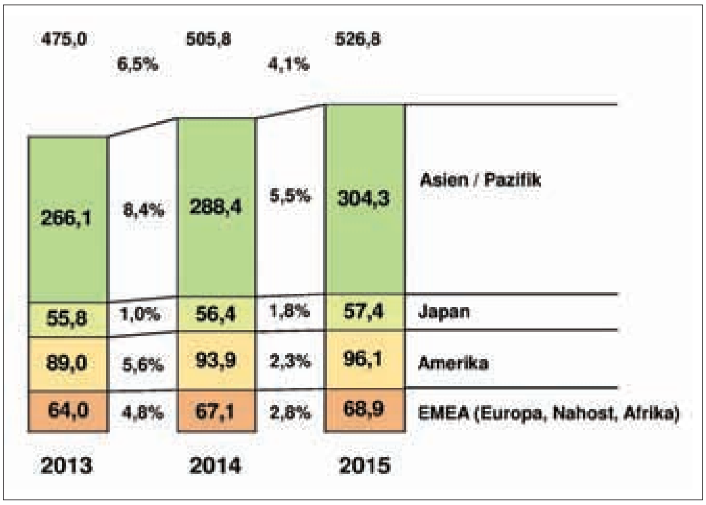
The economical situation for electronic components is very healthy – not only for the year 2014 but also for the foreseeable future. "Our industry is rushing from one success to an other, driven by the worldwide economical conditions. China is estimated to grow by more than 7 percent in 2014, the Eurozone by 0.8 percent and the USA with 2.2. percentage points, which will lead to an European market for electronic components of $63.6 billion in 2014 – a growth rate of 4.8 percent. And on a worldwide scale we anticipate a growth of 6.5 percent up to $506 billion in 2014 and a further step of more than 4 percent up to $527 in 2015. Semiconductors will jump from $332 billion in 2014 up to $345 billion in 2015", underlined Kurt Sievers, head of the ZVEI Association Electronic Components and Systems **(www.zvei.org)**.

**"Our industry is rushing from one success to an other, driven by the worldwide economical conditions", underlined Kurt Sievers, head of the ZVEI Association Electronic Components and Systems**

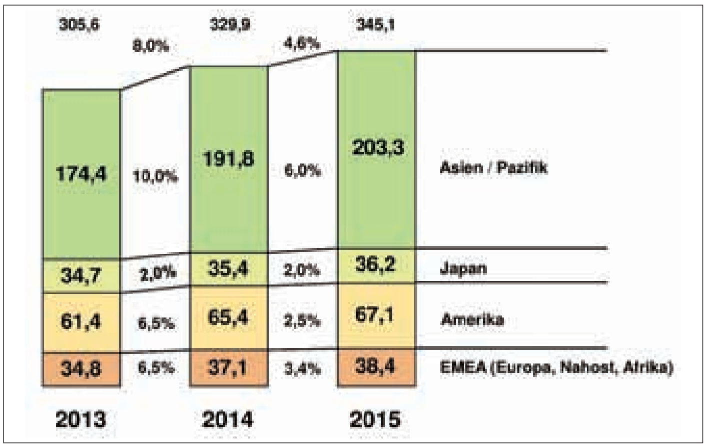
The German semiconductor market is dominated by the industrial and automotive sectors, and particularly the latter will grow by more than 7 percent up to €8.2 billion in 2014 with a further growth of more than 4 percentage points in 2015.

## Automotive lighting relies on electronics

"More than 95 percent in automotive lighting is in electronics", expressed Wolfgang Huhn, head of lighting at the German car maker Audi **(www.audi.de)** in his Automotive Conference keynote. "Most expensive headlamps are priced same as a gearbox, but with LEDs pricing will drop significantly

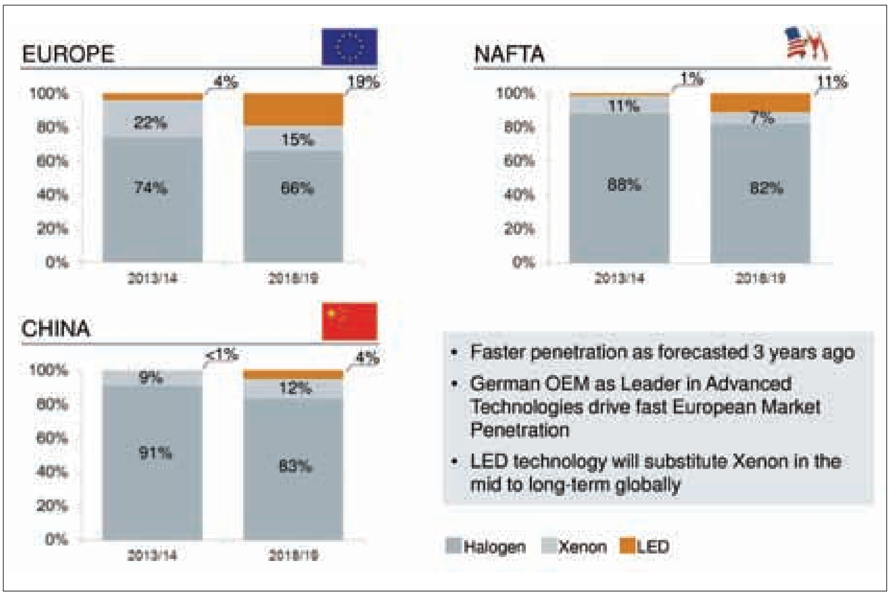



**Worldwide market ($ billion) for electronic components 2013-2015** **Source: ZVEI**




**Worldwide market ($ billion) for semiconductors 2013-2015** **Source: ZVEI**


"More than 95 percent in automotive lighting is in electronics", said Wolfgang Huhn, head of lighting at Audi



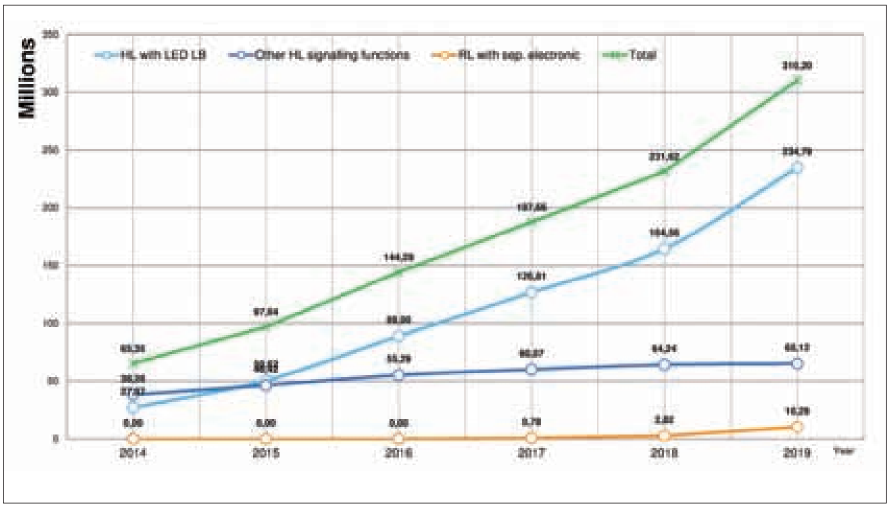

Penetration of headlamp technology by technology and region 2014-2019
Source: Hella

and in ten years Xenon-based lamps will be the past. Matrix LED lamps consisting of 25 high-beam LEDs per headlamp controlled by software will be the future even for the mass of cars, but the laser is the next big thing".

"LEDs have much better efficiency than Xenon headlamps but needs good thermal management", said Wolfgang Pohlmann, head of opto-mechatronic technology at Hella (**www.hella.com**). "Thus we expect that LEDs are penetrating the automotive market relatively fast".

According to Thomas Fröhlich, head of LED lighting at Magneti Marelli in Reutlingen/Germany (**www.al-lighting.com**), up to 3 percent CO2 emissions can be saved by moving from halogen towards LED headlamps, also some weight by reducing harnessing. "Worldwide production is growing from around 86 million cars in 2014 up to 103 million in the year 2019, in the EU this will correspond from 21 to 29 million, and for Asia from 43 to 55 million units with more advanced functions. LED share will grow from 3 percent in 2014 up to 23 percent in 2019 with corresponding LED driver channels up to 310 million. Thus optimized LED drivers are needed – the move towards 48 V secondary power supply in the car could ease LED driver design by eliminating DC/DC boost drivers and thus increasing efficiency".

"Adaptive driving beam is currently offered based on HID and LED light sources, but data acquisition via multi-purpose cameras is a pre-




**Estimated worldwide automotive LED driver channels 2014-2019 Source: Magneti Marelli**

requisite and data processing and software development becomes key in future headlamp design", said Claus Allgeier, head of automotive lighting at Osram **(www.osram-os.com)**. Today's cutting edge lighting technology is the Audi A8 LED Matrix Beam consisting of 5 secondary optics (each with a 5 LED chip linear matrix) which deliver matrix elements in light distribution to generate glare free high brightness. In total (per side) 25 single addressable LED chips are used to generate the Matrix part of the beam. Oncoming and preceding cars are not glared, passengers on the road are highlighted by the headlamp. The German project SEEL (partners Osram, Audi and Infineon) covers the development of an Matrix LED headlamp consisting of 5 modules (with primary and secondary optics, each with a 20 LED chip 2D matrix) delivering matrix elements. In total (per headlamp) 100 single addressable LED chips would be used to generate the matrix part of the beam. Light distribution is divided in 4 rows and 25 columns. "But Lasers offer unbeatable luminance because focal length and corresponding optics allow extremely small apertures and Laser radiation can be controlled precisely", Allgeier underlined. One of the first examples is the BMW i8.

Micrel's **(www.micrel.com)** MAQ3203 is capable of driving multiple HB LEDs in series at more than 90 % efficiency with ±5 % current accuracy from input voltages of 4.5 V to 42 V. With its hysteretic control architecture and high-side current sense scheme, the device drives the HB LEDs with constant current. The MAQ3203 operating frequency is adjustable up to 1.5 MHz which allows flexibility in design and offers a frequency dithering feature to mitigate EMI. The IC features a dedicated PWM dimming pin, an enable pin for very low power shutdown, over-temperature protection and an under-voltage lockout. The MAQ3203 has an external power switch and requires no external compensation. The device is available in a SOIC-8L package and will drive two 1.2A LED strings demonstrating both high and low beam capabilities.

On Semiconductor **(www.onsemi.com)** introduced two new devices for use in vehicle lighting systems. The NCV78763 power ballast and dual channel LED driver provides a single-chip that is capable of driving two strings of LEDs up to 60 V. A DC current of 1.6

A can be supported on each output. The built-in current-mode voltage booster controller enables input current filtering. An internal PWM dimming function, covering frequencies up to 4 kHz, is also included in addition to the option of PWM direct-feed for full frequency and resolution control from the external microcontroller. Optimized for front lighting applications, this device can be employed in high beam, low beam, turn indicator, static cornering, fog and daytime running lights. For each individual LED channel there is an independent buck switch output, through which both the output current and voltage can be configured to meet specific application criteria. Configuration is done via the device's serial peripheral interface (SPI). The NCV78763 is offered in three package variants: 5 mm x 5 mm QFN-32, 7 mm x 7 mm QFN-32 and 36-pin SSOP. The new NCV7691 current controller for automotive LED lamps targets rear combination lamps (RCL), center high-mounted stop lamps (CHMSL), and day-time running lights (DRL). This highly integrated pre-driver contains PWM and diagnostic capabilities, as well as battery connection and negative temperature coefficient (NTC) input in a single chip.

Rohm's **(www.rohm.com/eu)** new AEC Q100 qualified 12 channel BD1837XEFV-M automotive LED drivers are packaged in a small HT-SSOP28 with 10V output rating. 6 bit current brightness calibration for individual LED binning is available for each output while 6 global PWM channels allow dimming from almost 0 – 100 % on all outputs. The device includes 12 constant current output channels with a maximum of 50 mA per channel and, in order to achieve a higher output current, the channels can be combined in parallel. The device is able to perform comprehensive diagnostic checks (open / short load / temperature / under voltage) to detect LED failure and over- temperature on chip. Due to its emergency warning, it prevents total failure and makes the chip setting back to "limp function" (typically 10mA) if the external resistor fails. The settings of all internal registers can be read out to verify written information at any time while the integrated SPI interface ensures sophisticated communication even during over-temperature up to 150°C.

### Automotive embedded power

Infineon Technologies **(www.infineon.com/embeddedpower)** announced an Embedded Power family of bridge drivers addressing the growing trend towards intelligent motor control for a wide range of automotive applications. On a single chip a high-performance microcontroller using the ARM® Cortex™-M3 processor, as well as the nonvolatile memory, the analog and mixed signal peripherals, the communication interfaces along with the MOSFET gate drivers are integrated.

"In automotive applications 2.3 billion electric motors were used in the year 2012, at average 28 motors per car. In the year 2017 this usage will grow to 30 motors per car and thus reaching 2.9 billion units. An integrated IC for driving such motors in various applications such as pumps, fans or body control makes sense", said Theodore Varelas, Product Marketing Manager Automotive Embedded Power. The peripheral set of the TLE987x and the TLE986x includes a current sensor, a successive approximation 10-bit ADC synchronized with the capture and compare unit (CAPCOM6) for PWM control and 16-bit timers. Furthermore, a LIN transceiver is integrated to enable communication to the devices along with a number of general purpose I/Os. Both series include an on-chip linear voltage regulator to supply external loads. They operate from 5.4 V up to 28 V. The bridge drivers feature programmable charging and discharging current. The patented current slope control technique

**Theodore Varelas presented Infineon's new Embedded Drivers for electric motors in automotive applications**

optimizes the system EMC behavior for a wide range of power MOSFETs. The products can withstand load dump conditions up to 40 V while maintaining an extended supply voltage operating down to 3.0 V where the microcontroller and the flash memory are fully functional. Infineon provides starter kits to support the design-in.

## More power for DC/DC

The newly formed Architects of Modern Power (AMP) consortium **(www.ampgroup.com)** consisting of CUI (**www.cui.com)**, Ericsson Power Modules **(www.ericsson.com)**, and Murata **(www.murata-ps.com)** announced at Electronica its first standards aimed at establishing common mechanical and electrical specifications for the development of advanced power conversion technology for distributed power systems. The initial standards cover digital POL and DC/DC converters. Beyond purely mechanical specifications, it is the standardization of monitoring, control and communications functions, and the creation of common configuration files for plug-and-play interoperability that will ensure compatibility between products from these vendors. Two standards have been defined for digital point-of-load converters. The 'microAMP' specification covers supplies rated at 20 to 25 A in vertical and horizontal configurations, while the 'megaAMP' defines requirements for 40 to 50 A vertical and horizontal units. For bus DC/DC converters the 'ABC-ebAMP' standard relates to bus bricks measuring 58.42 x 22.66 mm and ranging from 264 to 300 W. For quarter-brick supplies, measuring 58.42 x 36.83 mm and ranging from 420 to 468 W, the group has defined the 'ABC-qbAMP' standard. These standards detail mechanical footprints, features, and configuration files. "Following the launch of Architects of Modern Power last month, the release of these standards marks an important first step on our shared technology roadmap", underlined AMP Group spokesperson and CUI VP of Advanced Power, Mark Adams. "All products rely on the Intersil Digital Power Controller, but the power stage might be different. CUI prefers IR's DrMOS". "Providing a true multi-sourced, high efficiency power ecosystem with exceptional supply chain reliability enables continuity of production for our customers", said Patrick Le Fèvre, Marketing Communications Director at Ericsson Power Modules, while Murata Power Solutions' VP of Strategic Product Marketing, Steve Pimpis, added, "we make this advanced technology available in a way that allows wider adoption than would be possible with single-source solutions".

Exar **(www.exar.com)** showcased its 10 A/15 A POL DC/DC modules XR79110/115 and gave an outlook on future releases. "A new version measuring 12 x 14 mm intended for telecom applications will provide 20 A at 0.6 to 5 V output featuring an internal inductor of around 1.7 µH", said Marketing Director Jon Cronk. Switching frequency is programmable up to 800 kHz. A next generation power management system will feature a 4-channel programmable buck controller for 6-40 V input and 0.6-5.5 V output, integrated synchronous FET Drivers, switching frequency up to 1.2 MHz in 7 x 7 QFN package.

Vishay **(www.vishay.com)** introduced a new family of integrated DrMOS power stages solutions in three PowerPAK® package sizes to meet the various design challenges in high-power and high-performance multiphase POL applications. The SiC789 and the SiC788 are offered in the MLP66-40L with a DrMOS Standard 4.0 (6 mm by 6 mm) footprint, while the SiC620 and the SiC620R are offered in the new 5 mm by 5 mm MLP55-31L package and the SiC521 is available in the 4.5 mm by 3.5 mm MLP4535-22L. "The devices are optimized for on-board DC/DC converters featuring switching frequencies up to 1 MHz and efficiencies up to 98 percent", said Norbert Pieper, SVP Sales Business Development. "Regarding automotive, the 48 V supply is a pre-step for autonomous driving, for this application we are designing new MOSFETs. And for EV applications we will release 1200 V IGBTs".

**Ericsson's Patrick Le Fèvre (left), CUI's Mark Adams, and Murata's Steve Pimpis announced first AMP Group standards for digital POL bus conversters**


**"The automotive 48 V supply is a pre-step for autonomous driving, for this application we are designing new MOSFETs", said Vishay's Norbert Pieper**


Over 13,000 visitors
Over 350 exhibitors
DRIVES & CONTROLS 2016
THE AUTOMATION, POWER TRANSMISSION & MOTION ENGINEERING EVENT
Three day seminar programme
Seven shows under one roof

# Hall Effect Technology Improved

Intelligent power control optimizes the use of electricity and ensures smooth control of equipment. For instance in machine tools, the current flow increases abruptly when the tool starts working on the part to be machined. The better and faster the feedback signal, the smoother the control of equipment operation. Intelligent power control is also a way of optimizing the use of electricity. Upgrading variable speed drives of electrical motors brings substantial energy savings. A fine control of current, no matter what the operating temperature, is able to provide substantial energy savings of up to 30% or more and improves speed and torque control.

The problem of torque ripple minimization in synchronous motors is a challenge for engineers and there are constant efforts made to reduce it. The new LEM LFxx10 current transducer family improves current measurement accuracy across the whole operating temperature range, dramatically improving the torque ripple performance. Previously, it was difficult to maintain consistent current measurement gain across the three phases of a motor drive due to accuracy variations among traditional current measurement sensors. This accuracy variation can result in excessive torque ripple. The LFxx10 family's extremely high measurement accuracy reduces torque ripple, allowing more comfort for elevators, locomotives or other transport applications, as well as allowing highest dynamics and positioning precision for machine-tools, robots and other automation applications.

### New drives require high current measurement accuracy

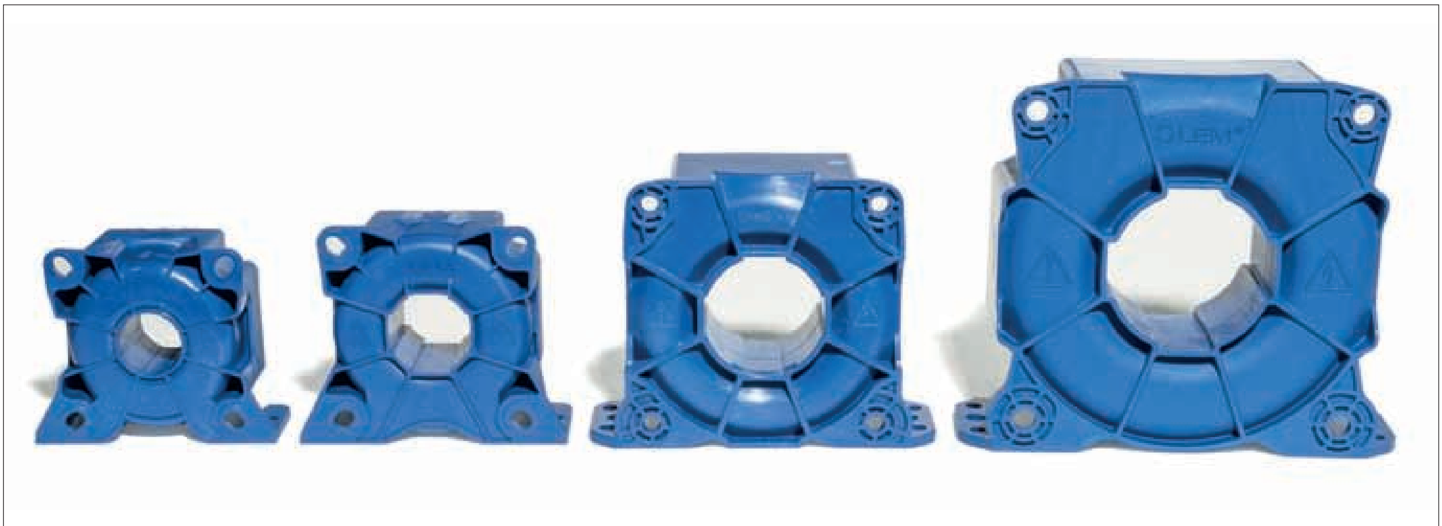
The LFxx10 family higher current measurement accuracy also enables better motor control efficiency. Energy savings are being driven by the gradual adoption of the new energy-related directives (ErP) for electrical motors. IE2 efficiency was imposed in 2011 and IE3 is required for small motors from 2015, with an extension to motors up to 7.5kW in 2017. The most cost-effective solution to reach these standards is to use a high-performance drive controller, with high current measurement accuracy.

Many applications face constraints due to immunity - for example modern onshore and offshore windmills, where the electricity produced needs to be fed into and controlled within the power grid. The stability of the current measurement on the grid side over temperature is a key requirement in this kind of application. Wind power applications demand the robustness and high accuracy that the LFxx10 current transducer family offers. While the basic application has not changed over the last 20 years, the adoption of permanent magnet generators and the increase in windmill size are raising the demands on current sensors.

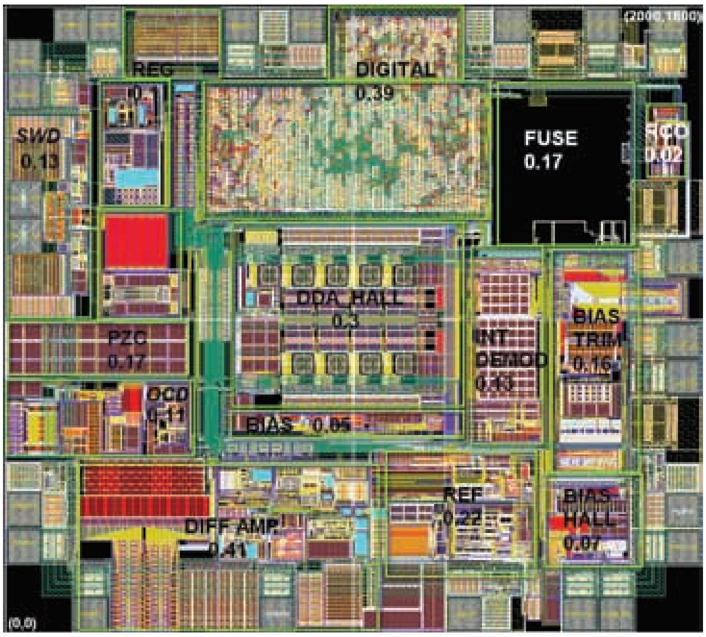
Firstly, the introduction of higher efficiency Permanent Magnet (PM) generators is leading to an increase in level current. The traditional double-fed generator requires a relatively low power inverter. In fact, the generator itself is the main power source and the inverter is only controlling the excitation of the generator. It therefore handles only a fraction of the main power. In contrast, for Permanent Magnet generator, the inverter needs to convert the frequency of all the power, increasing the current to be converted several fold. The LF family is offered in four ranges from 200 A to 1000 A and can suit most power needs. Additionally, a 2,000 A will be released next year.

Furthermore, the bigger size of the windmills (some offshore mills are already at 6 MW) is creating electromagnetic challenges. Some manufacturers chose to deal with the increase of power by splitting the inverter into several modules in parallel. These compact designs enclose several bus bars carrying thousands of amperes and generating very high stray fields. As described hereafter, the LF 510 and LF 1010 models are designed around a partial air-gap which significantly reduces the impact of external fields. This feature is particularly welcomed by engineers working on modular inverters.

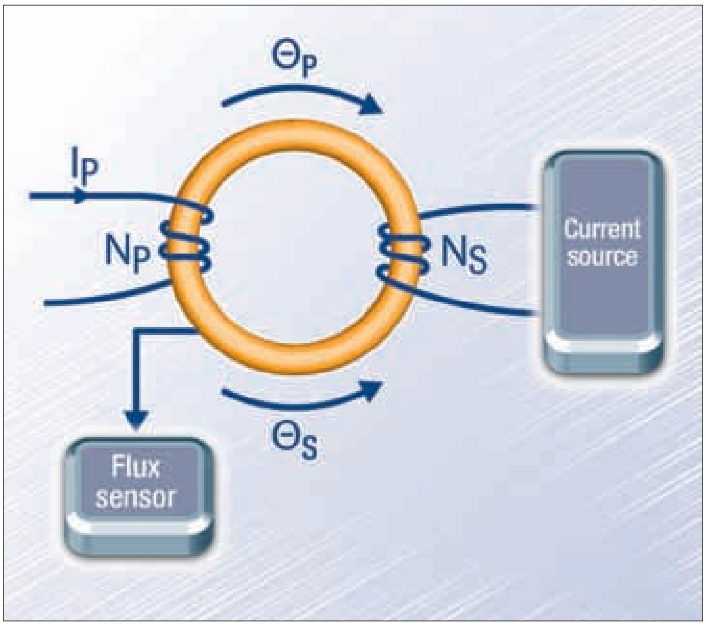
Finally, as the power generated increases, improvements in sensing accuracy offer even greater power savings. A good example is the impact of the offset error to the output current. The offset error is the value given by the transducer when no current is flowing at any temperature. It can also be seen as the current flowing when the sensor gives a 0 A output. In practice the offset current fools the inverter control loop and is responsible for the generation of a DC current. Since the windmill is connected to the grid through a transformer, this DC current is blocked and dissipates into the transformer. Thanks to its ASIC technology, the new LF xx10 family achieves an extremely low offset current and offset drift. For example, the LFxx10 offset drift is up to 5 times lower than the previous generation of current transducers LF xx05. The design features



**New LF xx10 current transducer range**




Chip layout of the ASIC used in the new LF xx10 current transducer range




Closed loop current transducer principle

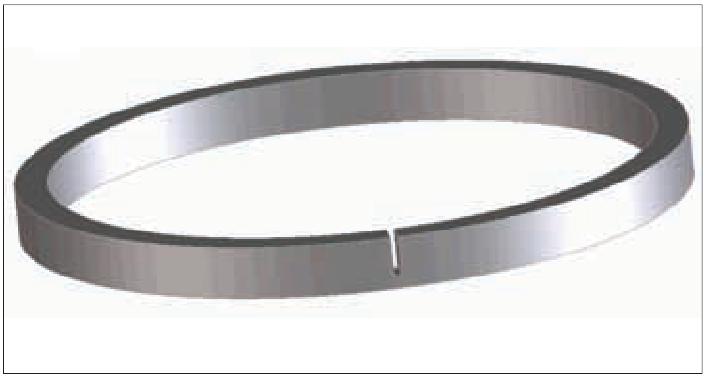
of the new LF xx10 family make it well-suited to support design engineers building windmills that are larger and more efficient than ever before.

### ASIC improves performance

With the new LF xx10 family, LEM brings the performance of a closed loop Hall effect technology-based transducer to the level of a closed loop Fluxgate technology based transducer. The Hall chip is a dedicated Application Specific Integrated Circuit that uses several high performance techniques (e.g. spinning and specialist IC geometry), some of which were patented, to improve the offset and offset drift dramatically when compared to previous solutions. Based on this new ASIC, a complete current transducer range has been designed to cover nominal current measurements from 200 A to 2000 A: LF 210-S, LF 310-S, LF 510-S and, LF 1010-S models– with a fifth one, the LF 2010-S, coming out in February 2015.

The LFxx10 series breaks new ground, delivering up to 5 times greater global accuracy over the temperature range (from 0.2 to 0.6 % of $I_{PN}$) versus the previous generation of closed loop Hall effect current transducers, with a maximum offset drift of just 0.1 % of $I_{PN}$.

Thanks to the partial air gap of the magnetic core, the LF 510, 1010 and 2010 models have a very low sensitivity to external AC and DC fields. This allows a more compact design as there is practically no sensitivity to high current conductors near to the transducer. The sensitivity against AC or DC fields (worst case) with the LF 1010-S model is five times better than with the LF 1005-S (previous generation). The typical error with an LF 1010-S is 2% of IPN compared with 10 % using an LF 1005-S, when submitted to the same conditions caused by AC or DC fields. The LF xx10 transducers have fast response time, with a typical delay (defined at 90 % of IPN) against a current step at IPN of less than 0.5 µs.



Partial air gap on magnetic core

### Working principle

For accurate measurement of DC currents, the technology compensates the current $\Theta_P$ created by the current $I_P$ to be measured by an opposing current linkage $\Theta_S$ created by a current IS flowing through a known number of turns $N_S$ to obtain:

$$\Theta_P - \Theta_S = 0 \text{ or } N_P \times I_P - N_S \times I_S = 0$$

with $N_P$ the number of primary turns and $N_S$ the number of secondary turns.

To obtain accurate measurement, it is necessary to have a highly accurate device to measure the condition $\Theta = 0$ precisely. To achieve accurate compensation of the two opposing current linkages ($\Theta_P$ and $\Theta_S$), a detector capable of accurately measuring $\Theta = 0$ must be used, which means the detector must be very sensitive to small values of a residual magnetic flux $\Psi$ (created by the current linkage $\Theta$) to achieve the greatest possible detector output signal.

Using this operating principle, together with the new LEM-designed Hall effect ASIC (previously mentioned) as the detector, the LF xx10 current transducers bring accuracy to the next level for nominal current measurements from 200 to 2000 A (4000 A peak), meeting the high-performance demands of the power electronics world and its applications.

www.lem.com

# Power Modules to the Rescue

There are an increasing number of suppliers offering power modules due to improvement in technology on many fronts. It is now time to take advantage of this new generation of power modules. The process of selecting a power module is important and designers need to select the best solution in terms of value (performance and size) versus cost effectiveness. **Brian Hedayati, Vice President, Marketing, Linear & Power Solutions, Micrel Inc., USA**

**The requirements for higher density** boards and reducing system size are driving the need for smaller DC/DC solutions, resulting with the evolution of power modules. It took many years for the power module technology to arrive to the mass market. In the early days, it was very difficult to design power converters. At the time, they were entirely designed with discrete and leaded components or taken from a tap off a transformer. The reality was that designing power converters was considered a black art. There were very few experts in this field who had a great understanding of all aspects of power conversion. The design cycles took more than a year because of multiple design iterations were needed due to stability issues, component failure, or EMI issues caused by high di/dt or dv/dt and improper or constrained layouts that increased the amount of radiated EMI.

Later, companies such as Unitrode developed PWM controllers, and power transistor suppliers started offering MOSFET technology to replace bipolar transistors. The switching conversion frequency increased to about 100 kHz, and surface-mount components entered the mainstream. With improvements in process, packaging, and MOSFET technology, DC/DC regulators with integrated controller and power switches arrived. This allowed even further reduction of board space and improvement of power density (see Figure 1).

Today there are only a few semiconductor suppliers offering an all-in-one DC/DC solution in a single package. In addition to the controller and power switches, inductors and passive components are now integrated into the package. To reduce the form factor of the module package, the inductor size had to be reduced dramatically while still offering good performance. This could be achieved by increasing the switching frequency, thus allowing a smaller inductor with less inductance to be used, which also reduces the DC resistance of the inductor. The trade-off would be an increase in switching losses from the controller and MOSFETs.

The good news is that semiconductor processes and MOSFET technology has improved significantly over the years, reducing the impact of the higher switching frequency. With smaller geometries, improved performance could be achieved and silicon size could be reduced. Newer MOSFETs with improved figure of merit, helps optimize the switching and conduction losses trade-off, allowing for improved efficiency, thereby allowing for a smaller package footprint to be used with adequate power dissipation. In addition, packaging technology has evolved where several Watts of power dissipation can be achieved in a small package as thermal resistance has been reduced. In addition, passive component supplies (capacitors, diodes, resistors) have been reducing their footprints to save space as well. With all of these technological improvements, this has enabled integrated power modules to achieve the level of power density that is available today (Figure 2).

## Why use power modules over a discrete approach?

Beside the fact that power modules achieve a smaller footprint than discrete solutions, there are many other advantages of using power modules. Although it is possible to get the highest efficiency using a discrete approach, if saving board space is your major requirement, you may benefit from trading off a few percent of efficiency to meet density requirements. For example, Micrel power modules achieve efficiency in the 90 % range, as well as great efficiency at light load due to HyperLight Load™ technology.

Discrete power converters require more space and careful component location as this becomes a concern. The layout and

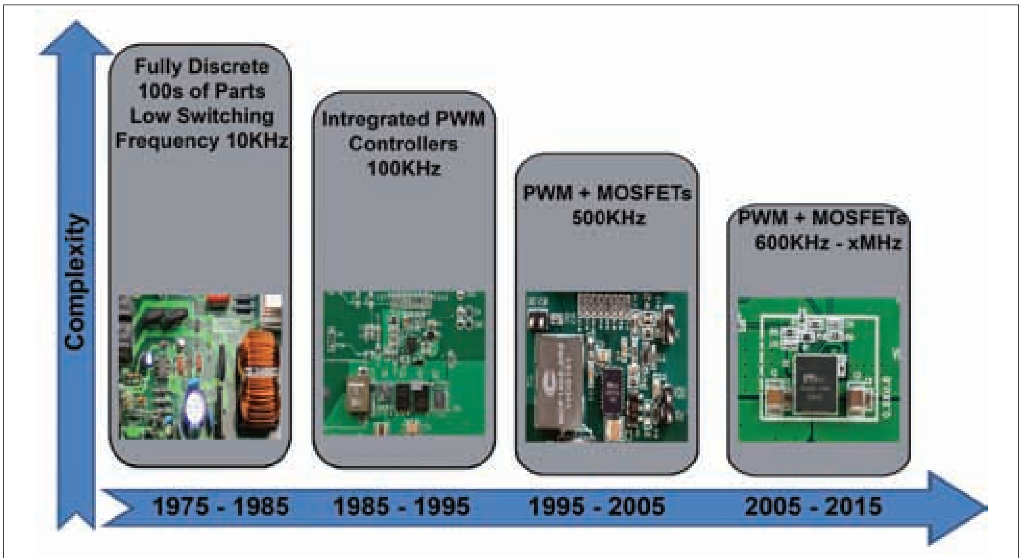



Figure 1: **DC/DC converter evolution and trends**

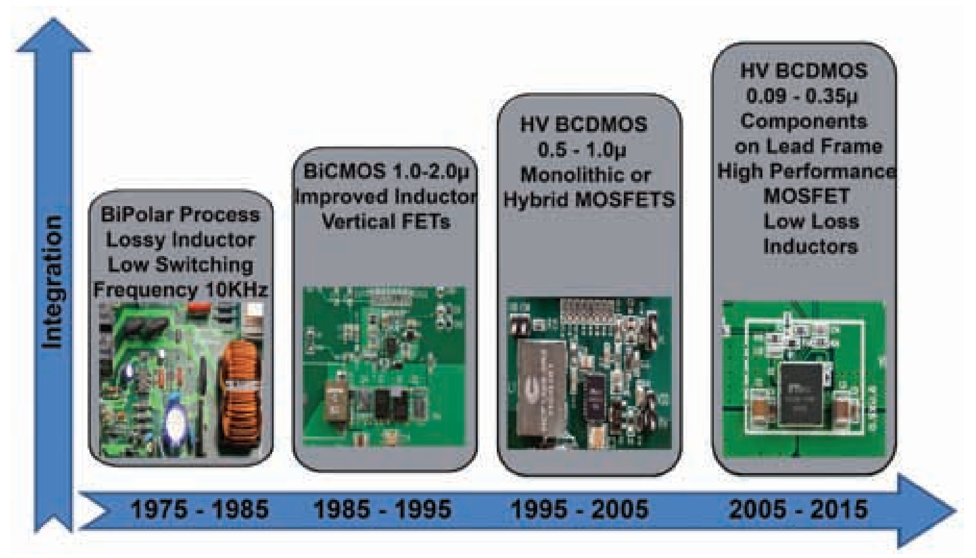



**Figure 2: The improvement in technology was needed on many fronts**

routing can be quite challenging to get an optimized layout. The AC current loops are larger and can more susceptible to radiated EMI issues as these loops act like an antenna. The integration of the key power components within a module minimizes the size of the loops with only the need to put the input and output capacitors close to the IC and connected to GND, which is fairly simple to implement. For the majority of the customers, meeting CISPR22, CLASS B or EN55022 requirements is a necessity. Figure 3 shows the performance of these new modules.

Additional performance considerations for power designs include load-transient and thermal management. The load transient is a function of control loop architecture, switching frequency, and output filter size. Thermal issues are related to the operating ambient temperature and the ability to remove heat from the power components. For power modules, this is one of the primary concerns as a majority of the heat is dissipated within the package. With a smaller foot print, there is less contact area to the board (for QFN type packages). As a result, having an advanced package with low thermal resistance (especially junction to board) in conjunction with a highly efficient regulator is a must in order to achieve the benefits of using a small power module solution (Figure 4).

## Meeting challenging system requirements

While fully integrated, the latest power module solutions allow the end-user some flexibility, such as setting the current limit, the frequency, and the output voltage with external resistors. In this way, the same module can be adjusted for different output voltages in the system. The ability to adjust the current limit allows for optimum over-current protection. The ability to adjust the frequency addresses the efficiency versus transient trade-off. Additionally, since many of the parts are included in the power module, the layout and routing of the design is much easier. Depending on the power module vendor, the size and shape of the exposed thermal pads can be different. Some vendors offer very easy pads locations with their QFN package while other use LGA/BGA packaging, which can be more difficult and more expensive to assemble.

When designing for distributed power system for industrial or medical applications, small high voltage solutions with wide operating input and output voltage ranges are ideal. The MIC28304 is a 70 V/3 A module in a small 12x12x3 mm package, which, when compared with a discrete solution, can reduce the PCB requirement by more than 60 %. The device's external components give the flexibility to set current limit frequency if there is a need to avoid certain switching frequency and output voltage, which is programmable from 0.8 V to 24 V. The device achieves impressive efficiency levels both at light load and full load in the HyperLight Load version. Finally, this power module meets EMI CISPR 22 Class B spec.

The requirements are different when designing for enterprise infrastructure, datacom, FPGA power, or distributed 12 V bus applications. These applications often require higher current, high efficiency, and

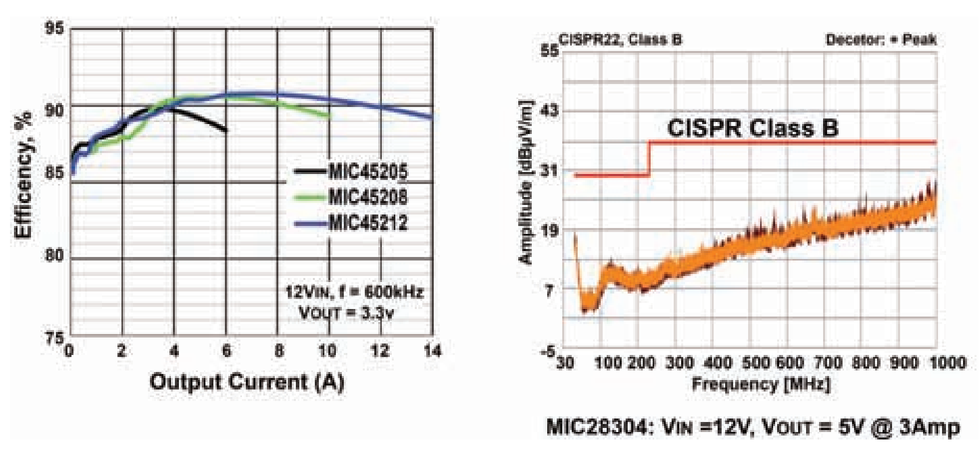



**Figure 3: Efficiency (left) and EMI performance**

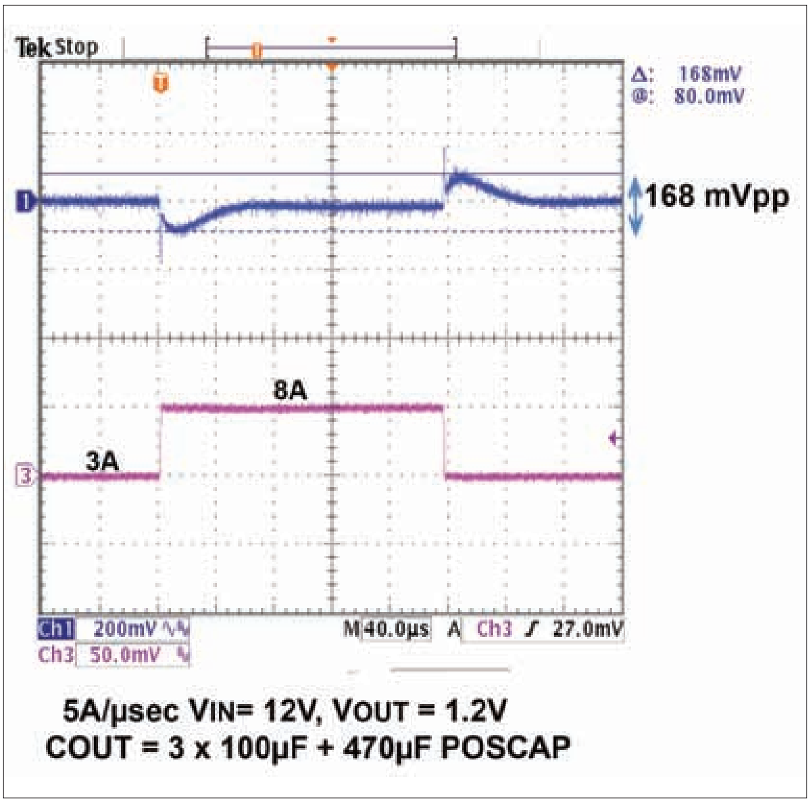



**Figure 4: Hyperspeed control offers fast load transient response**

small size as board space is a premium. The point of loads often need to be close to the processors. For this type of applications, the MIC452xx family of parts offers the smallest form factor and highest power density. The control architecture used is optimized for a fast loop response, resulting with the need for less output capacitance.. At the same time, the wide input voltage range 5 V to 24 V allows the use of the same family for supplying from a 5 V or 12 V common bus rail, reducing the number of parts to qualify and that have to be kept in inventory. Once again, a single device offers high flexibility and has minimum external components to achieve a very small form factor. Offered in a QFN packages, these devices are easier to lay out when compared with an LGA solution and all components can be placed on the top side (Figure 5). Some of the passive components can be placed on the bottom if an even smaller solution is required.

Other applications that are suited for DC/DC power modules include solid-state drives, hand-held devices, enterprise storage, and servers, Wi-Fi/WiMax modules, and wearable electronics, where board space and low-profile is often limited. In these types of applications, the high switching frequency of 4 MHz allows for a very small internal inductor, allowing for a very miniature packaged solution. In addition, with the high switching frequency, small output capacitors can be used without significant output ripple. The MIC33163 total solution requires only 4.6 mm x 7 mm of board space with a maximum height of 1.1 mm that is capable of delivering 1 A of output current (MIC33163). Due to the amount of board space needed by these devices, these devices are often used as a replacement to LDOs with significant improvement to efficiency These devices have an input voltage range from 2.7 V to 5.5 V with a 4 MHz switching frequency, and offer efficiency up to 93 % while meeting EMI performance (CISPR22 Class B).

## Conclusion

The latest DC/DC power modules are simple to use with a minimum number of external parts and ares allow easy PCB layouts. Their compact form factors use minimal board space, and new control architectures are used to achieve fast transient response, which saves on the number of filter capacitors. The new generation of power modules has small form factors, yet still offer excellent conversion efficiencies. System reliability is enhanced since they are fully tested and have minimum external components, which is especially important for applications where the systems are exposed to moisture and harsh environments. Ultimately, the ease of use offered by power modules is driving their increased adoption. Knowing a design will work the first time and having the flexibility to accommodate changing specifications late in the design cycle are strong compelling reasons to consider using power modules.

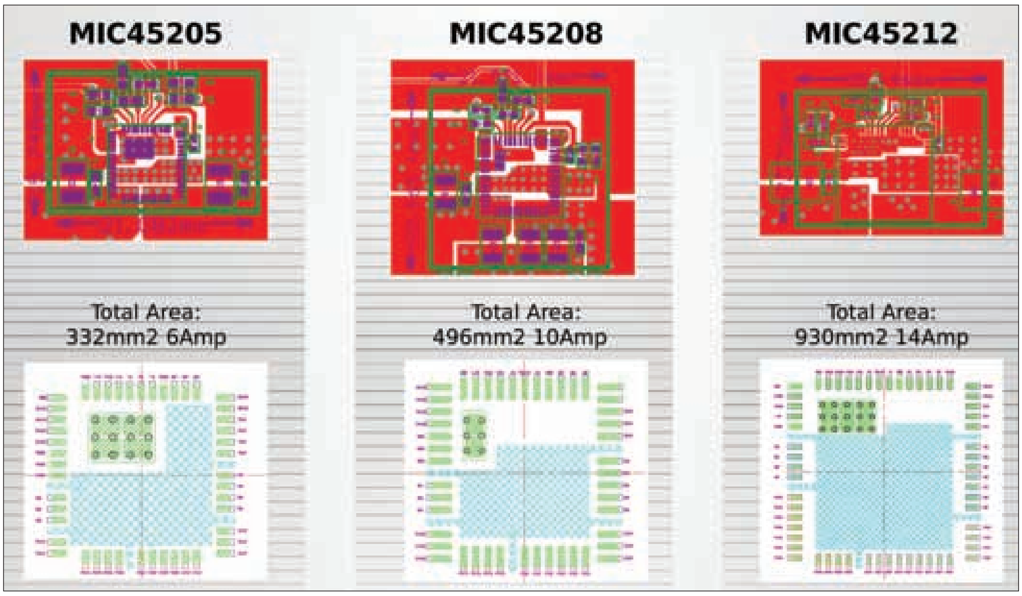



**Figure 5: Simple land patterns optimized for thermal performance and eliminating assembly issues**

# Finding True Maximum Power Point

In solar power systems, the bulk of the expense is in the panel and batteries. Any cost-effective solar power solution maximizes the capacity usage and lifetime of these components. For instance, a high quality charger increases battery run time, reducing capacity requirements, and extends battery lifetime, minimizing maintenance and replacement costs. Likewise, using a DC/DC controller that extracts the maximum available energy from the solar panel reduces the size and cost of the panels required. **Tage Bjorklund, Senior Applications Engineer, Power Products, Linear Technology Corp., USA**

The LT8490 is a charge controller for lead acid and lithium batteries that can be powered by a solar panel or a DC voltage source. It includes true maximum power point tracking (MPPT) for solar panels and optimized built-in battery charging algorithms for various battery types - no firmware development required. 80 V input and output ratings enable the LT8490 to be used with panels containing up to 96 cells in series. The power stage uses four external N-channel MOSFETs and a single inductor in a buck-boost configuration. Unlike most charge controllers, the buck-boost configuration allows the charger to operate efficiently with panel voltages that are below, above or equal to the battery voltage. The minimum panel voltage is 6 V.

Batteries live longer and run longer when the charge algorithm is optimized for the battery type. Likewise, a high performing MPPT charger, which tracks the solar panel maximum power point during partial shade conditions, allows the use of a smaller and lower cost solar panel. Creating a discrete-component charger solution to perform all of these duties would be costly and time consuming, typically requiring a microcontroller, a high performance switching regulator and a lengthy firmware development cycle.

## Single-IC solar powered battery charger solution

The LT8490 is an MPPT battery charger controller with a long list of features including:

- integrated MPPT algorithm (no firmware development required) reduces time to market

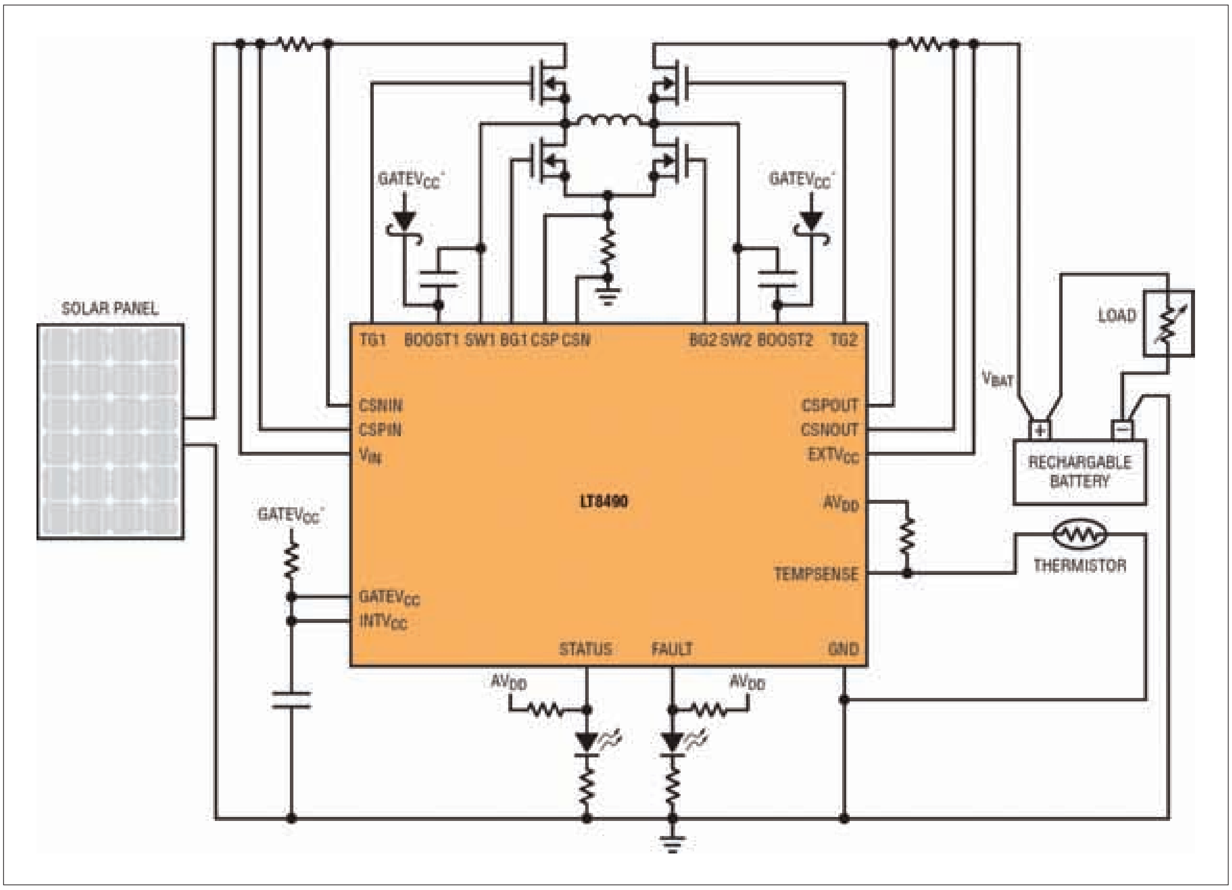



**Figure 1:** **Simplified solar powered battery charger schematic**

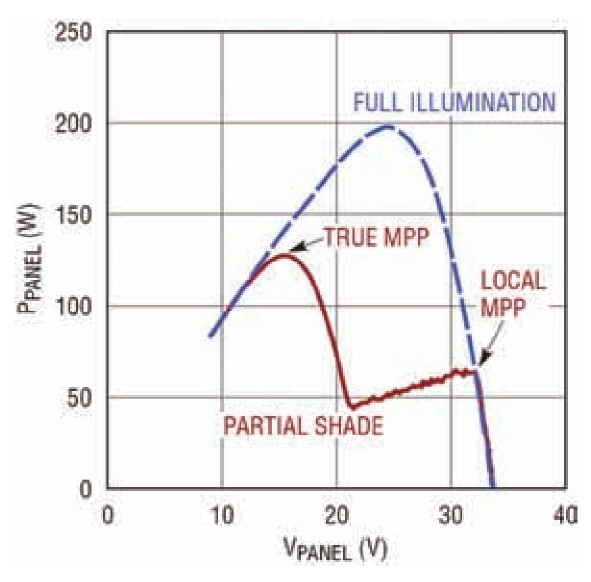



**Figure 2:** **The power curve of a 60-cell 250 W solar panel with entire panel illuminated and with a small shadow partly covering one cell (see Figure 3)**

- integrated buck-boost controller allows $V_{IN}$ to be above, below or equal to $V_{BAT}$
- supports lead-acid and lithium-ion batteries
- 6–80 V $V_{IN}$ and 1.3–80 V $V_{BAT}$

The LT8490 can be powered by a solar panel or any DC voltage source. For a particular battery voltage, a wide range of solar panel types can be used, as the panel voltage can be lower or higher than the battery voltage. The LT8490 accepts panel inputs from 6 V to a maximum (cold temperature) open circuit voltage of 80 V; a range corresponding to 16 to 96 series-connected solar cells.

Since the power stage is external, it can be optimized for the application. Charge current limits (and input current limit when a DC voltage source is used) can be configured as needed.

## True maximum power point tracking

When operating from a solar panel, the LT8490 maintains the panel voltage at the panel's maximum power point (Figure 1). Even during partial shade conditions, when more than one local maximum power point appears (an effect of bypass diodes inside the solar panel), the LT8490 detects and tracks the true maximum.

Figure 2 shows the P-V curves for a common 60-cell 250 W panel under two different lighting conditions. The maximum power point (200W) occurs at 25 V when the panel is fully illuminated. In partial shade (see Figure 3), the available power at a 25 V panel voltage drops to 50 W, with the new true maximum power point (128 W) appearing at 16 V. Note that the original 25 V/200 W power peak actually moves to a local maximum ~32 V/63 W.

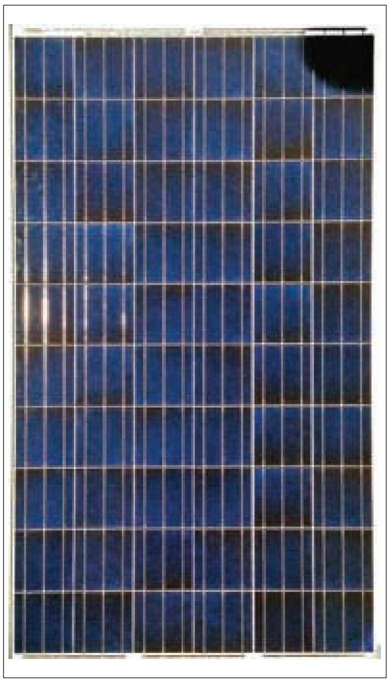


**Figure 3:** **Solar panel shaded in top right corner**

This dual local maximum effect is the downfall of traditional MPPT functions found in a number of controllers, for they follow the initial 25 V/200 W peak as it shifts to 32 V/63 W. In contrast, the LT8490 finds the true MPP at 16 V/128 W, yielding an additional 65 W from the panel. It does this by measuring the entire power curve of the panel at regular intervals and locating the true maximum power peak at which to operate. In this case, more than twice as much charge power is extracted, with even greater gains possible in other shade conditions.

## Charge control functions

Charge algorithms can be configured according to the requirements of each application by adjusting the voltage on two configuration pins. Lead-acid batteries built with AGM, gel and wet cell technologies require slightly different charge voltages for best lifetime, and Li-ion and LiFePO4 cells have charge requirements that are different from lead-acid batteries. Thus some of the built-in and configurable charge control functions are charge voltage temperature compensation (typically for lead-acid batteries) using NTC sensor; over or under battery temperature stops charge current to protect the battery; dead battery detection stops the charging, to avoid a hazard; adjustable trickle charging of a deeply discharged battery reduces risk of damage; constant current charging that changes to constant voltage charging as the battery voltage reaches its final value; reduction of charge voltage to a lower float voltage level when the battery is fully charged; and charging time limits can be set when operating from a DC voltage source.

## Conclusion

The LT8490 is a full-featured true MPPT charge controller that can operate from a solar panel or a DC voltage source with a voltage range from 6V to 80V, charging lead-acid or lithium batteries from 1.3V to 80V. The power stage is easily configured by selecting four MOSFETs and an inductor, allowing the charger to operate with VIN above, below or equal to the battery voltage. All necessary functions are included, with built-in battery charging algorithms and MPPT control, requiring no firmware development.

# Defining Schottky Diodes based on Power Dissipation

As wireless devices grow more sophisticated and consumers demand longer battery lives, manufacturers need to save power wherever possible. One area where a large amount of power is consumed is in the LED backlight for LCD displays. To drive these LEDs a boost circuit is implemented to increase the battery voltage to a level large enough to overcome the forward voltage of the LEDs. Choosing the correct Schottky diode for this boost circuit can help reduce the overall power dissipation of the system. For this reason, defining Schottky diodes based on overall power dissipation rather than individual parameters of the device is a preferable approach. **Steven Shackell, ON Semiconductor, Phoenix, USA**

The main parameters on which new Schottky diodes were defined in the past were forward voltage and reverse leakage current. Two large contributors to these specifications are the Schottky barrier metal and the Schottky contact area. Since the parameters share a dependence on the same variables, there is a trade-off between the two. As the forward voltage is reduced, the reverse leakage current is increased, and vice versa. As the industry has driven to lower and lower forward voltages, the reverse leakage currents have been steadily increasing. It has now reached a point where additional reductions in forward voltage result in larger increases to the reverse leakage current, resulting in higher overall power dissipation.

Nevertheless, it is still common to think that the forward voltage is the main contributor to the power dissipation and reverse leakage current is of less importance; this is not necessarily true anymore. For example, if the output voltage of the boost converter (see Figure 1) is much larger than the input voltage the resulting duty cycle will be very large. The larger the duty cycle of the boost converter the longer the Schottky diode is reverse biased. In addition to the larger duty cycle, the output current of the boost converter could range from 10 to 40 mA. This is usually the case for the boost converter used in the LED backlight application for a wireless device. Table 1 compares a boost optimized Schottky diode from ON Semiconductor (Device 1) with another popular low forward voltage Schottky diode (Device 2). Although the forward voltage of Device 2 is 24 % lower, the power dissipation is 39 % higher.

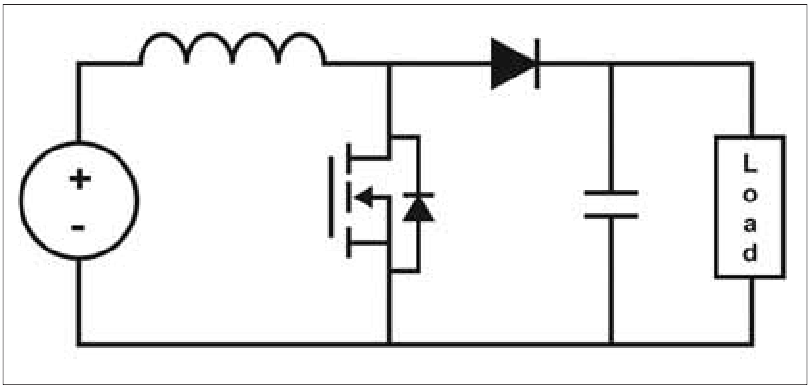



**Figure 1:** Schematic of boost converter

### Calculating the power dissipation

In the above table the power dissipation (PD) is calculated by the equations 1 and 2:

$$D = \frac{V_{out} + VF - V_{in}}{V_{out} - V_F} \quad (1)$$

$$P_D = D \times V_{out} \times I_R + (1 - D) \times V_F \times I_F \quad (2)$$

where D = Duty Cycle of Boost Converter, $P_D$ = Schottky Diode Power Dissipation, $V_{out}$ = Output Voltage of Boost Converter, $V_{in}$ = Input Voltage of Boost Converter, $I_F$ = Average Forward Current through Schottky Diode, $V_F$ = Forward Voltage of Schottky Diode at $I_F$, $I_R$ = Reverse Leakage Current of Schottky Diode at $V_{out}$.

The first step in calculating the power dissipation is to calculate the duty cycle. The values of Device 2 in Table 1 will be used to do this. In wireless devices the input voltage/battery voltage can be as low as 2.5 V. The output voltage depends on the configuration of the LEDs. A common configuration is one string of 10 LEDs. For white LEDs the forward voltage is around 3.3 V. For this configuration the output voltage will be

| Device | $V_F$ @ 10 mA | $V_F$ @ 100 mA | $I_R$ @ 30V | $P_D$ @ $I_F$ = 10 mA | $P_D$ @ $I_F$ = 100 mA |
|---|---|---|---|---|---|
| 1 | 270 mV | 366 mV | 19.2 µA | 0.75 mW | 3.54 mW |
| 2 | 199 mV | 277 mV | 95.7 µA | 2.80 mW | 4.92 mW |

**Table 1:** Boost optimized Schottky vs. low $V_F$ Schottky

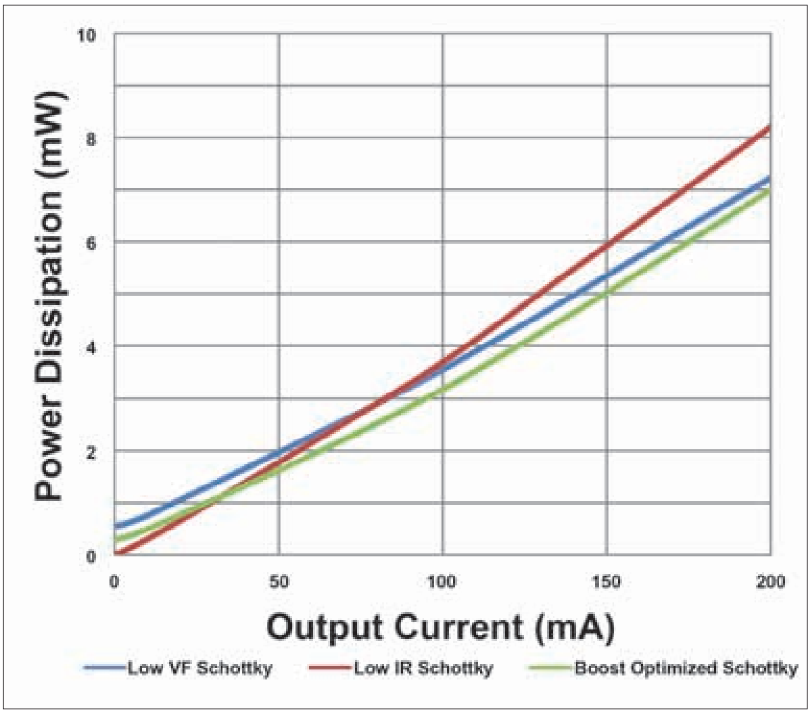



**Figure 2: Power dissipation of different Schottky diodes**

33 V. The forward voltage of Device 2 is 0.2 V at 10 mA. When these values are plugged into Equation 1 the resulting duty cycle is 92.5 %. This means that the Schottky diode will be reverse biased for 92.5 % of the time and forward biased for only 7.5 % of the time. Now let's take the values from Device 2 in Table 1 to calculate the power. When the device is reverse biased the voltage is 33 V and the leakage current will be around 100 µA. The resulting power when the device is reverse biased is 3.3 mW. Now looking at when the device is forward biased, the voltage will be 200 mV and the current will be 10 mA. This will give a forward biased power of 2 mW. When combining these values with the percentage of each bias, it is seen that the reverse bias contributes 3.05 mW and the forward bias contributes 0.15 mW. This example shows that in fact most of the power is generated from the leakage current.

The above example assumes the forward current is 10 mA. It is important to keep in mind that as the forward current increases the more the power dissipated in the forward biased condition will increase. However, the reverse biased power will remain the same. From this we can conclude that system designers need to consider the leakage current of Schottky diodes in low output current boost converters more than in high current boost converters to minimize total power dissipation.

Looking at the power dissipation over a range of output currents will further show the importance of choosing a boost optimized Schottky diode. Figure 2 plots the power dissipations of three equally sized devices: a Low $V_F$ Schottky, a low $I_R$ Schottky and a boost optimized Schottky.

As described above the low leakage device has the better power dissipation at lower output currents, but as the current increases the power dissipation rises more rapidly.

When looking at the low forward voltage Schottky diode, the influence of the high leakage is apparent at the low output currents. However, the power dissipation slope is less steep and the power dissipation becomes less than the low leakage device at higher output currents. The boost optimized Schottky diode combines the best-of-both of the previous devices. It has much better performance than the low forward voltage device at low currents and continues this trend to the higher currents. It is not superior to the low leakage device at low currents but the power savings are significant at higher currents. Additionally, the boost optimized Schottky diode takes the large current spikes from the inductor of the boost converter into account; the low leakage device does not perform well with these current spikes.

Low leakage devices will normally have a lower forward repetitive peak current rating, or $I_{FRM}$, than a boost optimized Schottky diode or low forward voltage Schottky diode. With a low leakage device the forward voltage tends to rise very quickly at currents above the rated DC current. In return, the device cannot handle the large current spikes as well as the other Schottky diodes.

## Conclusion

The importance of defining Schottky diodes based on power dissipation rather than individual device characteristics is now even more important as the trade-off between forward voltage and reverse leakage is becoming larger. ON Semiconductor's approach is an example of developing Schottky diodes based on power dissipation that will allow system designers to maximize battery lifetime in portable applications.

# Challenges of Wide Bandgap Power Semiconductor Testing

Devices based on Silicon Carbide (SiC) and Gallium Nitride (GaN) can switch at much higher frequencies and also have far lower leakage than Silicon, so at the same time as there is a need for sourcing higher voltages in testing, there is also a need for greater current measurement sensitivity. It can be quite challenging to characterize these new devices at very low levels of current. DC instrumentation must be capable of characterizing significantly higher rated voltages and peak currents than ever before while providing the measurement resolution and accuracy characterizing these new materials demands.
**Mark A.Cejer, Marketing Director, Tektronix/Keithley Instruments, Cleveland, USA**

**Wide bandgap semiconductor materials** like Gallium Nitride (GaN) and Silicon Carbide (SiC) will be integral to the development of the next generation of power semi devices. Because they offer roughly a 10X advantage over traditional Silicon in terms of conduction and switching properties, they're ideal for creating power electronics, which are often used as switches or blocking devices. These advantages, in concert with their higher durability and reliability, make these devices invaluable for emerging applications that depend on power conversion efficiency, including hybrid electric and electric vehicles, alternative/renewable energy generation and storage, power supplies, motors and drives, lighting, consumer electronics, household appliances, and many others.

Devices like power diodes, thyristors, power MOSFETs, and IGBTs fabricated with these materials typically have higher power density, smaller size, and lower on-resistance than those made of Silicon, all of which add up to greater operating efficiency. They can also operate at higher temperatures, voltages, and frequencies with lower power loss than Silicon devices.

DC instrumentation must be capable of characterizing significantly higher rated voltages and peak currents than ever before while providing the measurement resolution and accuracy characterizing these new materials demands. When the devices are in the on-state, they have to pass through tens or hundreds of amps with minimal loss, which means the internal resistance ($R_{ds(on)}$) is very low; when they are off, they have to block thousands of volts with minimal leakage currents, so the drain currents will be very low. Consider that typical drain leakage currents on a SiC power FET might be on the picoamp range, but an automated power device tester might be limited only to resolving hundreds of nanoamps or even microamps. Meeting this challenge demands a new generation of test hardware that is both more powerful and more sensitive.

## On-state characterization

A high current instrument capable of sourcing high levels of current and measuring low-level voltages or resistances is commonly used for on-state characterization. If the device under test (DUT) has three terminals, a second source measure unit (SMU) instrument is used at the device control terminal to place the device in the on-state. Figure 1 illustrates a typical configuration for characterizing the on-state parameters of a power MOSFET.

One of the most recognizable types of test results for a semiconductor device is a plot of its output characteristics, which

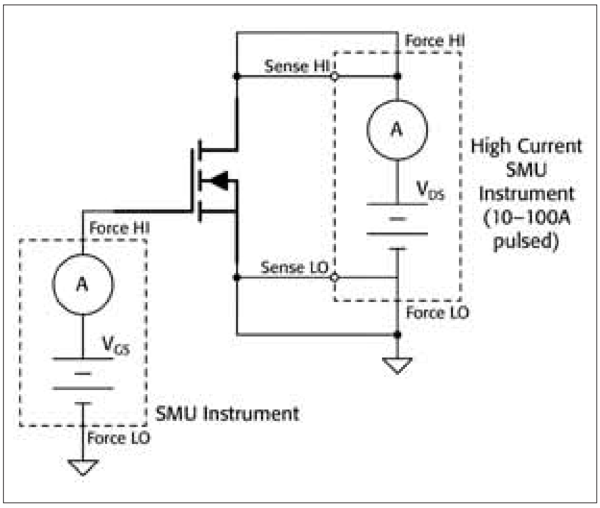



**Figure 1: Typical SMU configuration for on-state characterization of power devices**

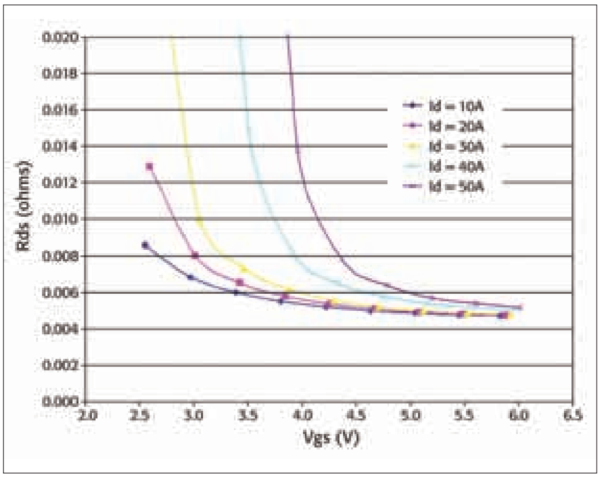



**Figure 2: Results from performing a pulsed $R_{ds(on)}$ current sweep to test up to 50 A on a power MOSFET device using a high-power SMU instrument. It is possible to test up to 100 A by connecting two high-power SMU instruments in parallel**

depicts the relationship between the output voltage and current. Figure 2 shows $R_{ds(on)}$ measurement data from a power MOSFET device by using a pulsed current sweep.

Power semiconductor devices are often high gain devices; oscillation is common when characterizing such devices, which can result in erratic measurements. Verifying the presence of oscillation demands source-and-measure instruments with high-speed A/D converters and the ability to characterize pulse transients accurately. Resolving this oscillation involves adding a resistor in series with the device control or input terminal, for example, the gate of a MOSFET or IGBT, so test engineers often choose test fixtures (Figure 3) that can handle the high-power signals involved as well as accommodate the addition of a discrete resistor.

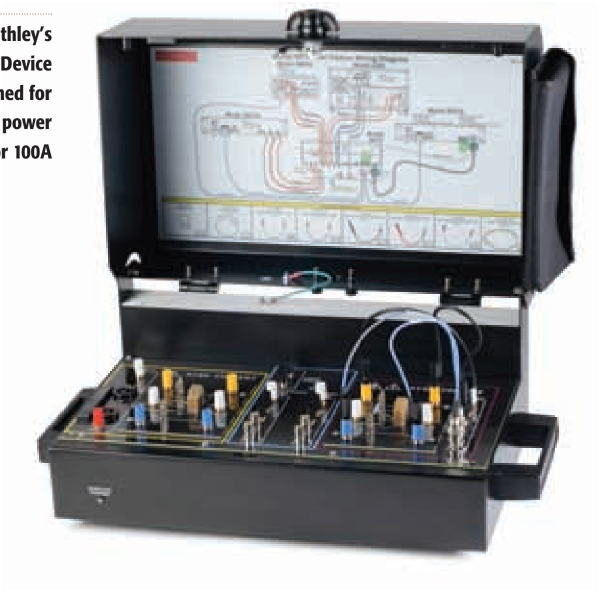
## Off-state characterization

For power semiconductor devices, off-state characterization often involves the use of a high voltage instrument capable of sourcing hundreds or thousands of volts and measuring small currents. Because it's often performed between two device terminals, a single SMU instrument is often sufficient to perform the measurement. However, an additional SMU instrument can be used to force the device into its off-state or to add certain stress to certain terminals.

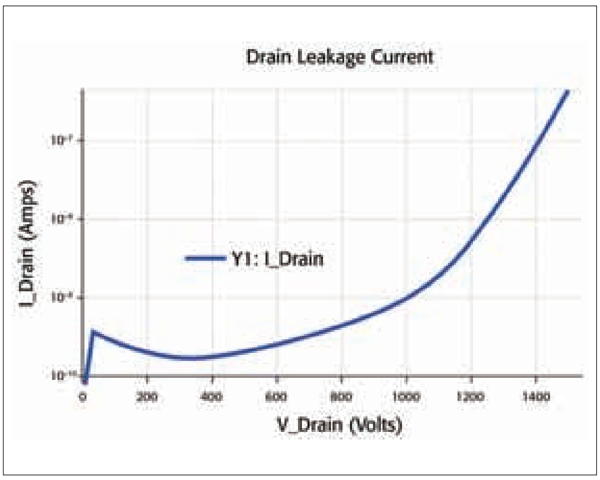
Breakdown voltages and leakage currents are the primary DC tests performed when the device is off. A device's off-state breakdown voltage determines the maximum voltage that can be applied to it. The primary withstanding voltage of interest to power management product designers is the breakdown voltage between drain and source of a MOSFET or between the collector and emitter of an IGBT or BJT. For a MOSFET, the gate can be either shorted or forced into a "hard" off-state, such as by applying a negative voltage to an n-type device or a positive voltage to a p-type device. This is a very simple test that can be performed using one or two SMU instruments. The lower power SMU instrument is connected to the gate and forces the transistor off. It can force 0 V for a gate shorted test or force a user-specified bias voltage. A high voltage SMU instrument, such as the Model 2657A, applies the necessary high voltage to the drain and measures the resulting drain current.

Leakage current is the level of current that flows through two terminals of a device even when the device is off, so minimizing leakage current minimizes power loss. While testing a power device's off-state, it is generally desirable to test the drain or collector leakage current, the values of which are typically on the nanoamp, picoamp, or even sub-picoamp levels. Figure 4 is a plot of off-state drain voltage vs. drain current results for a commercially available SiC power MOSFET.

**ABOVE Figure 5: With up to 2 GHz bandwidth and 10 GS/s real-time sample rate, Tektronix MSO/DPO5000B oscilloscopes offer the performance needed to handle the fast switching times seen in devices based on the newer compound processes, including GaN and SiC. MSO/DPO5000B oscilloscopes can be used with the full range of Tektronix voltage and current probes**



**RIGHT Figure 3: Keithley's Model 8010 High Power Device Test Fixture is designed for testing packaged high power devices at up to 3000V or 100A**




**LEFT Figure 4: A look at the drain leakage current as the drain voltage is swept while the transistor is in the off-state**

## Future outlook

Switching power supplies are one of many power conversion technologies that are beginning to incorporate wide bandgap devices. Optimizing the designs of these products requires the use of higher-frequency tools. Oscilloscopes (Figure 5), high performance probes, and power analysis software are the AC tools of choice for characterizing components at high frequencies, analyzing the performance of a power conversion design, and understanding the source of problems. They make it possible to measure parameters like switching losses (turn-on, turn-off and conduction) and characterize the device's operating region (Safe Operating Area, SOA).

More technical details can be found in the 'Testing Power Semiconductor Devices application note' (www.keithley.com/data?asset=57464).

# Motor and Resolver Integrated

The Mosolver is an innovative closed-loop motion actuator which infuses a position feedback sensor into the magnetic structure of a high pole count AC hybrid servo motor. The position sensor coils are placed within the motor structure so as to intercept a portion of the flux used to operate the motor. The ripple current associated with the PWM drive provides the flux variation required to induce a voltage in the sense coils. When properly sampled, the sensor output provides sine and cosine information similar to a resolver, and these signals are available even when the motor is stationary. **Donald P. Labriola, QuickSilver Controls Inc., USA, Edward Hopper, Maccon GmbH, Munich, Germany**

**High pole count Permanent Magnet AC** synchronous motors, when operated in open loop, are called microstepper motors. The high pole count design produces superior torque density, while the highly tooled production combined with the low quantity of rare-earth magnets required result in a low cost motor. Open loop operation also typically uses very simple control schemes. Unfortunately, when operated in open loop, these motors are subject to low and mid frequency resonances, lost steps, and drop-out. They typically are used at one-third to one-half of their torque rating, wasting significant torque capability while also producing excess heat.

These same motors, when operated in a true closed loop mode, such as Vector control, are known as Hybrid Servos. Closed loop operation eliminates the low frequency resonance associated with the rotor inertia interacting with the rotary magnetic "spring" constant. Commutating the motor causes the stator field angle to track the rotor position so as to produce the maximum torque for a given commanded current.

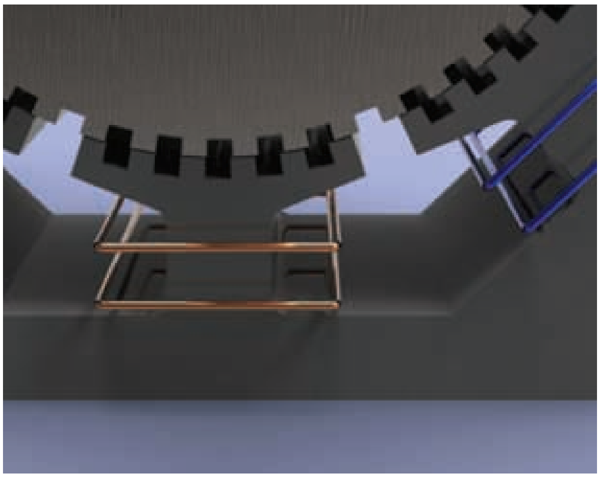


**Figure 1: Sense coils and rotor-stator alignment**

## Mosolver construction

Microstepper class motors are typically constructed with the tooth spacing on the stator slightly different from that used by the rotor to prevent all the teeth from aligning simultaneously. The simultaneous alignment gives rise to large detent torque as well as cogging. Figure 1 shows a typical 52:50 tooth spacing. The teeth on stator are set at a slightly tighter angular spacing (as if there were 52 teeth) than those on the rotor (with 50 teeth).

Figure 2 (left) shows the sense coil used in the 2-phase Mosolver tested. For this stator design, using sensing coils on all eight stator pole structures helps cancel out the effects of rotor runout and minimizes the number of turns required for each sensor coil to get robust signals. Each sensor coil is split into four quadrants with quadrants 1 and 3 being wound in the clockwise direction while quadrants 2 and 4 are wound in the counter clockwise direction. The voltage produced by a particular quadrant of the sense coil is dependent upon the number of turns of that coil, and the rate of change of the flux

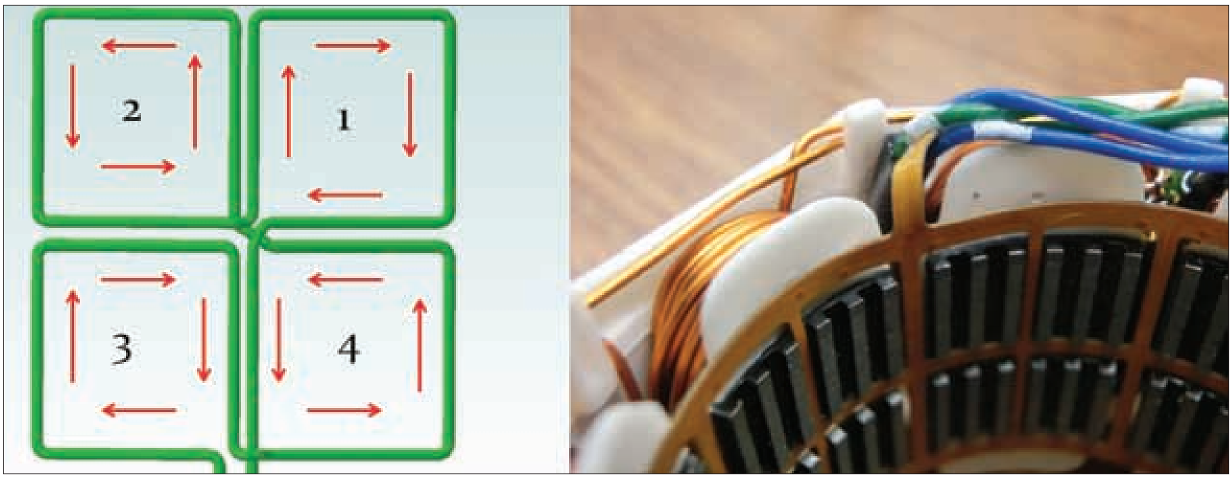



**Figure 2: Sense coil implemented as a flex circuit used in the 2-phase Mosolver**

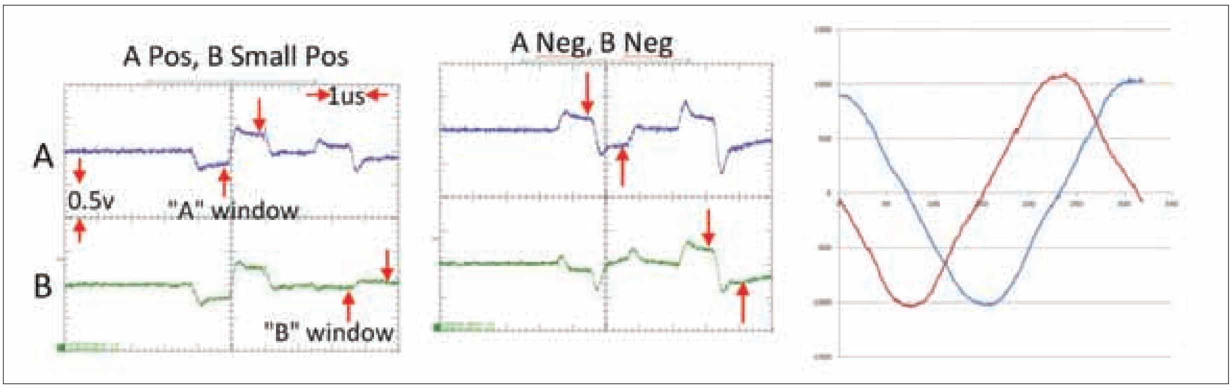



**Figure 3: Analog signals from the sensor coil signals after they have been multiplied by 3 by a differential amplifier (left, middle), and sampled data from the Sine and Cosine windings taken while the Mosolver is rotating**

passing through that coil window, while the polarity is affected by both the sign of the rate of change of the flux and by the direction in which the coil is wound.

The total voltage produced by the sense coil depends on the division of the stator flux (and thus ripple) into different groups of teeth passing through the various sense coil loops, the division being moderated by the relative overlap of the stator teeth to the rotor teeth. With the sense coils in sectors 1 and 3 wound in the opposite direction compared to sectors 2 and 4, the output signal resulting is related to the difference in the rate of change of flux through sectors 1 and 3 versus that through 2 and 4.

Physically, the sense coils were implemented as a flex circuit which is inserted into the stator before the rotor is inserted. The sensor is completely contained in the otherwise unused spaces within the stator structure and thus protected mechanically. The total weight of the system increases only minimally, and may actually be reduced due to the material removed to produce the groove in which the coil lays. As no material is added to the rotor, its inertia is not changed.

## Sensor data

Figure 3, left and middle frames, shows the analog signals from the sensor coil signals after they have been multiplied by 3 by a differential amplifier. These signals are then sampled by the internal A/D converter. The sampling times are configured to take data at the end of the reverse pulse (just before the driver transitions to the forward pulse), and again about the same time into the forward pulse. This is done for both channels. The PWM logic must prevent multiple driver transitions while in the read window while still providing the PWM signals needed to produce the commanded torque for the system.

Figure 3 right shows the sampled data from the Sine and Cosine windings taken while the Mosolver is rotating. These signals are decoded into angle by the DSP (processor). The absolute angle within an electrical cycle provides sinusoidal commutation information for the motor, and does not require phasing adjustments as the same magnetic structure for the motor is used for the sensor. This electrical cycle repeats 50 times per mechanical revolution of the rotor within the stator. The processor extends the counts from each electrical cycle to track position over multiple revolutions of the motor. Each electrical cycle is divided into 640 increments producing 32000 increments per revolution. One electrical cycle (7.2 degrees mechanical) is shown. The Y axis is ADC counts, the X axis is time.

## Conclusions

The shared use of the magnetic structure of a motor for both torque production and for position measurement has been shown effective and viable from stationary operation up to 4000 RPM. The resulting structure is compact and physically robust with the sensor completely enveloped within the motor structure. The signals are robust and the position sensing shows good resolution. The sensor is inexpensive, and there is very little impact on the electronics complexity for the digital drive. Phasing alignment of the sensor for commutation is not needed as the motor and sensor share the same magnetic structure.

This patented method has now been demonstrated in high pole count motors, and is also applicable to many other motor styles by appropriate placement of the sensor coils. The availability of inexpensive, compact, and robust position feedback in high pole count motors invites a transition to the improved performance of closed loop operation in a market segment currently dominated by open loop operation. The high torque density provided also allows these Hybrid Servos to also push up into the existing servos market segment through reduced size and cost, and the frequent elimination of gearheads.

## Literature

*Donald P. Labriola "Mosolver™ - Integrated Motor and Resolver – Operational", PCIM Europe 2014 Proceedings, pp. 227-232*

# 1 kV Power Switch

Fairchild introduced at Electronica the 1000 V integrated power switch, offering the industry's highest breakdown voltage in a single package for designing reliable SMPS for smart meter, appliance and industrial systems. The FSL4110LR integrates a VDMOS SenseFET with built in line compensation for wide input voltage range from 45V AC to 460 V AC. It also includes built- in input over voltage protection and a safe auto-restart mode for all protection conditions. The device provides Abnormal Over Current Protection (AOCP), which protects the power converter from transformer abnormalities and is particularly important for smart metering applications. The FSL4110LR is a solution for flyback converters that need to meet three phase input voltage or unstable single phase input voltage requirements.

**www.fairchildsemi.com**

## 600 V Fast Body Diode N-Channel MOSFETs

**Vishay Intertechnology introduced the first two devices in its new 600 V EF Series (Siliconix SiHx28N60EF and SiHx33N60EF) of fast body diode n-channel power MOSFETs. Offered in four packages, the 28 A SiHx28N60EF and 33 A SiHx33N60EF feature ultra-low on-resistance of 123 Ω and 98 Ω, respectively, and low gate charge. These values translate into extremely low conduction and switching losses to save energy in high-power, high-performance switch mode applications. The devices increase reliability in these applications by offering a 10x lower reverse recovery charge than standard MOSFETs. This allows the devices to regain the ability to block the full breakdown voltage more quickly, helping to avoid failure from shoot-through and thermal overstress.**

**www.vishay.com/doc?91600**

# Active Filter Minimizes Leakage Currents

In conventional converter-based power drive systems with long motor cables, very high earth leakage currents can occur in standard 3-phase industrial power grids. They are caused by capacitive coupling between the EMC input filter, the frequency converter, the motor cable and the motor itself. The EPCOS LeaXield™ is designed to minimize earth leakage currents by connecting between the grid and the EMC input filter. LeaXield detects the common-mode currents on the load-side via a current sensing transformer. It then feeds an inverse of these currents via an amplifier and a capacitor network to the power line to produce almost complete cancellation of the leakage currents. It is suitable for all applications, in which converter-generated leakage currents can trip the RCD, especially in the frequency range from 1 kHz to approximately 500 kHz. LeaXield is now designed for rated currents of up to 150 A for 3-phase grids at frequencies of 50/60 Hz and a rated voltage of 520 V AC. The new active filter can be used in systems with leakage currents of up to 1000 mA. The LeaXield module can be retrofitted to existing converter-based installations in order to improve the EMC and the RCD compatibility and can be integrated into new EMC filter solutions in order to downsize the expensive current-compensated filter chokes.


**www.epcos.com**


# New 1200 V IGBT Platform

IR's new generation 8 (Gen8) 1200V IGBT platform utilizes trench gate field stop technology and is available with current ratings from 8 A up to 60 A with typical VCE(ON) of 1.7 V and a short-circuit rating of 10 µs. The new technology offers softer turn-off characteristics ideal for motor drive applications, minimizing dv/dt to reduce EMI, and over-voltage, increasing reliability and ruggedness. A narrow distribution of parameters offers excellent current sharing when paralleling multiple IGBTs. The thin wafer technology delivers improved thermal resistance and maximum junction temperature up to 175°C. Pricing for the IRG8P08120KD begins at US $3.05 in 10,000-unit quantities.

**www.irf.com**

## Analog Controller Optimizing Rechargeable Battery

Analog Devices introduced two components that work together as an integrated analog controller to offer energy recycling for rechargeable battery formation and grading system solutions. The AD8450/1 analog front-end and controller, and the ADP1972 buck/boost PWM controller provide energy efficiency benefits in the charging and discharging cycles, both as the current is provided through a PWM controller as well as when it is directed back to the grid or to charge other cells. Unique to this two-device architecture is the use of analog control loops, which offer significant benefits over the current digital solution. These benefits include faster control of up to 1.5 MHz for the critical signal path, greater than 90 percent efficiency and higher accuracy over temperature. The solution is designed for battery formation and grading systems for medium- and high-energy batteries used in hybrid and electric vehicles, energy storage and industrial tools. Other benefits of include the ability to share lower-cost precision D/A converters and A/D converters over multiple channels. The addition of synchronization with phase-shifting between channels reduces input filtering. Also, the solution minimizes the need for complex coding and cuts system calibration time in half. Both synchronous and non-synchronous architectures are available.


**www.analog.com/AD8450**

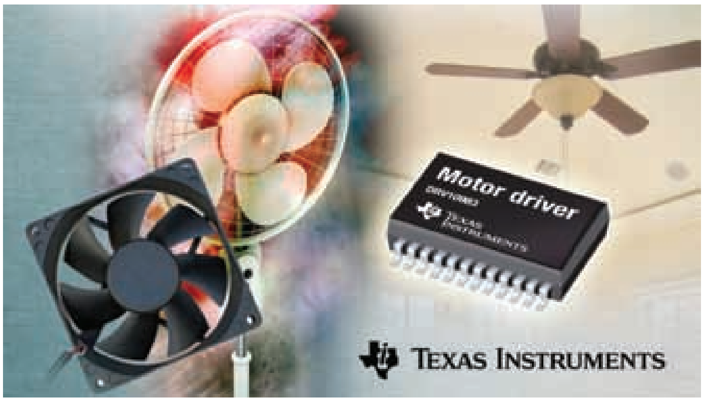

TARGET YOUR BUYERS
FROM OVER 60,000
QUALIFIED CONTACTS
■ E-CAMPAIGN
■ LIST RENTAL
■ LEASE
DfA media
Direct
Contact: Ian Atkinson
on +44 (0)1732 370340
ian.atkinson@dfamedia.co.uk
Plant&Works Engineering
Drives&Controls
Hydraulics&Pneumatics
THE JOURNAL OF FLUID POWER AND SYSTEMS
POWER ELECTRONICS EUROPE

# Three-Level Power Modules

Vishay Intertechnology introduced four new IGBT power modules designed specifically for string solar inverters and medium power range UPS. Combining Ultrafast Trench IGBTs, high-efficiency HEXFRED® and FRED Pt® diode technologies, and thermistors for easy thermal management in single packages featuring pressfit technology, the offer integrated solutions for 3-level NPC topologies and interleaved multiple-channel MPPT boost converters. For 3-level NPC topologies, the VS-ENQ030L120S provides a collector-to-emitter breakdown voltage of 1200 V and a collector current rating of 30 A. Designed for 3-level inverter stages, the VS-ETF075Y60U and VS-ETF150Y65U offer designers a choice of 75 A and 150 A collector current ratings and 600 V and 650 V collector-to-emitter breakdown voltages, respectively, and provide high-temperature performance to +175 °C. Optimized for double boost converters, the 15 A VS-ETL015Y120H features a collector-to-emitter breakdown voltage of 1200 V, high-efficiency Silicon boost diodes, integrated 62 A bypass diodes, and panel short-circuit full-current reverse polarity protection diodes. The devices provide low internal inductance and switching losses, while offering operating frequencies up to 20 kHz.

**www.vishay.com/modules/igbt-modules/sales**

# Sensorless 24 V DC Motor Driver




Texas Instruments offers the first 24 V, sinusoidal, sensorless, brushless DC (BLDC) motor driver. The DRV10983 gives customers the ability to quickly tune their motors for reliable start-up and optimal performance using a configurable, 3-A driver with integrated control logic. Utilizing 180-degree, sinusoidal, sensorless technology, the DRV10983 delivers up to 75 % quieter solutions for applications like cooling fans, ceiling fans, blowers and small appliances. The 180-degree operation, coupled with advanced start-up algorithms, enables quieter operation with no annoying clicks or pops at start-up.  Pure tone harmonics, a significant noise adder in fan applications, are reduced by as much as 25 dBA. The single-chip solution with integrated power FETs, sensorless control logic and optional 100-mA, 3.3- or 5-V step-down converter reduce board space, system cost and development time. The DRV10983EVM evaluation module is a cost effective, sensorless solution for running three-phase BLDC motors. It includes a BLDC motor and comes complete with a graphical user interface (GUI), schematics and Gerber files.

**www.ti.com/drv10983-pr-eu**


Texas Instruments introduced six AEC-Q100-qualified gate drivers with short propagation delays of less than 15 ns. The UCC275xx-Q1 family of single- and dual-channel gate drivers provides high power efficiency, reliability and flexibility for applications such as powertrain, bi-directional converters (12- to 48-V and 12- to 400-V input), onboard charging, traction inverters, advanced driver assistance systems (ADAS), safety, headlamps and instrumentation clusters. With peak currents ranging from 2.5 A to 5 A and propagation delays of less than 15 ns, these automotive output-stage drivers can replace discrete totem pole solutions. The temperature range of -40°C to 140°C and negative input voltage of -5 V enables handling of ground bouncing experienced in harsh environments. By supporting 4.5 V to 35 V wide bandgap switches such as SiC MOSFETs and IGBTs can be switched that are capable of withstanding high temperatures without compromising efficiency. Additionally, the inverting functions of the UCC27518A-Q1 and UCC27519A-Q1, and non-inverting functions of the UCC27531-Q1, UCC27517A-Q1, UCC27519A-Q1 and UCC27524A-Q1 add the flexibility to handle different types of inputs.

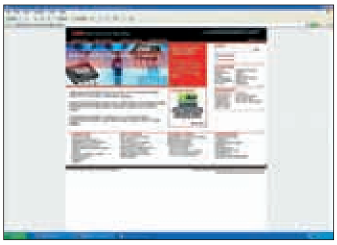
**www.ti.com/ucc27531q1-pr-eu**

# High Power Density DC/DC Module

Intersil introced the ISL8240M, a dual 20 A/single 40 A step-down power module that is capable of delivering up to 100 W of output power in a 2.9 $cm^2$ footprint. Thus the ISL8240M provides designers with a turnkey DC/DC converter solution for high current applications. The ISL8240M is pin-to-pin compatible with the company's ISL8225M 30A power module, expanding the output current to 40 A and delivering up to 100 W output power. This offers designers a high level of flexibility, enabling a single PCB design across platforms. The ISL8240M is also capable of delivering up to 240 A output when six modules in parallel operation are current shared. Input voltage range covers 4.5 V to 20 V and adjustable output ranges from 0.6 V to 2.5 V. The ISL8240M power module is priced at $39.85 each in 1,000-piece quantities. The ISL8240MEVAL3Z and ISL8240MEVAL4Z provide an evaluation platform for the ISL8240M and are priced at $88.00.


**www.intersil.com/products/ISL8240m**

## AC/DC Connverters



**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

## Arbitrary 4-Quadrant Power Sources

**www.rohrer-muenchen.de**
Rohrer GmbH
Tel.: +49 (0)89 8970120

## Busbars

**www.auxel.com**
Auxel FTG
Tel: + 33 3 20 62 95 20

## Capacitors

**www.psl-group.uk.com**
PSL Group UK Ltd.
Tel +44 (0) 1582 676800

## Certification

**www.productapprovals.co.uk**
Product Approvals Ltd
Tel: +44 (0)1588 620192

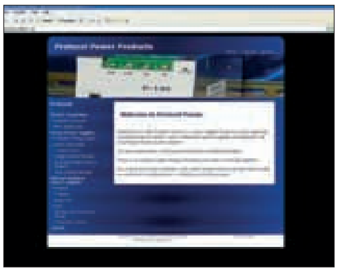
## Connectors & Terminal Blocks

**www.auxel.com**
Auxel FTG
Tel: +44 (0)7714 699967

## DC/DC Connverters

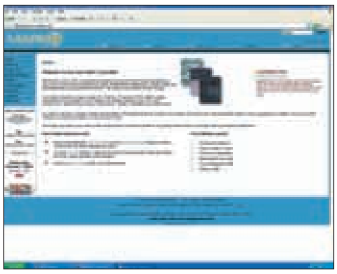
**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200



**www.protocol-power.com**
Protocol Power Products
Tel: +44 (0)1582 477737

## Diodes



**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

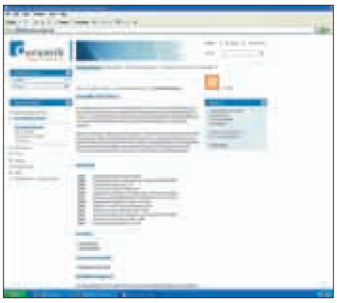
**www.neutronltd.co.uk**
Neutron Ltd
Tel: +44 (0)1460 242200

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028

**www.voltagemultipliers.com**
Voltage Multipliers, Inc.
Tel: 001 559 651 1402

**www.proton-electrotex.com/**
Proton-Electrotex JSC/
Tel: +7 4862 440642;

## Direct Bonded Copper (DPC Substrates)



**www.curamik.co.uk**
curamik® electronics GmbH
Tel: +49 9645 9222 0

## Discrete Semiconductors

**www.digikey.com/europe**
Digi-Key
Tel: +31 (0)53 484 9584

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028

## Drivers ICS

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## EMC/EMI

**www.dextermag.com**
Dexter Magnetic Technologies, Inc.
Tel: 001 847 956 1140

## Ferrites & Accessories

**www.dextermag.com**
Dexter Magnetic Technologies, Inc.
Tel: 001 847 956 1140

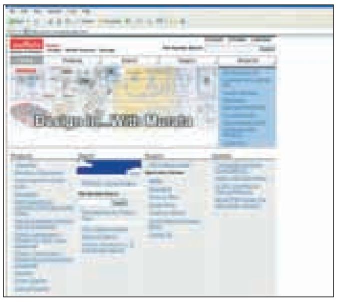
## GTO/Triacs

**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

## Hall Current Sensors

**www.dgseals.com**
dgseals.com
Tel: 001 972 931 8463

## Harmonic Filters



**www.murata-europe.com**
Murata Electronics (UK) Ltd
Tel: +44 (0)1252 811666

## IGBTs

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Line Simulation

**www.hero-power.com**
Rohrer GmbH
Tel.: +49 (0)89 8970120

## Magnetic Materials/Products

**www.dextermag.com**
Dexter Magnetic Technologies, Inc.
Tel: 001 847 956 1140

**www.rubadue.com**
Rubadue Wire Co., Inc.
Tel. 001 970-351-6100

## Mosfets

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028

**www.neutronltd.co.uk**
Neutron Ltd
Tel: +44 (0)1460 242200

## Optoelectronic Devices

**www.digikey.com/europe**
Digi-Key Tel: +31 (0)53 484 9584

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Packaging & Packaging Materials

**www.curamik.co.uk**
curamik® electronics GmbH
Tel: +49 9645 9222 0

## Power Amplifiers

**www.rohrer-muenchen.de**
Rohrer GmbH
Tel.: +49 (0)89 8970120

## Power ICs

**www.digikey.com/europe**
Digi-Key Tel: +31 (0)53 484 9584

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Power Modules

**www.psl-group.uk.com**
PSL Group UK Ltd.
Tel +44 (0) 1582 676800

**www.fujielectric-europe.com**
Fuji Electric Europe GmbH
Tel: +49 (0)69-66902920

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028

**www.proton-electrotex.com/**
Proton-Electrotex JSC/
Tel: +7 4862 440642;

## Power Protection Products

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Power Semiconductors

**www.psl-group.uk.com**
PSL Group UK Ltd.
Tel +44 (0) 1582 676800

**www.proton-electrotex.com/**
Proton-Electrotex JSC/
Tel: +7 4862 440642;

## Power Substrates

**www.universal-science.com**
Universal Science Ltd
Tel: +44 (0)1908 222211

## Resistors & Potentiometers

**www.isabellenhuette.de**
Isabellenhütte Heusler GmbH KG
Tel: +49/(27 71) 9 34 2 82

## RF & Microwave Test Equipment.

**www.ar-europe.ie**
AR Europe
Tel: 353-61-504300

## Simulation Software

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

**www.universal-science.com**
Universal Science Ltd
Tel: +44 (0)1908 222211

## Smartpower Devices

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

## Switches & Relays

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

## Switched Mode Power Supplies

**www.biaspower.com**
Bias Power, LLC
Tel: 001 847 215 2427

## Switched Mode Power Supplies

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Thermal Management & Heatsinks

**www.abl-heatsinks.co.uk**
ABL Components Ltd
Tel: +44 (0) 121 789 8686

**www.curamik.co.uk**
curamik® electronics GmbH
Tel: +49 9645 9222 0

**www.dau-at.com**
Dau GmbH & Co KG
Tel: +43 3143 23510

**www.power.ti.com**
Texas Instrumments
Tel: +44 (0)1604 663399

**www.universal-science.com**
Universal Science Ltd
Tel: +44 (0)1908 222211

**www.psl-group.uk.com**
PSL Group UK Ltd.
Tel +44 (0) 1582 676800

## Thyristors

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

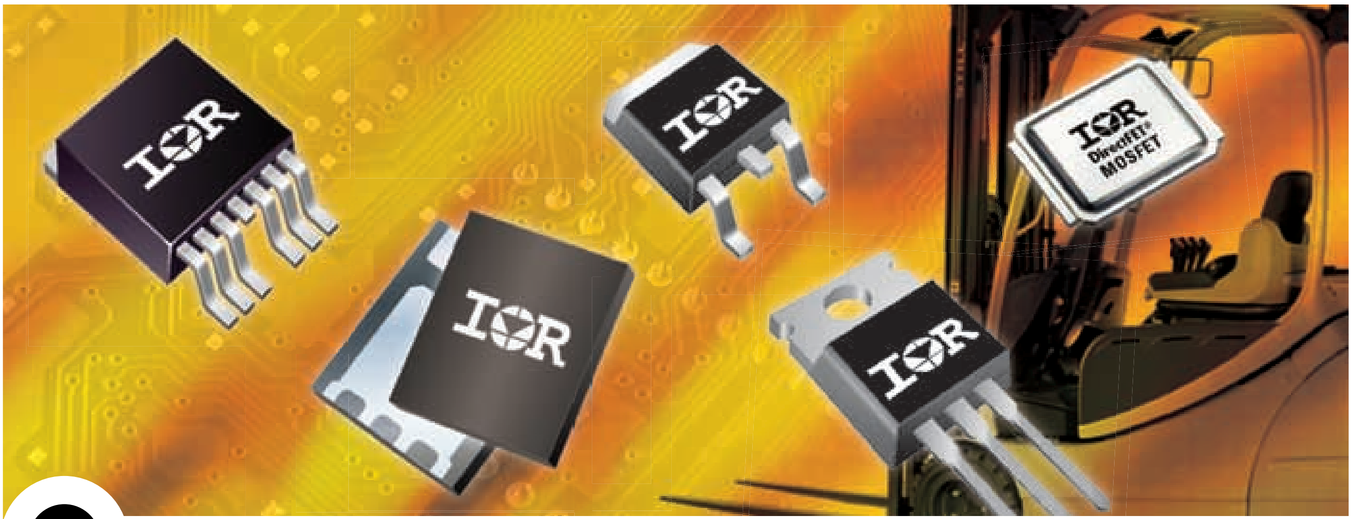
**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

**www.proton-electrotex.com/**
Proton-Electrotex JSC/
Tel: +7 4862 440642;

## Voltage References

**www.irf.com**
International Rectifier Co.
(GB) Ltd
Tel: +44 (0)1737 227200

## ADVERTISERS INDEX




# Rugged, Reliable MOSFETs for Industrial Applications

| Part Number | $V_{DS}$ (V) | $R_{DS(on)}$ Max. VGS=10V (mΩ) | $I_D$ (A) | $Q_G$ (nC) | Package |
|---|---|---|---|---|---|
| IRF7739L2 | 40 | 1 | 270 | 220 | DirectFET-L8 |
| IRFB7430 | 40 | 1.3 | 409 | 300 | TO-220 |
| IRFH7004 | 40 | 1.4 | 259 | 129 | PQFN 5X6 mm |
| IRFS7440 | 40 | 2.5 | 208 | 90 | $D^2PAK$ |
| IRFS3006-7 | 60 | 2.1 | 240 | 200 | $D^2PAK$-7 |
| IRFS3006 | 60 | 2.5 | 195 | 200 | $D^2PAK$ |
| IRFH5006 | 60 | 4.1 | 100 | 67 | PQFN 5x6 mm |
| IRF7749L2 | 60 | 1.3 | 108 | 220 | DirectFET-L8 |
| IRFB3077 | 75 | 3.3 | 210 | 160 | TO-220 |
| IRFH5007 | 75 | 5.9 | 100 | 65 | PQFN 5x6 mm |
| IRF7759L2 | 75 | 2.2 | 83 | 220 | DirectFET-L8 |
| IRFP4468 | 100 | 2.6 | 195 | 360 | TO-247 |
| IRFH5010 | 100 | 9 | 100 | 65 | PQFN 5x6 mm |
| IRF7769L2 | 100 | 3.5 | 124 | 200 | DirectFET-L8 |
| IRFS4010-7 | 150 | 4 | 190 | 150 | $D^2PAK$ |
| IRFS4010 | 150 | 4.7 | 180 | 143 | $D^2PAK$ |
| IRFH5015 | 150 | 31 | 56 | 33 | PQFN 5x6 mm |
| IRF7779L2 | 150 | 11 | 67 | 97 | DirectFET-L8 |
| IRFP4668 | 200 | 9.7 | 130 | 161 | TO-247 |
| IRFH5020 | 200 | 59 | 41 | 36 | PQFN 5x6 mm |
| IRFP4768 | 250 | 17.5 | 93 | 180 | TO-247 |
| IRFH5025 | 250 | 100 | 32 | 37 | PQFN 5x6 mm |
| IRF7799L2 | 250 | 38 | 35 | 110 | DirectFET-L8 |

### Features
- Low on resistance per silicon area
- Optimized for both fast switching and low gate charge
- Excellent gate, avalanche and dynamic dv/dt ruggedness

### The IR Advantage
- Best die to footprint ratio
- Large range of packages
- Available from 40 V to 250 V

### Applications
- DC Motor Drives
- Uninterruptible Power Supplies (UPS)
- DC-DC Converters
- Power Tools
- Electric Bikes

**Your FIRST CHOICE for Performance**

**For more information call +49 (0) 6102 884 311**
**or visit us at www.irf.com**

International
IOR Rectifier
**THE POWER MANAGEMENT LEADER**