POWER ELECTRONICS EUROPE

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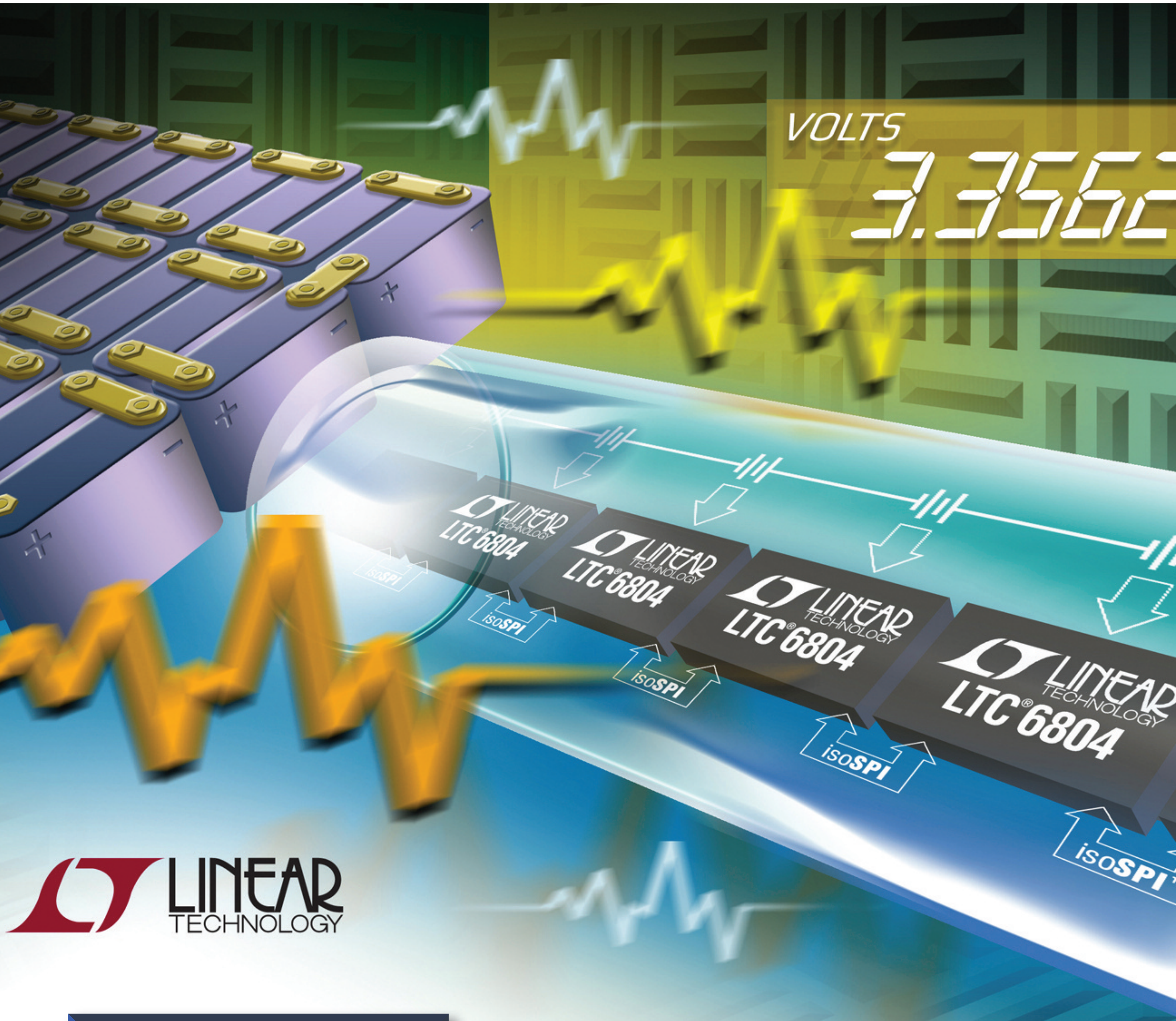
BATTERY MANAGEMENT

Highly Accurate Hybrid/Electric Battery Monitor



THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

Also inside this issue

Pre-Applied Thermal Interface Material (TIM)

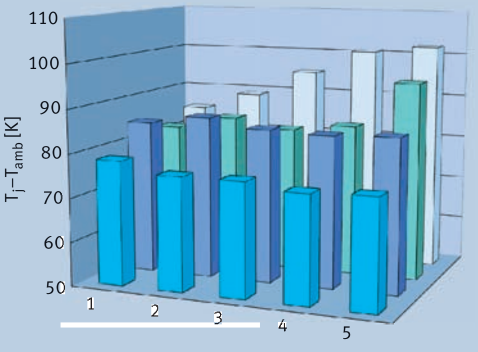
The Infineon-qualified solution

With the ongoing increase of power densities in power electronics the thermal interface between power module and heatsink becomes a larger challenge. A thermal interface material, especially developed for and pre-applied to Infineon's modules outperforms the general purpose materials available.

TIM does not only provide the lowest thermal resistance, it also fulfills the highest quality standards given for power modules to achieve the longest lifetime and highest system reliability.

Main Features

- Best in class thermal resistance
- Pre-applied to Infineon Modules
- Dry to the touch
- Optimized for dedicated Infineon Modules



Benefits

- Reduced process time in manufacturing
- Simplified mounting
- Increased system reliability
- Increased system lifetime
- Optimized thermal management
- Improved handling in case of maintenance

www.infineon.com/tim

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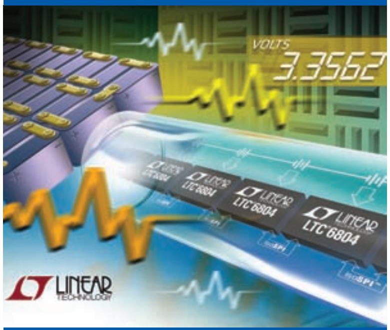


Highly Accurate Hybrid/Electric Battery Monitor

Lithium-Ion batteries require considerable care if they are expected to operate reliably over a long period. They cannot be operated to the extreme end of their state-of-charge (SOC). The capacity of Lithium-Ion cells diminish and diverge over time and usage, so every cell in a system must be managed to keep it within a constrained SOC. To provide sufficient power for a vehicle, tens or hundreds of battery cells are required. These cells must be configured in a long series; as much as 1000 V and higher. The battery electronics must operate in this very high voltage environment and reject common mode voltage effects, while differentially measuring and controlling each cell in these strings. The electronics must be able to translate information from the battery stack to a central point for processing. On top of these requirements, operating a high-voltage battery stack in a vehicle or other high-power applications imposes tough conditions, such as operation with significant electrical noise and wide operating temperatures. The battery management electronics are expected to maximize operating range, lifetime, safety and reliability, while minimizing cost, size and weight. Linear Technology's 3rd generation Battery Management System provides many desirable features for monitoring large and distributed battery packs in vehicle and industrial applications. Full article on page 25.

Cover supplied by Linear Technology Corporation

IGBTs are historically known for having long tail currents with focus on drive applications and anything switching up to 30 kHz was known as "High Speed", where conduction losses were penalized to get switching losses down. In 2008, Infineon launched a ground breaking technology called the HighSpeed3, which is the highest efficiency IGBT capable of switching up to 100 kHz with a MOSFET-like turn-off switching behavior. Now Infineon's TRENCHSTOP™ 5 technology is capable of switching well beyond 100 kHz. **Mark Thomas, Discrete IGBT Product Marketing, Infineon Technologies AG, Villach, Austria**

Innvation Never Stops

Recent shows have underlined the potentials of energy saving through latest achievements in power electronics.

Cree entered at Electronica the Power Module market with a self-designed 1200 V / 100 A half-bridge at Electronica. Regarding switching frequency the power module's low-induction construction allows for 100 kHz maximum. According to Cree for inverter applications the sweet spot is around 50 kHz. Also ROHM's full SiC power module – integrating SiC MOSFETs and SBDs enables high frequency operation above 100 kHz and can reduce losses by 85% compared with conventional Si IGBT modules. Additionally Semikron announced at SPS/Drives its activities in Silicon Carbide Power Modules. First poducts shown were a SiC hybrid module featuring a SiC free-wheeling diode and a Si IGBT switch. Efficiency is 97 % at 30 kHz switching frequency compared to 94.5 % with a Si diode. Second product is a 20 A MiniSKiiP incorporating a SiC MOSFET and a SiC diode allowing for an increase of 150 % (7 kW to 3 kW) in output power at 30 kHz switching frequency compared to a Si IGBT module. Finally 10 kW SiC SEMITOP and 300 kW SKiM modules with sintered interconnects and customer-specific configurations will be available on request.

Compared with conventional Silicon-based power devices, GaN-based power devices are rated up to 600 V and feature also lower on-resistance and the ability to perform high-frequency operations. Since these characteristics improve the conversion efficiency of power supply units and make them more compact, this technology is ideal not just for servers but for a broad range of applications including solar and drive inverters, battery chargers or electric vehicles.

A 400 W appliance inverter prototype has been demonstrated by International Rectifier using 600 V GaN switches a for driving the motors. The GaN-on-Silicon devices replacing IRAM IGBTs exhibit six times lower conduction and two times lower switching losses at an output power of 415 W in only 10 percent of the package size for the power stage. And considering that the GaN switches can operate without the need for a heatsink a reduction of a factor 100 for the power stage volume compared to the existing IGBT solution can be realized. The company's ultimate goal is to integrate a GaN Power System on a chip.

Fujitsu Semiconductor plans to commercialise GaN power devices on a Silicon substrate, increasing the diameters of the silicon wafers and enabling low-cost production. The company began work on GaN technology in 2009 and began providing specific power-supply-related partners with sample GaN power devices in 2011. Since then, Fujitsu has worked on optimizing the devices for use in power supply units. A mass-production line for 6-inch wafers has been established at Aizu-Wakamatsu plant, full-scale production of GaN power devices will begin in the second half of 2013. A prototype server power-supply unit incorporating a GaN PFC achieved output power of 2.5kW. This impressive performance makes GaN power devices suitable for use in high-voltage, large-current applications.

Also so-called wafer level magnetics (WLM) developed by Enpirion present a leap in traditional technology, which will take magnetic components from their 3-dimensional discrete shape to a planar 2-dimensional thin-film form that can be deposited with standard wafer processes on top of CMOS wafers. WLM is fully qualified for full-scale mass production in a high volume foundry and enables Power System-on-Chips based on electroplated wafer level magnetics. Developed with a view to achieving monolithic Power System-on-Chips, the WLM technology can be easily transferred to other micro-magnetic applications. Increased switching frequency allows the use of smaller inductors utilizing electroplated WLM materials that can be post-CMOS processed. The Fe-Co based alloy (FCA) has high resistivity, low coercivity and maintains high effective permeability at frequencies higher than 20MHz. FCA's high magnetic saturation makes it suitable for use as single or multiple layers in power circuits, where it is compatible with flip-chip, wire-bonding and solder re-flow packaging methods. Enpirion developed a turnkey process module, which features low cost of ownership plating equipment to deposit FCA on 6 inch or 8 inch wafers. This technology already achieves Power System-on-Chips with rated currents up to 1.5 A.

Thus innvation never stops and will lead to new devices and applications in 2013. We wish our readers a good jump into the (happy) new year.

Achim Scharf
PEE Editor

Center of the World for Electronics

The 25th electronica, the International Trade Fair for Electronic Components, Systems and Applications, closed on November 16 in Munich with more than 72,000 visitors. A total of 2,669 exhibitors from 49 countries presented the future of electronics and showcased application-oriented solutions during the four-day fair, which revolved around intelligent and energy-efficient solutions in the sectors for energy storage, LEDs and smart grids. The next electronica takes place in Munich from November 11 – 14, 2014.

Norbert Bargmann, Deputy CEO of Messe München, was more than satisfied with the fair's results: "This year's fair confirm the electronics industry's significance as the most important branch of industry in the world. The market is constantly confronted with new requirements that manufacturers meet with intelligent solutions. This year's hot topics included energy-efficient technologies and the latest developments in medical electronics. Automotive electronics, which account for an ever-increasing share of modern motor vehicles, was central theme in all exhibition categories: from control elements for energy harvesting and battery management to new charging techniques for electric automobiles."

Besides Germany, the countries with the largest contingents of visitors were Italy, Austria, Great Britain and Northern Ireland, Switzerland, France, the Russian Federation and the USA, in that order. The number of visitors from Canada, the Russian Federation, Turkey, the USA, the Czech Republic, Austria and Asia saw a significance increase. Nicole Schmitt, Exhibition Group Director for electronica: "The large percentage of international guests proves once again that electronica is the world's leading trade fair for the electronics industry."

Besides Germany, the countries with the largest numbers of exhibitors were China, Taiwan, the USA, Great Britain, Italy, Hong Kong, France, Switzerland and Japan. In total 2,669 exhibitors from 49 countries were on stage.

The industry is looking forward to the year 2013 with cautious optimism. That was also confirmed by Kurt Siever, Head of the Electronic Components and Systems Association and the PCB and Electronic Systems Association in the ZVEI (German Electrical and Electronic Manufacturers' Association). "After a minor slump of two percent in 2012 down to $ 460 billion, we expect the world market for electronic components to grow by some four percent in 2013. Forecasts also call for an increase in sales in the global semiconductor industry in 2013. The European market for electronic components of € 46 billion in 2012 is forecasted to grow slightly by one percent."

Market opportunities for the future

The speakers at this year's CEO Round Table all agreed on one thing: "Smart grid" will be one of the electronics industry's key topics in the future. The four CEOs from Freescale Semiconductor (Greg A. Lowe), STMicroelectronics (Carlo Bozotti), NXP Semiconductors (Rick Clemmer), and Infineon Technologies (Reinhard Ploss) saw that as a great opportunity for the semiconductor industry. After all, without smart meters and smart lighting solutions, it will not be possible to ensure the energy-efficient supply of electricity in the future. The industry still faces a few challenges. Electricity must be fed, transported and controlled, and several components are needed to do so. The interaction and reliability of these components are essential to avoid ultimately ending up in the dark.

NXP's Clemmer expects an annual growth of 20 % for smart meters – providing a great opportunity for (power) semiconductors. According to ST's Bozotti roughly 20 % of the capacity in the traditional grid is used to manage the power peaks, which is highly inefficient. Smart meters can improve this situation significantly. In Italy already 33 million smart meters are installed. Freescale's Lowe added, that China will install 300 million smart meters by the year 2016. And Infineon's Ploss views the smart grid as the Internet of power. But getting out the reactive power out of the grid one have to move to high-voltage DC transmission which also can improve electrical power distribution efficiency by a factor of 2.

Infineon also announced FY 2012 results ended September. The worldwide economic slowdown had the greatest effect on demand for power semiconductors for use in industrial, computing and consumer applications, and this is the case not only with Infineon.

Revenue in the Power Management & Multimarket segment fell by seven percent and that of the Industrial Power Control segment by nine percent compared to fiscal year 2011. By contrast, the Automotive and Chip Card & Security segments both achieved revenue growth of seven percent. Overall, revenue from these four core segments, at €3.774 billion, almost reached last fiscal year's level. "Our strongest pillar remains Automotive, here we profited from the successes of premium manufacturers and from growth in Asia. In the fourth quarter of fiscal year 2012, our Automotive revenues dropped slightly to 416 million euros. After record quarters, this is the result of seasonal developments", CEO Reinhard Ploss explained. "What do we expect in the current fiscal year? The market research company IHS is forecasting a rise in worldwide automobile production of only 1.9 percent in calendar year 2013. We are not immune to the structural weaknesses in the European automobile market and slower growth in North America, India and China. For the running quarter we expect a slight decline in revenues. In the Industrial Power Control segment we are feeling the effects of investment slowdowns by our industrial customers, thus revenues dropped by nine percent during fiscal year 2012".

"Macroeconomic headwinds are getting stronger and we do not see this changing in the near term. We are therefore forecasting a drop in revenue for

The CEO Round Table focused on the impact of the Smart Grid for (power) semiconductors

"The smart grid is the Internet of power. High-voltage DC transmission can improve electrical power distribution efficiency by a factor of 2", stated Infineon's CEO Reinhard Ploss

the 2013 fiscal year. Nonetheless, Infineon continues to focus on energy efficiency, mobility and security", Ploss stated.

International Rectifier is also cautious about the running fiscal year. "Though the last quarter came in better than our guidance, industry conditions remain challenging," stated CEO Oleg Khaykin. "While the high performance computing and server end markets were strong, the increase was offset by lower demand in our other major end markets, particularly appliances and industrial goods." For the running quarter customer inventory levels appear to be at relatively reasonable levels, demand continues to remain weak and orders have not shown signs of improvement through the first part of the quarter. "As such, we currently expect December quarter revenue to range between $215 and $230 million. We remain optimistic about our medium-term growth prospects and expect that our operational restructuring activities will help to return to profitability," Khaykin said at Electronica. Overall he expects revenues around $1 billion for the full FY 2013.

And Power Module manufacturer Vicor **(www.vicorpower.com)** faces eight consecutive quarters of declining earnings and is in a phase of transition. "Among our traditional market segments, the defense electronics has experienced a sustained decline in revenue due to federal budget constraints. Similarly, our revenues from supercomputing platforms are substantially reduced because of slowing demand and low cost competition. Demand in our commercial market segments, notably industrial equipment and transportation, has been characterized recently by greater uncertainty, as businesses, with limited visibility into their own prospects, reduce their spending and investment. This has been experienced across our European customer base, given that region's decline into recession, and increasingly across our North American customer base, as customers defer business decisions until the political stalemate associated with the pending federal budget 'sequestration' is addressed", said CEO Dr. Patrizio Vinciarelli.

GaN at work

IR took the opportunity to demonstrate 600 V GaN switches in a 400 W appliance inverter prototype for driving the motors. "The GaN devices replacing

"While GaN is expected to cannibalize some of our existing business we expect to increase our overall market share", said IR's CEO Oleg Khaykin.

IRAM IGBTs exhibit six times lower conduction and two times lower switching losses at an output power of 415 W in only 10 percent of the package size for the power stage. And considering that the GaN switches can operate without the need for a heatsink a reduction of a factor 100 for power stage volume compared to the existing IGBT solution can be realized", said Tim McDonald, IR's Vice President of Emerging Technologies. "We plan to release a corresponding product by end of calendar year 2013, a family of discrete cascoded 600 V GaN switches with 50 to 200 milliohm on-resistance. In 2014 we plan to release a series of 600 V-modules including µIPMs and moving forward our roadmap includes GaN Power ICs integrating power transistors and drivers. The ultimate goal is to integrate a GaN Power System on a chip, perhaps by the year 2018!"

"And by the way, the IGBT Power Module packaging used in today's inverter is very expensive", added IR's CEO Oleg Khaykin at the live demo. "It has a large DBC substrate, requires an expensive over-molding process and needs a large heatsink."

More power with SiC

Cree **(www.cree.com)**, so far supplier of Silicon Carbide (SiC) wafers for device manufacturers and SiC devices such as Schottky Barrier Diodes (SBD) and MOSFETs up to 1700 V breakdown voltage, now enters the Power Module market with the self-designed 1200 V / 100 A half-bridge CAS100H12AM1.

This subcontractor-made power module, measuring 87.5 mm x 50 mm, contains five Cree 20 A / 1200 V MOSFETs featuring zero turn-off tail current and five 10 A / 1200 V Schottky Diodes featuring zero reverse recovery current per high- and low-side legs – in total ten SiC MOSFETs and ten SiC diodes. The switches are rated for 150°C junction temperature, the diodes for 175°C. These devices are not taking advantage of the inherent higher temperature capabilities of SiC well beyond 200°C. The module itself is rated at 125°C case temperature and is available with AlSiC or Si3N4 DBC baseplate. The initial product offering still uses aluminum bond wires due to the subcontractor's production capabilities, but advanced interconnection technologies are investigated for future products.

Regarding switching frequency the power module's low-induction construction allows for 100 kHz maximum. According to Cree for inverter applications the sweet spot is around 50 kHz. The new All-SiC Power Module is targeted as building block for system designs in Solar, UPS and motor drive inverters up to 100 kW; light wind and traction inverter applications as well as high-power auxiliary converters.

The Cree SiC power module is available through distributors DigiKey **(www.digikey.com)** and Mouser **(www.mouser.com)**.

Japanese ROHM **(www.rohm.com/eu)** has advanced the development of next-generation SiC Schottky Barrier Diodes and MOSFETs backed by the manufacturing capability of SiCrystal (Erlangen/Germany) as part of the

"Our new full-SiC 1200 V/100 A power modules are very competitively priced", stated Cree's Marketing Manager Paul Kierstedt

"Our new generation of 1200 V/100 A SiC power modules can cut volume by 50 percent compared to conventional Si modules", said ROHM's Marc Frochte

company. The combination of low loss and high voltage capability as well as fast recovery time makes these devices suited for many applications, including PFC (power factor correction) circuits, converters and inverters as used in EV/HEV and industrial units. ROHM's new high-voltage isolated SiC gate drivers facilitate low-power consumption and small designs. Together with SiC devices the new series guarantees a stable, high speed operation even in high power regions. In addition, ROHM's full SiC power module – integrating SiC MOSFETs and SBDs enables high frequency operation above 100 kHz.

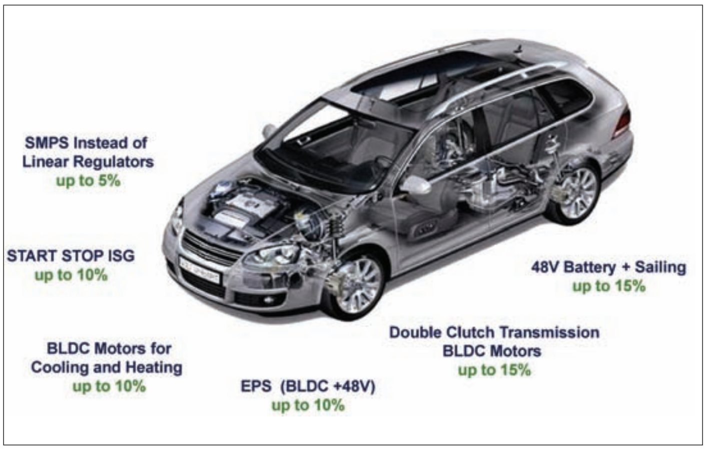
The new modules featuring aluminum bond wiring integrate a dual-element SiC SBD/ SiC MOSFET pair that reduces loss during power conversion by 85% compared with conventional Si IGBT modules. In addition, high-frequency operation of at least 100kHz is possible. And although the modules are rated at 100A, their high-speed switching capability, reduced loss, and improved heat dissipation characteristics make them replacements for 200-400 A Si-IGBT modules. "Replacing a conventional 400 A-class IGBT can cut volume by 50 %, and the lower heat generated requires less cooling countermeasures, contributing significantly to end-product miniaturization", said European Product Marketing Manager Marc Frochte. First SiC power modules targeted for automotive applications (Honda) have been shown already at Electronica 2010.

Also new IGBTs have been introduced by Infineon and International Rectifier, advanced LED drivers by Power Integrations **(www.powerint.com)** and AC/DC power modules by Vicor **(www.vicorpower.com)**.

Power electronics improve fuel efficiency

Some 300 participants from 19 countries attended the electronica automotive conference and discussed on the topics infotainment, safety and last but not least fuel efficiency and CO2 reduction by using (power) electronics.

"The electrification of the powertrain in the automobile and replacement of hydraulic controls is today's major trend, and last but not least multi-stage board-nets", pointed out Vishay's **(www.vishay.com)** SVP Business Dev. Norbert Pieper. Fuel savings and efficiency improvements are the steps to be taken. SMPS instead of linear regulators could improve efficiency up to 5 %, incorporation of start-stop ISG up to 10 %, BLDC motors for cooling and heating also up to 10 %, electronic power steering (EPS) also up to 10 %, double-clutch transmission with BLDC motors up to 15 % and finally the 48 V board-net for driving fully electric applications more powerful also up to 15 %. "Savings on what you have is better than looking for alternatives", Pieper stated. The trend towards more BLDC motors is supported by Vishay through new power semiconductor packages which can be directly integrated into the motor casing.



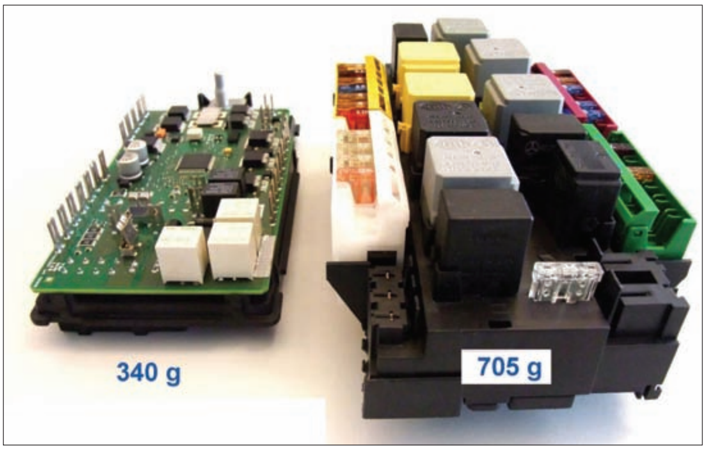
Efficiency improvements by implementing more electric/electronic functions in the car
Source: Vishay

Infineon's **(www.infineon.com)** System Architect Body Electronics Dr. Alfons Graf focused on energy efficiency improvements through optimization of the various subsystems in the vehicle. According to his assumptions efficiency or electrical power and weight have a significant impact on the fuel consumption and therefore CO2 emissions. In example 100 W extra electricity consumption for air conditioning or other consumers will add to an extra 0.1 l of fuel consumption per 100 km, also the addition of 50 kg of weight. Additional fuel consumption of 1 l / 100 km will increase CO2 emission by roughly 25 g / km. In other words, 1 g CO2 / km less equates to 40 W or 20 kg less adding additional cost of 5 – 95 Euro to manufacture the car. On the other hand – savings of 1 W will cost the car manufacturer in average between 0.25 and 0.55 Euro, 1 A less amounts to 3 – 7 Euro, and 1 kg less weight costs 3 – 5 Euro.

According to Graf, for fuel savings it is mandantory to reduce the weight and power consumption of the car significantly. But the costs to improve energy efficiency will increase with the increasing complexity of the envisioned solutions. Today Start-Stop systems or some electric accessories for power-on-demand such as electric water pump, variable-speed air compressor, and electric power steering are more or less common. These items will add some 25 Euro in order to save 1 g CO2 emission per km. Next step to be taken in the time frame 2013 – 2016 will cover the implementation of advanced Start-Stop systems with recuperation of energy, perhaps a 48 V board net, LiIon battery, and downsizing of the combustion engine via high-pressure direct injection and variable turbo charging by electric motor control. To install such systems the cost will definitely go up around 35 Euro. For the years to come beyond 2016 Graf would expect a further downsizing hand in hand with advanced hybridization or range extenders and perhaps more e-vehicles on the road. But to achieve such a scenario one has to spend some more money in the range of 50 Euro to save 1 g CO2 per km. In order to realize this functionality the semiconductor content will increase up to 15 Euro for each saved gram of CO2. And, by the way, the EU CO2 target is 95 g / km.

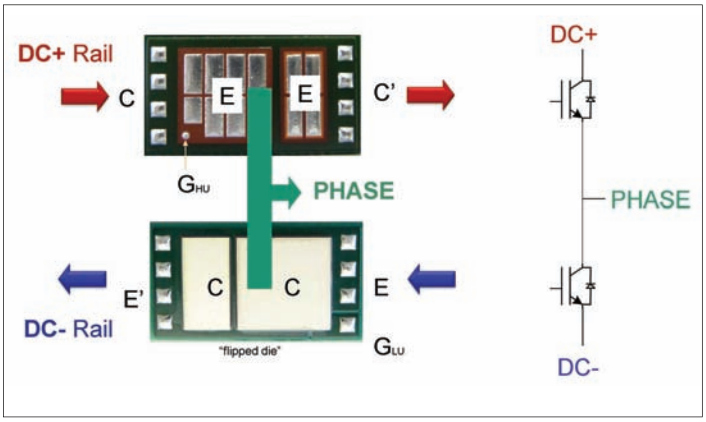
There are many possibilities for reducing electrical power through more efficient solutions already available such as replacing incandescent bulbs by

LEDs (headlamps, rear lights, ambient lighting) saving a total of 50 W; PWM regulated fuel pump (saving ~ 80 W), electric power steering (savings ~ 250 W or 6 g CO2), or substitution of relays by power semiconductors. The majority of vehicles contain 7 – 15 relays in the power distribution center, by using new technologies size and weight can be greatly improved, but also the price point by 18 Euro. "To improve fuel efficiency and overall efficiency of a car we have to go many small steps and all of these steps are supported by semiconductors", Alfons Graf concluded.



By using (power) semiconductors size and weight of a power distribution center can be greatly improved **Source: Infineon Technologies**

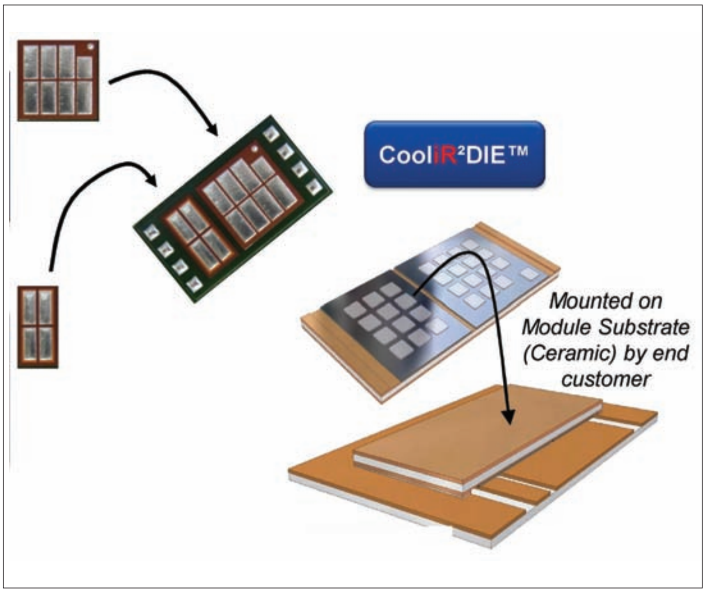
International Rectifier's **(www.irf.com)** Senior Manager Automotive Power Benjamin Jackson outlined the transition from traditional cars towards electrical vehicles (EVs). The ongoing rise of fuel prices and the CO2 emission



Bondless die assembly and manufacturability of CoolIR?Die **Source:IR**

regulations particularly in Europe there are constrains on the input of the vehicle (fuel) and on the output (emissions), in order to deal with that efficiency has to be improved. "And this is the whole motivation for designing hybrid electrical vehicles. The main inverter in EVs has to be highly reliable since it replaces the internal combustion engine. And it is subjected to higher temperatures. Thus we have developed a new packaging and interconnection concept called "Solderable Front Metal" allowing for double-sided cooling as well as eliminating the bond wires".

Brand name of this technology is CoolIR? aimed for applications above 50 kW incorporating MOSFETs/IGBTs/Diodes (up to 1200 V) with die sizes up to



Layout of a compact half-bridge using CoolIR?Die **Source:IR**

225 mm?. The thin chips (70 µm) are mounted onto a DBC substrate for CTE matching with the module substrate, for topside electrical isolation and for the possibility to mount the IGBT collector up or down. Thus no handling of the thin bare dies is required, wire bonding is eliminated and pick & place manufacturing for mounting on module substrate can be used.

By having flipped dies the collector and emitter pads the power IGBTs in a half-bridge can be placed in an adjacent manner to each other – simplifying significantly the routing and reduces stray inductance. And by eliminating the wire bonds not only inductance and on-resistance can be reduced, but also reliability can be drastically improved. "Early prototypes have demonstrated more than 810,000 power cycles at 85°C junction temperature, whereas traditional wire bonded modules see lifetimes of around 100,000 cycles at this temperature", Franklin concluded. **AS**

Stagnation at High Level

With a record number of 1,461 exhibitors this year's SPS IPC Drives has been held on Nurembergs Fairgrounds, a slight increase compared to the 1,429 exhibitors in 2011. The result of this event are also of interest for the power electronics industry, because it is an indicator of what happens in their important customer base.

"Our exhibitors are happy", said Mesago's Head Johann Thoma. "We have more exhibitors from China, Russia and the USA certainly looking for broadening their customer base in Germany and Europe. The Euro discussion is more a psychodelic one since investments in dives and automation are more or less independent from this mood".

A detailled overview on the current market situation has been given by the ZVEI, the German Central Assoziation for the Electrical/Electronics Industry. "The electrical drive industry in Germany can look back for 17 and 20 percent growth in the years 2010 and 2011 respectively. In 2011 the market rose up to Euro 10.7 billion and exceeded the result of 2008. The market for motors increased by 17 percent in 2011, the market for inverters by 24 percent and thus crossed for the first time the Euro 3 billion barrier. For the running year we expect a slight growth up to Euro 10.8 billion, driven mainly by the drive electronics growing by some 2.2 percent. For 2013 we expect a stabilization, in other words a stagnation at high level", expressed Günther Baumüller, member of the ZVEI board automation. "The finacial markets and political decisions have a huge impact on the real economy what is making predictions not easier. In this context it is interesting to see how the regional markets will develop. In the Americas and in Asia the drive business runs much better than in Europe, particularly in Southern Europe".

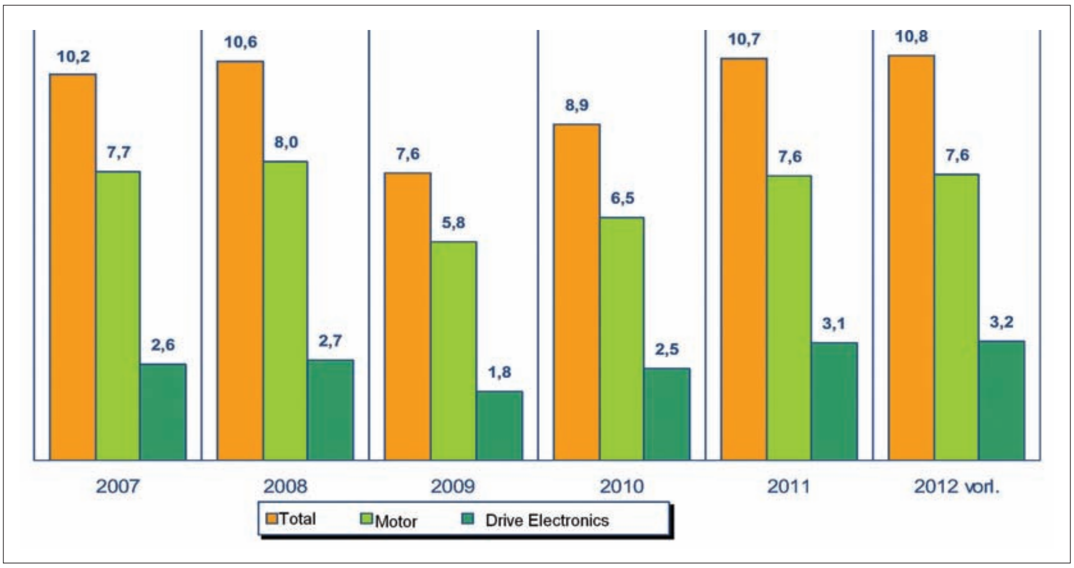
The EU Directive M640/2009 will make electrical drives more efficient, which means that by the year 2015 drives with an output power above 7.5 kW solely confirming to energy efficiency class IE3 can be sold across the EU, alternatively IE2 motors with an additional variable speed controller. From the year 2017 IE3 motors have to be equipped with frequency inverters. "And that is just the beginning. Since March 2012 the European Commission has initiated four studies named lots 28 to 31 evaluating the energy saving potentials in drives, pumps and compressors. These new ideas will change the world of drives and machines drastically, since alls relevant components and even the designed systems will in the future evaluated according to efficiency classes", Baumüller concluded.

Power electronics for inverters

What can be achieved with modern power electronics has been shown by Mitsubishi Electric with the MiEV showing the various subsystems such as frequency inverter and battery monitor, one of the eyecatchers at the fairgrounds.

Infineon **(www.infineon.com/tim)** demonstrated for the first time for the public its activities in Thermal Interface Materials for Power Modules.

ABOVE: Electrical cars consume a heavy amount of power electronics as shown by Mitsubishi



LEFT: German market development for electrical drives (in € billion)

Source: ZVEI

Solid State Alternatives To TWT Amplifiers

The New 1 – 2.5 GHz "S" Series Solid State Power Amplifiers

There are several important things to consider when choosing a test amplifier. Things like harmonics, linearity, durability, power, reliability, and of course life cycle cost. Too often, you have to settle for an old TWTA design approach to achieve this power in such a small footprint, but now you can have it all in a state-of the-art affordable instrument to meet your demanding requirements.

With AR's new 100, 250 and 500-Watt 1-2.5 GHz "S" Series amplifiers you can have the reliability and performance advantages of solid state without the hassles that the old TWTA designs have. And if 500 watts wasn't enough, we will soon be coming out with even higher power. And because it's made by AR, it's backed by a worldwide service and support network that's second to none. So why settle for just any amplifier when you can get one with all the features you've been wishing for?

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Infineon's Martin Schulz demonstrated power modules with pre-applied thermal interface material

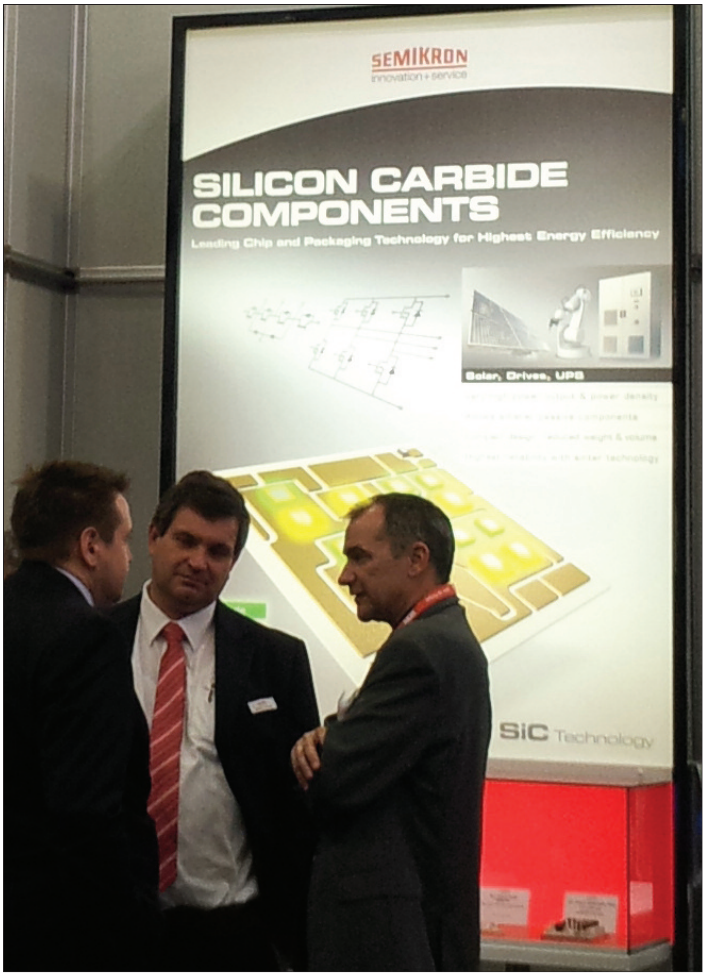
Convertional thermal pastes and other materials are designed for lower temperatures and packages and not for the large area of power module baseplates or DBCs. Nevertheless, though power modules are sold in relatively low volumes the area to be deposited by thermal interface materials is relatively big compared to chips in computing applications, "Henkel/Loctite views this segment as a market opportunity and works with Infineon on an appropriate solution in a 7-year project covering hundred man-years", said Infineon's Application Engineer Martin Schulz.

Thixotrophy is the academic term for the properties of this joint efforts. Certain gels that are thick under normal conditions become thin or flow when stressed. "In our case the thermal interface pre-applied in small circles over the baseplate becomes less viscous above 45°C and forms a thin layer featuring less thermal resistivity than the standard module. Power cycling tests on a 2 MW inverter confirm that reliability can be increased by a factor 4. It does not degrade and keeps its thermal conductivity across the complete baseplate. Additonal measures ensure that the hot spots below the heat-generating semiconductors have high thermal conductivity", Schulz stated. The technology is suitable for power modules equipped with power semiconductors in the 150°C class.

LEM announced new current transducers in the 50 A range

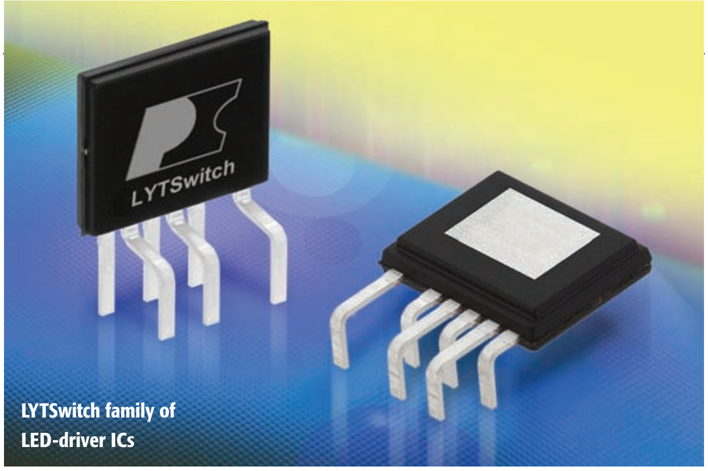
LEM **(www.lem.com)** introduced its new HLSR series of current transducers, that provide a cost-effective alternative to resistive shunt/optocoupler configurations for insulated current measurements up to 50 A. The five new HLSR transducers will satisfy application requirements in, for example, industrial inverters and motor drives; switch-mode and uninterruptible power supplies; specialist power supplies such as welding units; air conditioning; home appliances; but also in renewable-energy systems, for example, in solar combiner boxes and in solar inverters to track the maximum-power-point (MPPT). LEM's HLSR series uses open-loop Hall-effect current sensing technology, to measure AC, DC or pulsed currents with nominal values of 10, 20, 32, 40 or 50 A RMS. LEM's proven expertise in open-loop Hall-effect technology allows these new devices to achieve a response time of 2.5 μs, with very low gain and offset drift over their operating temperature range of -40 to +105 °C.

Semikron **(www.semikron.com)** announced on the booth its activities in Silicon Carbide Power Modules. First poducts shown were a SiC hybrid module



Semikron entered the SiC Power Module market at SPS/IPC/Drives

featuring a SiC free-wheeling diode and a Si IGBT switch. Efficiency is 97 % at 30 kHz switching frequency compared to 94.5 % with a Si diode. Second product is a 20 A MiniSKiiP incorporating a SiC MOSFET and a SiC diode allowing for an increase of 150 % (7 kW to 3 kW) in output power at 30 kHz switching frequency compared to a Si IGBT module. Finally 10 kW SiC SEMITOP and 300 kW SKiM modules with sintered interconnects and customer-specific configurations will be available on request. **AS**



LYTSwitch family of LED-driver ICs

Dimmable driver for High-Power LEDs

Power Integrations introduced its latest family of LED-driver ICs, aimed at consumer, commercial and industrial lighting applications. The new LYTSwitch™ IC family delivers tight regulation and high efficiency for tube replacements and high-bay lighting, while providing exceptional performance in TRIAC-dimmable bulb applications.

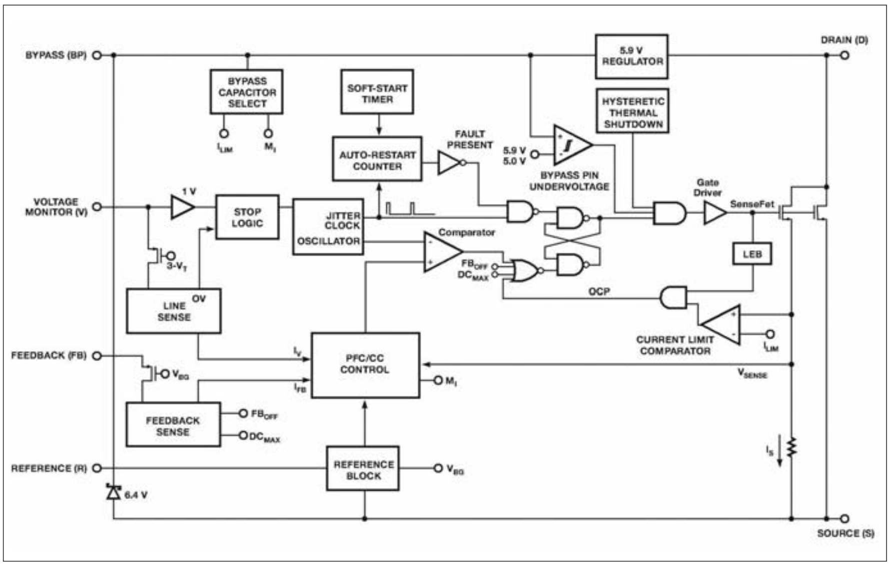
A LYTSwitch device monolithically combines a controller and high-voltage power FET into one package. The controller provides both high power factor and constant current output in a single-stage. The LYTSwitch controller consists of an oscillator, feedback (sense and logic) circuit, 5.9 V regulator, hysteretic over-temperature protection, frequency jittering, cycle-by-cycle current limit, auto-restart, inductance correction, power factor and constant current control. The devices enable off-line LED drivers with high power factor which easily meet international requirements for total harmonic distorsion (THD) and harmonics. Output current is tightly regulated with better than ±5% CC tolerance. Efficiency of up to 92% is easily achieved in typical applications. The turn-on characteristics enable drivers with a wide dimming range and fast start-up, even when turning-on from a low conduction angle.

LYTSwitch ICs are highly integrated and employ a primary-side control technique that eliminates the opto-isolator and reduces component count. This allows the use of low-cost single-sided PCBs.

Combining PFC and CC functions into a single-stage also helps reduce cost and increase efficiency. The 132 kHz switching frequency permits the use of small, low-cost magnetics. LED drivers using the LYTSwitch family do not use primary-side aluminum electrolytic bulk capacitors. This means extended driver lifetime, especially in bulb and other high-temperature applications.

Dimmable 25 W TRIAC LED driver

This design with the LYT4317E is also configurable for non-dimmable applications by simple component value changes. It was optimized to drive an LED string at a voltage of 36 V with a constant current of 0.7 A



LYTSwitch Functional block diagram

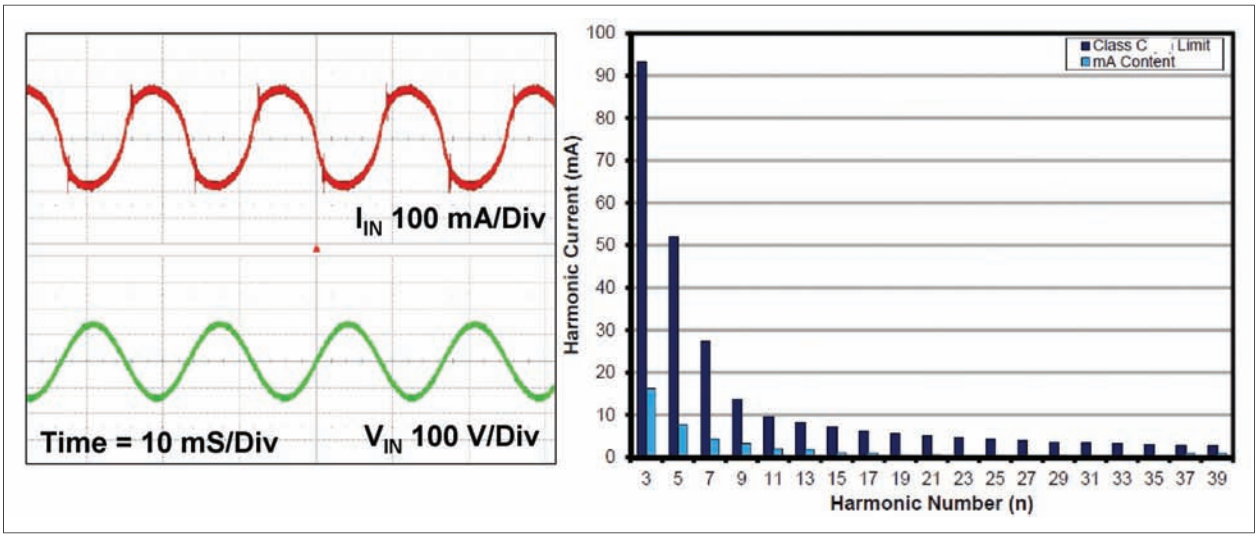
ideal for Lumens PAR lamp retro-fit applications.

The key goals of this design were compatibility with standard leading edge TRIAC AC dimmers, very wide dimming range (1000:1, 700 mA:0.7 mA), high efficiency (>85%) and high power factor (>0.9). The design is fully protected from faults such as no-load (open load), over-voltage and output short-circuit or over-load conditions and over-temperature.

The LYTSwitch device (U1-LYT4317E) integrates the power FET, controller and start-up functions into a single package. Configured as part of an isolated continuous conduction mode flyback converter, U1 provides high power factor via its internal control algorithm together with the small input capacitance of the design. Continuous conduction mode operation results in reduced primary peak and RMS current. This both reduces EMI noise, allowing simpler, smaller EMI filtering components and improves efficiency. Output current regulation is maintained without the need for secondary-side sensing which eliminates current sense resistors and improves efficiency.

Fuse F1 in the application diagram provides protection from component failures while RV1 provides a clamp during differential line surges, keeping the peak drain voltage of U1 below the 725 V rating of the internal power FET. Bridge rectifier BR1 rectifies the AC line voltage. EMI filtering is provided by L1-L3, C1, C4, R2, R24 and R25 together with the safety rated Y class capacitor (CY1) that bridges the safety isolation barrier between primary and secondary. Resistors R2, R24 and R25 act to damp any resonances formed between L1, L2, L3, C1 and the AC line impedance. A small bulk capacitor (C4) is required to provide a low impedance source for the primary switching current. The maximum value of C2 and C4 is limited in order to maintain a power factor of greater than 0.9.

To provide peak line voltage information to U1 the incoming rectified AC peak charges C6 via D2. This is then fed into the VOLTAGE MONITOR pin of U1 as a current via R10. This sensed current is also used by the device to set the line input over-voltage protection threshold.



PFC waveforms (left) and THD (light blue) of the LYTSwitch

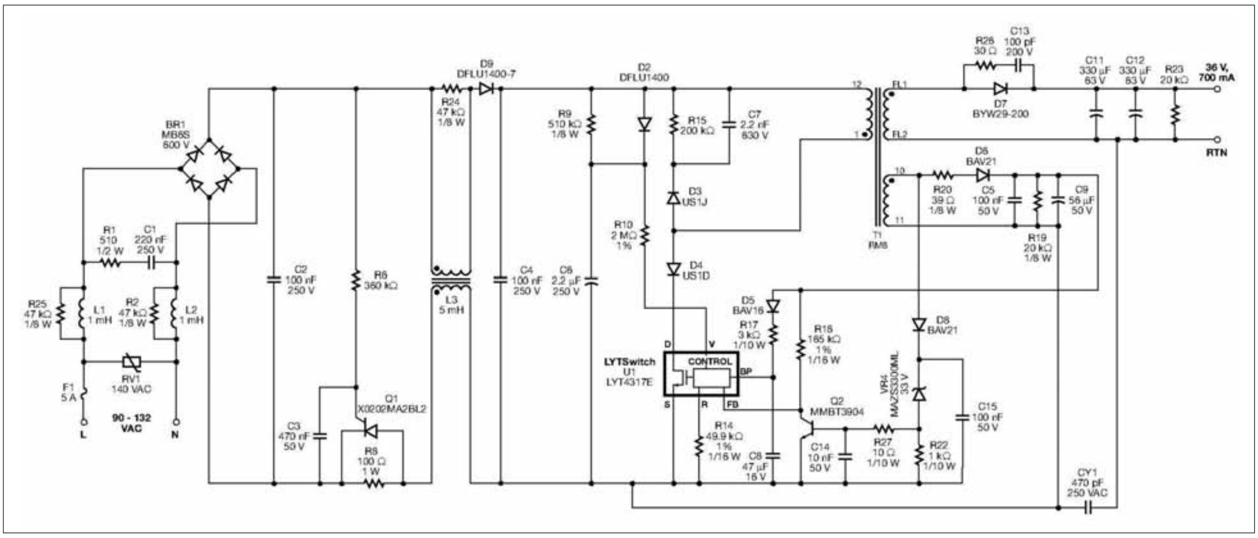
Resistor R9 provides a discharge path for C6 with a time constant much longer than that of the rectified AC to prevent generation of line frequency ripple.

The VOLTAGE MONITOR pin current and the FEEDBACK pin current are used internally to control the average output LED current. For TRIAC phase-dimming applications a 49.9 kΩ resistor (R14) is used on the REFERENCE pin and 2 MΩ (R10) on the VOLTAGE MONITOR pin to provide a linear relationship between input voltage and the output current and maximizing the dimming range.

Diode D3, R15 and C7 clamp the drain voltage to a safe level due to the effects of leakage inductance. Diode D4 is necessary to prevent reverse current from flowing through U1 for the period of the rectified AC input voltage that the voltage across C4 falls to below the reflected output voltage (V_{OR}).

Diode D6, C5, C9, R19 and R20 create the primary bias supply from an auxiliary winding on the transformer. Capacitor C8 provides local decoupling for the BYPASS pin of U1 which is the supply pin for the internal controller. During start-up C8 is charged to ~6 V from an internal high-voltage current source tied to the device DRAIN pin. This allows the part to start switching at which point the operating supply current is provided from the bias supply via R17. Capacitor C8 also selects the output power mode (47 µF for reduced power was selected to reduce dissipation in U1 and increase efficiency for this design).

The bias winding voltage is proportional to the output voltage (set by the turns ratio between the bias and secondary windings). This



Schematic of an isolated, TRIAC dimmable, 25 W/36 V/700 mA LED Driver

allows the output voltage to be monitored without secondary-side feedback components. Resistor R18 converts the bias voltage into a current which is fed into the FEEDBACK pin of U1. The internal engine within U1 combines the FEEDBACK pin current, the VOLTAGE MONITOR pin current and drain current information to provide a constant output current over a 1.5:1 output voltage variation (LED string voltage variation of ±25%) at a fixed line input voltage.

To limit the output voltage at no-load an output overvoltage protection circuit is set by D8, C15, R22, VR4, R27, C14 and Q2. Should the output load be disconnected then the bias voltage will increase until VR4 conducts, turning on Q2 and reducing the current into the FEEDBACK pin. When this current drops below 10 mA the part enters auto-restart and switching is disabled for 300 ms allowing time for the output and bias voltages to fall.

The transformer secondary winding is rectified by D7 and filtered by C11 and C12. An ultrafast TO-220 diode was selected for efficiency and the combined value of C11 and C12 were selected to give peak-to-peak LED ripple current equal to 30 % of the mean value. For designs where lower ripple is desirable the output capacitance value can be increased. A small pre-load is provided by R23 which discharges residual charge in output capacitors when turned off.

TRIAC dimmable LED driver measuring 33.6 mm x 68.1 mm fitting in a PAR38 enclosure

TRIAC phase dimming control compatibility

The requirement to provide output dimming with low-cost, TRIAC-based dimmers introduces a number of trade-offs in the design.

Due to the much lower power consumed by LED based lighting the current drawn by the overall lamp is below the holding current of the TRIAC within the dimmer. This can cause undesirable behaviors such as limited dimming range and/or flickering as the TRIAC fires inconsistently. The relatively large impedance the LED lamp presents to the line allows significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. This too can cause similar undesirable behavior as the ringing may cause the TRIAC current to fall to zero and turn off.

To overcome these issues simple two circuits, the SCR active damper and R-C passive bleeder, are incorporated. The drawback of these circuits is increased dissipation and therefore reduced efficiency of the supply. For non-dimming applications these components can simply be omitted.

The SCR active damper consists of components R6, C3, and Q1 in conjunction with R8. This circuit limits the inrush current that flows to charge C4 when the TRIAC turns on by placing R8 in series for the first ~1 ms of the TRIAC conduction. After approximately 1 ms, Q1 turns on and bypasses R8. This keeps the power dissipation on R8 low and allows a larger value during current limiting. Resistor R6 and C3 provide the delay on Q1 turn on after the TRIAC conducts. Diode D9 blocks the charge in capacitor C4 from flowing back after the TRIAC turns on which helps in dimming compatibility especially with high power dimmers.

The passive bleeder circuit is comprised of R1 and C1. This helps keep the input current above the TRIAC holding current while the input current corresponding to the effective driver resistance increases during each AC half-cycle.

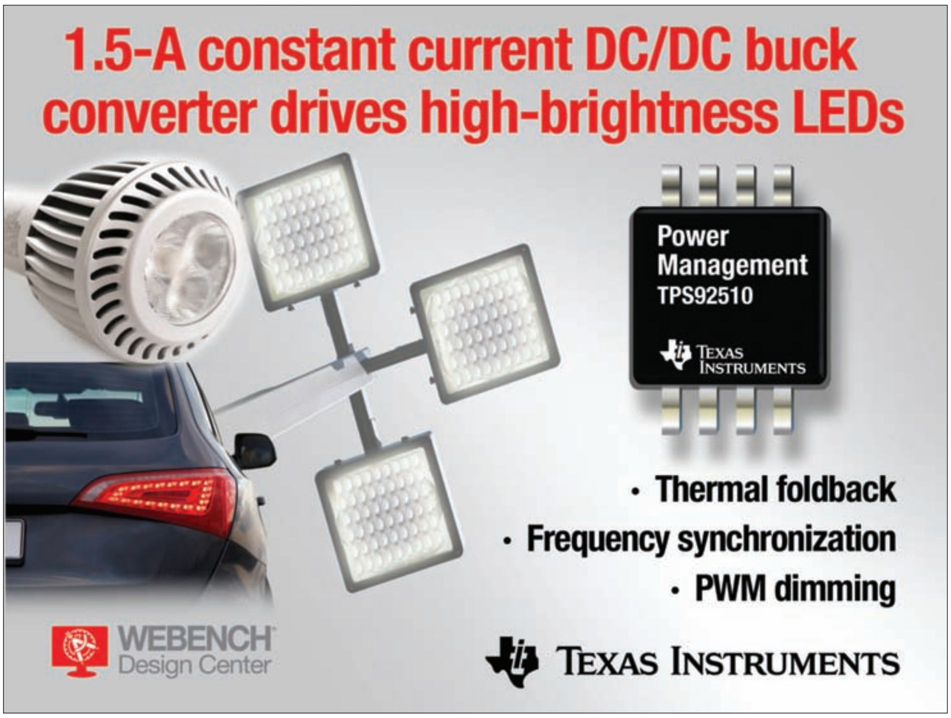
www.powerint.com/products/lytswitch-family/lytswitch

LED Driver with Frequency Synchronization and PWM Dimming

TI's new TPS92510 is a 60-V, 1.5-A, buck regulator with an integrated high-side N-channel MOSFET. To improve performance during line and load transients the device implements a constant frequency, peak-current mode control which reduces output capacitance and simplifies external frequency compensation design. The wide switching frequency of 100 kHz to 2500 kHz allows for efficiency and size optimization when selecting the output filter components. Together with TI's WEBENCH® LED Architect, the lighting developer can quickly design a power management circuit to drive a string of up to 17 high-brightness LEDs at up to 97 percent power efficiency in automotive, industrial and general illumination applications.

The TPS92510 integrates a thermal foldback feature that reduces the average output current to ensure that the sensed LED temperature never exceeds a specific value, improving the reliability of the overall system. An integrated frequency synchronization feature allows a reduction of unwanted beat-frequencies in multi-string applications and simplifies EMI filtering. The adjustable input voltage UVLO feature accommodates the various deep discharge levels of multiple battery types.

The TPS92510 includes also cycle-by-cycle over-current protection, and thermal shutdown protection. It is available in a 10-pin MSOP PowerPADTM package.

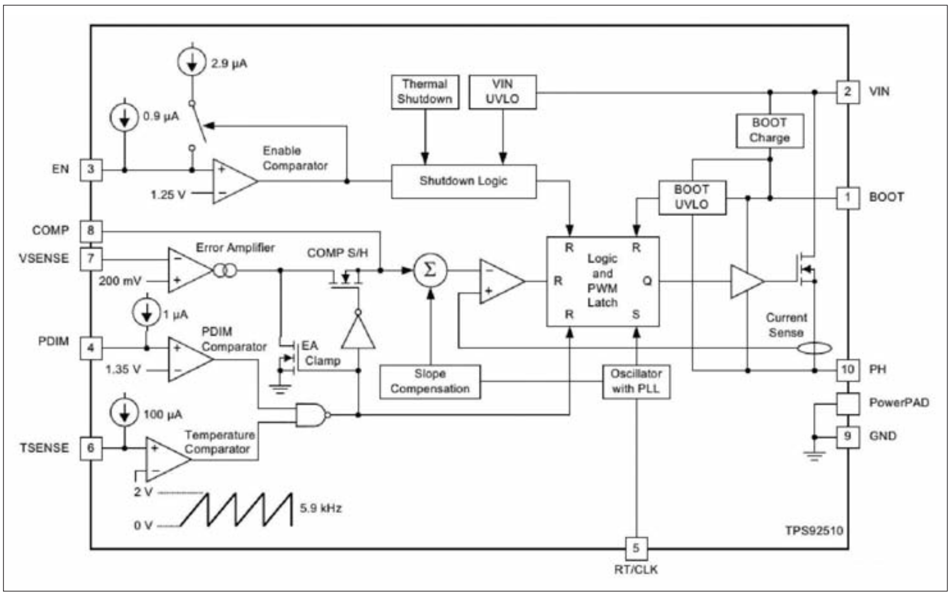


Start-up procedure

The VIN and EN UVLO conditions must be satisfied before the TPS92510 is allowed to switch. When the EN pin (see functional block diagram) is held low the device enters a low-power shutdown mode, and some internal circuits are deactivated to conserve power. When EN returns high these circuits are enabled, which results in a delay of approximately 50 µs (typical) before switching starts. During start-up the TPS92510 operates in a minimum pulse width mode, which is an open-loop control. At the start of each switching cycle the internal oscillator initiates a SET pulse.

The high-side MOSFET turns on with a minimum pulse width of 300 ns (typical), independent of the COMP voltage. The device does not pulse skip. While operating in minimum pulse width mode the LED bypass capacitor (see simplified application diagram) is being charged, causing an in-rush current. Also, the COMP voltage begins to rise as the error amplifier output current charges the compensation network. When the COMP voltage reaches approximately 0.7 V, the error amplifier is ensured to be out of saturation and to have sufficient gain to regulate the loop. The TPS92510 then transitions from minimum pulse width mode to regulation mode. During regulation mode the error amplifier is now in closed-loop control of the system. The gain of the error amplifier quickly increases the duty cycle, which causes the output voltage to increase. Once the output voltage approaches the forward voltage of the LED string the LED current quickly begins to increase until it reaches regulation.

The TPS92510 is designed to output a minimum pulse width during each switching cycle of 280 ns (typical). The control loop cannot regulate the system to an on-time less than this



TPS92510 functional block diagram

- Trench-FS IGBT
- High thermal cycling capability
- Low spike voltage & oscillation free
- Excellent turn-on dIc/dt control by R_G

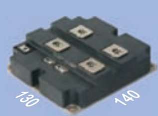
High Power IGBTs

1200V & 1700V

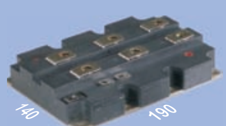
- Low thermal impedance
- Low internal inductance
- $T_{j,max}$ = 175°C
- $T_{j,op}$ = -40 ~ 150°C
- $T_{stg,min}$ = -40°C
- V_{iso} = 4.0kV
- CTI > 600

1700V also available with AlSiC-Baseplate

1 in 1



1200A
1600A
2400A



2400A
3600A

2 in 1

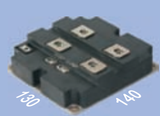
600A
800A
1200A

3300V

- Low thermal impedance
- Low internal inductance
- $T_{j,max}$ = 150°C
- $T_{j,op}$ = -40 ~ 150°C
- $T_{stg,min}$ = -40°C
- V_{iso} = 6.0kV
- CTI > 600
- VPD = 2.6kV

AlSiC Baseplate

1 in 1



800A
1000A

1200A
1500A

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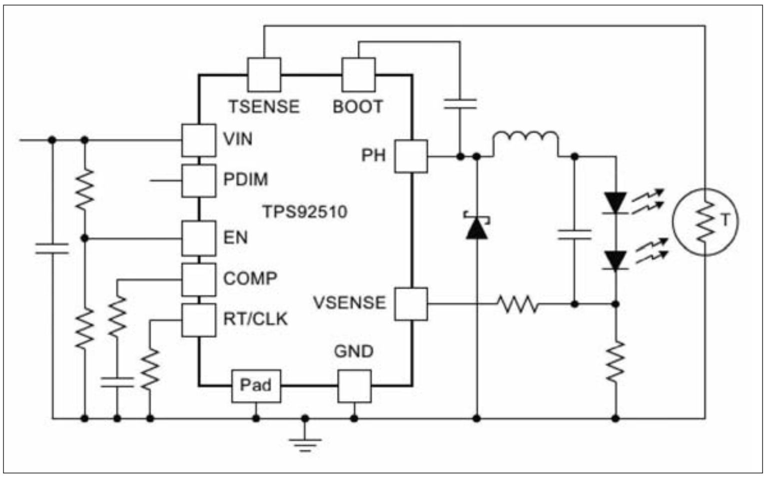
amount, and it does not skip pulses. When attempting to operate below the minimum on-time the system loses regulation and the LED current increases.

The device is enabled when the VIN pin voltage is above 2.5 V and when the EN pin voltage is above 1.25 V. The VIN pin voltage threshold has no hysteresis. The EN pin has an internal pull-up current source, I1, of 0.9 µA that provides a default ON state when the EN pin is floating. Once the EN pin voltage exceeds 1.25 V, an additional 2.9 µA of hysteresis, IHYS, is added. This additional current provides some input voltage hysteresis.

Via an adjustable, fixed-frequency, peak current mode control, at each switching cycle an internal oscillator initiates the turn-on of the MOSFET. The LED current flows through the sense resistor and develops the feedback voltage on the VSENSE pin. The error amplifier output (COMP pin) is compared to the high-side MOSFET current. When the MOSFET current reaches the level set by the COMP pin voltage the MOSFET is turned off.

The switching frequency is adjustable over a wide range from approximately 100 kHz to 2500 kHz by placing a resistor on the RT/CLK pin. The RT/CLK pin voltage is typically 0.5 V and must have a resistor to ground to set the switching frequency. To reduce the solution size one typically sets the switching frequency as high as possible, but trade-offs of the supply efficiency,

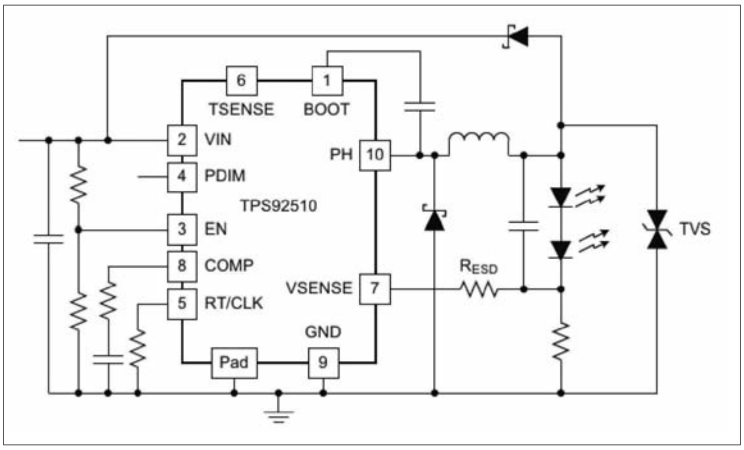


Simplified application diagram

maximum input voltage and minimum controllable on time should be considered. The minimum controllable on time limits the maximum operating input voltage.

The RT/CLK pin can be used to synchronize the regulator to an external system clock by connecting a square wave to the RT/CLK pin through the circuit network. The square wave amplitude must transition lower than 0.5 V and higher than 2.2 V on the RT/CLK pin and have an on-time greater than 40 ns and an off-time greater than 40 ns. The synchronization frequency range is 300 kHz to 2200 kHz. The rising edge of the PH is synchronized to the falling edge of RT/CLK pin signal. The external synchronization circuit default frequency is set by connecting the resistor from the RT/CLK pin to ground should the synchronization signal turn off.

The TPS92510 incorporates a PWM dimming input pin, which directly controls the enable/disable state of the internal gate driver. When PDIM is low, the gate driver is disabled. The PDIM pin has a 1-µA pull-up current source, which creates a default ON state when the PDIM pin is floating. When PDIM goes low and the gate driver shuts off, and the LED current quickly reduces to zero. During the PDIM off-time the COMP voltage of the sample-and-hold switch on



Output voltage clamp circuitry

the error amplifier output remains unchanged. Also, the error amplifier output is internally clamped low. These techniques help the system recover to its regulation duty cycle quickly.

The TPS92510 is designed to operate up to 100% duty cycle as long as the BOOT to PH voltage is greater than 2.1 V. If the BOOT capacitor voltage drops below 2.1 V, then the BOOT UVLO circuit turns off the MOSFET, which allows the BOOT capacitor to be refreshed. The current required from the BOOT capacitor to keep the MOSFET on is quite low. Therefore, many switching cycles occur before the BOOT capacitor is refreshed. In this way, the effective duty cycle of the converter is quite high.

Attention must be taken in maximum duty cycle applications which experience extended time periods with little or no load current. When the voltage across the BOOT capacitor falls below the 2.1 V UVLO threshold, the high-side MOSFET is turned off, but there may not be enough inductor current to pull the PH pin down to recharge the BOOT capacitor. The high-side MOSFET of the regulator stops switching because the voltage across the BOOT capacitor is less than 2.1 V. The output capacitor then decays until the difference between the input voltage and output voltage is greater than 2.1 V, at which point the BOOT UVLO threshold is exceeded, and the device starts switching again until the desired output current is reached. This operating condition persists until the input voltage and/or the load current increases. It is recommended to adjust the VIN stop voltage greater than the BOOT UVLO trigger condition at the minimum load of the application using the adjustable VIN UVLO feature with resistors on the EN pin.

A thermal foldback protection has been implemented to limit the LED temperature in case of a system failure, such as an incorrectly programmed LED current, a poor thermal design or increasing thermal impedance over time. A 100-µA current source generates a voltage across an NTC resistor that is located near the LED load. When the NTC voltage drops below 2 V at the TSENSE pin (due to excessive LED temperature) the device begins to modulate the converter at a frequency of 5.9 kHz. The more the NTC voltage drops, the longer the off-time of the converter. Therefore, the delivered output power is reduced until the NTC cools, the TSENSE voltage (VTSENSE) increases, and the system no longer requires reduced output power. The thermal foldback protection slowly reduces the output power, as a function of the thermal time constant. Thermal foldback protection is intended for protection only. It is not intended to be used as a regulation feature. During thermal foldback the error amplifier output is internally clamped low, and the COMP sample-and-hold switch is open, preserving the COMP pin voltage.

When the TPS92510 junction temperature reaches 150°C, the driver immediately disables the high-side MOSFET. The COMP sample-and-hold switch closes, and the COMP pin internally clamps low until the junction temperature drops by approximately 20°C. At this time, the COMP clamp is removed and the driver attempts to regulate.

LED fault protection mechanisms

An open circuit can be the result of an open LED or an open wire connection. In either case, the voltage at the VSENSE pin becomes zero, and this causes the COMP pin voltage to rise, commanding wide duty cycles. The output voltage eventually rises to the input voltage. This is a safe operating mode, provided that the output capacitors are rated for the input voltage potential.

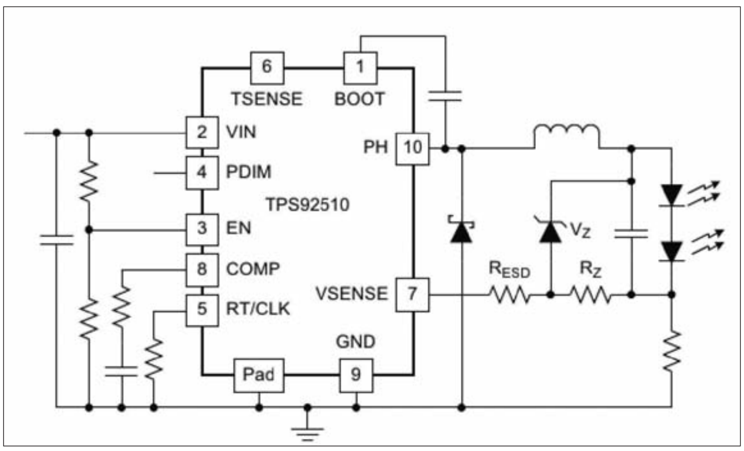
As shown in the output voltage clamp schematic, a transient voltage suppressor (TVS) device from VOUT to GND, or a diode from VOUT to the VIN pin can be used to clamp the L-C resonant output voltage ringing caused by the inductor and the output capacitor at the moment the LED string opens, particularly at high-input voltage and high-output voltage operating conditions. The TVS should have a voltage rating greater than the maximum output voltage, so that it does not conduct under normal operation. Either of these devices can be used to limit the output voltage to safe levels during an open LED fault.

If the current sense resistor also opens, current attempts to flow into the ESD structure of the VSENSE pin. To prevent damage to the device, a series resistor (RESD) on the VSENSE pin can be used to limit this current. The VSENSE pin has an internal, 8-V clamp, and the continuous current should be limited to a maximum of 20 mA.

An external overvoltage protection circuit consisting of V_Z and R_Z shown in the output voltage limiter, can be applied to the VSENSE pin to regulate the output voltage to less than the input voltage potential.

Some LEDs fail to a shorted state. It is unlikely that multiple LEDs fail short simultaneously. If a bypass capacitor is in parallel with the LED string it is charged to the LED string forward voltage. When one or more LEDs instantaneously short, the bypass capacitor senses a voltage transient from the initial LED string voltage to something less, depending on the number of LEDs that are now shorted. The voltage change across the capacitor causes the capacitor to discharge some energy in the form of a transient current through the LED string. This current flows from the bypass capacitor through the LED string, but not through the current sense resistor. Therefore, the TPS92510 does not sense the fault event, and does not respond to it. The peak transient current is a function of the change in forward voltage due to the shorted LED(s), and the dynamic resistance of the LED string at the moment the short occurs. This current can be substantial, and may require a protection circuit, unless the LEDs can survive the transient current. After the LED has shorted the error amplifier continues to regulate the programmed LED current at the new, lower output voltage.

www.ti.com/tps92510-pr-eu



Output voltage limiter circuitry

Highly Accurate Hybrid/Electric Battery Monitor

Lithium-Ion batteries require considerable care if they are expected to operate reliably over a long period. They cannot be operated to the extreme end of their state-of-charge (SOC). The capacity of Lithium-Ion cells diminish and diverge over time and usage, so every cell in a system must be managed to keep it within a constrained SOC. Linear Technology's 3rd generation Battery Management System provides many desirable features for monitoring large and distributed battery packs in vehicle and industrial applications, as outlined by **Greg Zimmer, Product Marketing Engineer at Linear Technology Corporation.**

To provide sufficient power for a vehicle, tens or hundreds of battery cells are required. These cells must be configured in a long series; as much as 1000 V and higher. The battery electronics must operate in this very high voltage environment and reject common mode voltage effects, while differentially measuring and controlling each cell in these strings. The electronics must be able to translate information from the battery stack to a central point for processing (Figure 1).

On top of these requirements, operating a high-voltage battery stack in a vehicle or other high-power applications imposes tough conditions, such as operation with significant electrical noise and wide operating temperatures. The battery management electronics are expected to maximize operating range, lifetime, safety and reliability, while minimizing cost, size and weight.

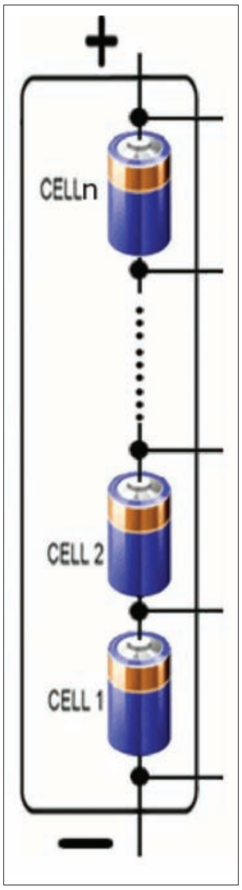


Figure 1: For achieving high voltages a number of cells have to be connected in series and each cell requires a differential measurement of its state-of charge

Requirements of the battery management electronics

The electronic system that measures and manages the battery stack (also known as the BMS) has three key requirements:

- The BMS must know the health of each battery cell in the stack. Primarily, this is accomplished by estimating the State-of-Charge of each cell in the battery system. The current SOC can be combined with historical information for determining the status of each cell.
- The BMS must control the state-of-charge for each cell in a system. This is done by controlling the charge, discharge and balancing of each cell in a system.
- Ensure safety. The BMS must know the electronics are properly working such that the battery info is valid. The golden rule is "no over voltage cell can appear as an OK voltage cell". In order to do this, the BMS has to communicate the status of all cells and the BMS electronics to the rest of the system.

The key element in the battery management electronics is the battery monitor IC. The battery monitor performs the difficult task of accurately measuring the voltage, current, and temperature of each cell and passing the data to a control circuit. A controller then uses the cell data to compute the state of charge and state of health of the pack. The controller may command the battery monitor to charge or discharge certain cells to maintain a balanced state of charge within the pack.

Third generation BMS

The LTC®6804 (Figure 2) is a high voltage battery monitor can measure up to 12 series connected battery cells at voltages up to 4.2 V, with 16 bit resolution and less than 0.04 % maximum measurement error. High precision is maintained over

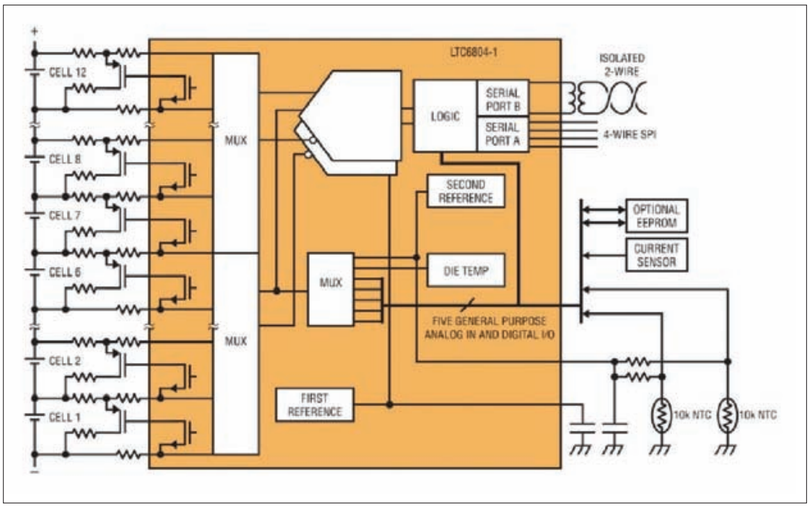


Figure 2: The LTC6804 measures 12 battery cells (LiIon, NiMh, Supercaps) with high accuracy in 290 microseconds

time, temperature and operating conditions by a sub-surface Zener voltage reference, similar to references used in precision instrumentation. When stacked in series, the LTC6804 enables the measurement of every battery cell voltage in large high voltage systems, within 290 µs. Six operating modes are available to optimize update rate, resolution and the low pass response of the built-in 3rd order noise filter. In the fastest mode, all cells can be measured within 290 µs.

Multiple LTC6804s can be interconnected over long distances and operated simultaneously, using proprietary 2-wire isoSPI interface. This interface provides high RF noise immunity up to 1 Mbps data rate and up to 100 meters of cable, using only a twisted pair of wires. Two communication options are available: With the LTC6804-1, multiple devices are connected in a daisy chain with one host processor connection for all devices; With the LTC6804-2, multiple devices are connected in parallel to the host processor, with each device individually addressed.

The LTC6804 was designed to minimize power consumption, especially during long term storage where battery drain is unacceptable. In sleep mode, less than 4 µA from the battery are drawn, and because the supply pin can be independently disconnected, battery current can be reduced to less than 1 µA.

General purpose I/O pins are available to monitor analog signals, such as current and temperature, and can be captured simultaneously with the cell voltage measurements. Additional features include passive balancing for each cell with a programmable balancing timer for up to 2 hours, even in sleep mode. The LTC6804 can also interface with external I?C devices, such as temperature sensors, ADCs, DACs or EEPROM. Local EEPROM can be used to store serialization and calibration data to enable modular systems.

The LTC6804 was designed to surpass the environmental, reliability and safety demands of automotive and industrial applications. It is fully specified for operation from -40°C to 125° and has been engineered for ISO 26262 (ASIL) compliant systems and a full set of self-tests ensure that there are no latent fault conditions. To accomplish this, the device includes a redundant voltage reference, extensive logic test circuitry, open wire detection capability, a watchdog timer and packet error checking on the serial interface.

Impact of measurement accuracy

Li-Ion cells generally have a flat discharge curve, with only a few millivolts of difference for each percentage of change in SOC (Figure 3). Because of this, the cell voltage measurement error directly translates into a limitation of the usable SOC range of operation. At a typical cost of $ 600 per kilowatt-hour today, a typical 16 kWh battery pack represents a significant portion of an electric vehicle's cost, and puts intense demand on achieving the best possible measurement accuracy.

Typically, in today's battery monitoring ICs, the voltage reference contributes the largest amount of error to cell measurement: The sources of error come from the initial accuracy, temperature drift, thermal hysteresis and long term drift. Hysteresis refers to an offset voltage induced in the reference when thermally cycled. The most significant thermal event occurs during the solder process.

The current generation of battery monitors relies on band gap voltage references. Band-gap references have gained in popularity in the last decade because of their low power, low dropout voltage and small size. However, the band-gap reference voltage is sensitive to mechanical stress. Mechanical stress is induced in an integrated circuit from the expansion and contraction of the plastic package and the copper lead frame through mechanical strain, humidity, and temperature. As an example, during PCB assembly the electronics experience several thermal shocks from the soldering process and a voltage reference can experience thermal hysteresis.

Precision is maintained over time, temperature and operating conditions by a sub-surface Zener voltage reference, similar to the type of voltage reference used in precision instrumentation (see Figure 3). Our test results show that the LTC6804 thermal hysteresis is at least 5x better than other parts, including our own LTC6802 and LTC6803.

Advantage of the Delta Sigma ADC

The measurement accuracy is also bolstered by dual 16-bit ADCs. With a resolution of 100 µV, the LTC6804 can measure all battery cells in the system within 290 µs. General purpose I/O signals are also available to measure external analog signals. The specified measurement range is from 0 to 5 V, accommodating a wide range of battery chemistries, including Lithium-Ion, NiMH and super capacitors.

The battery stack measurement electronics need to be designed in the context of the automobile or high-power system in which it will be used. The systems typically generate significant electrical noise and transients from inverters, actuators, switches, relays, etc. This noise has to be removed via pre-filtering, ADC filtering, or post process filtering. An RC filter at each cell input is a simple, effective way to reduce some noise, but not nearly enough to reduce the noise prevalent in most battery systems. There is a trade-off with RC filtering– input resistance can create IR errors on the monitor input, and also significantly slow down the signal of interest. For example, for an RC to offer significant attenuation at 10 kHz, a roll off at 160 Hz or lower is needed. Adding active filtering on each channel is expensive and impractical. Post processing is generally not practical for a large battery stack, where a large number of samples need to be downloaded from a long series of battery cells. As a compromise, sample averaging within the battery monitor is possible; however, this provides only a modest amount of filtering.

Linear Technology's battery monitor ICs use delta-sigma ADCs, rather than the much faster SAR type converter. Our designers recognized that a fast acquisition was useless if system noise swamped the signal. Delta-Sigma converters have built-in, high order, low pass filtering. To leverage this feature, the LTC6804 was designed with

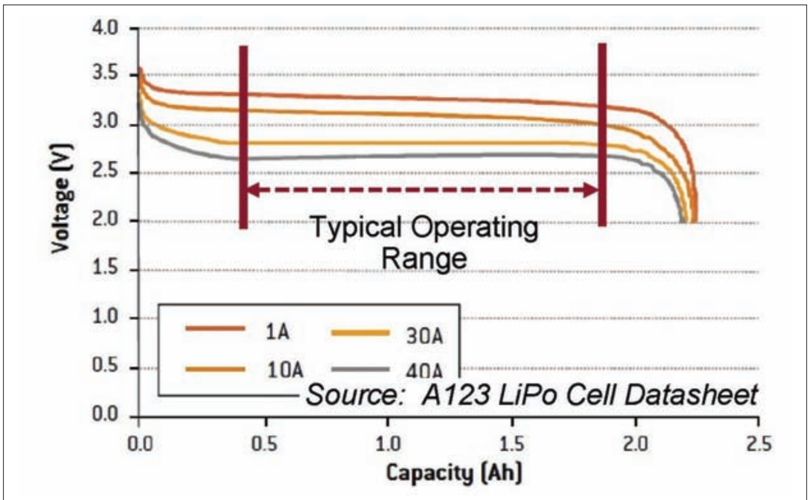
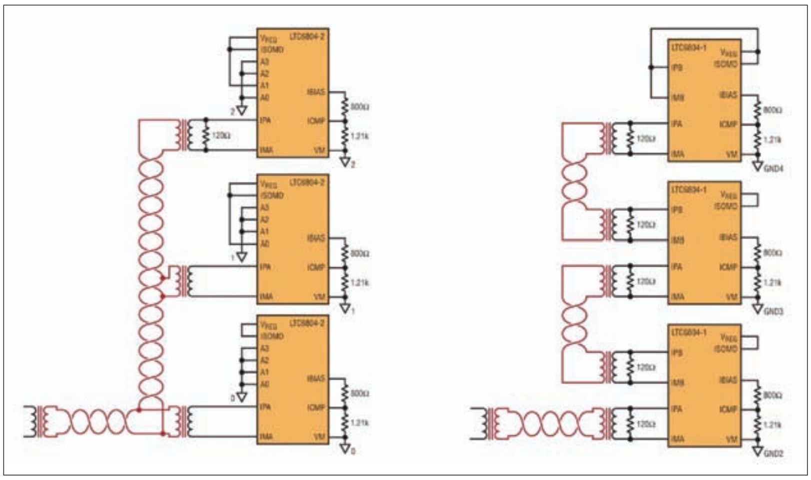
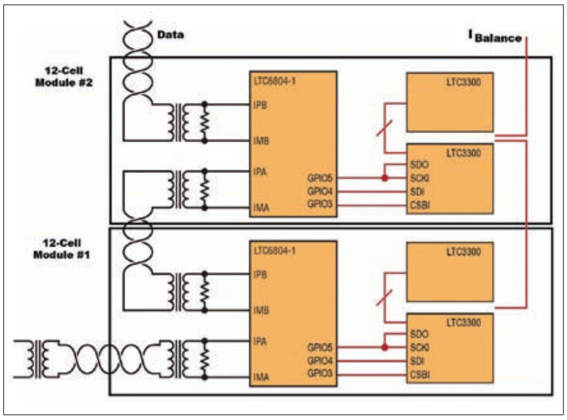


Figure 3: Discharge characteristics of a LiIon battery at 25°C





ABOVE Figure 4: The LTC6804-1 (left) connects multiple devices are in a daisy-chain while the LTC6804-2 connects multiple devices in parallel to the host processor

LEFT Figure 5: Bidirectional active balancing controlled with the LTC6804 SPI interface

six user programmable ADC speeds. This allows the user to choose the best filtering and ADC speed combination for their system. At its highest speed, all cells in the high voltage stack can be measured within 290 µs. The slow ADC setting with a cutoff frequency of 26 Hz can be used to eliminate EMI for periodic calibration.

Distributed battery packs supported

To accommodate the large quantity of cells for high powered systems, the batteries may need to be divided into packs, and distributed throughout available spaces in the vehicle. With 10 to 24 cells in a typical module, a modular design allows for a battery pack to be used as a building block across all platforms; a modular design simplifies maintenance and warranty issues, and can be used as the basis for very large battery stacks. It allows battery packs to be distributed over larger areas for more effective use of space.

The LTC6804 was designed with several features to support a modular design. First, the GPIO can be configured to operate as a SPI or I^2C Port. This allows the device to interface to local EEPROM, where serialization and calibration data can be stored. Once a module has been built, the electronics to remain connected and the LTC6804 can stay in a sleep mode, using less than 4 µA. This ensures that there is no appreciable battery drain, or unbalancing of battery cells, even after months or years of storage. Each module can be stored as an independent pack, ready to be used as needed. Finally, the isoSPI interface provides a method for interconnecting modules, even with significant distance from pack to pack.

To support a distributed, modular topology with high electromagnetic interference (EMI), a robust communication system, is required. Most commonly, this is achieved with an isolated CAN interface, requiring a microprocessor, digital isolator and CAN transceiver. The LTC6804 eliminates the cost and software complexity of CAN by including a built-in isoSPI interface. The isoSPI combined with a simple transformer allows for data up to 1 Mbps to be communicated over long distances using only a twisted pair cable. This allows data transfer between modules and the LTC6804 is available with 2 interconnection options. Using the LTC6804-1, multiple devices are connected in a daisy-chain with one host processor connection for all devices. Using the LTC6804-2, multiple devices are connected in parallel to the host processor, with each device individually addressed.

The signal strength of the isoSPI pulses and the impedance of the 2-wire connection are adjustable. The user can increase signal current by changing resistor values. This flexibility means that the isoSPI bus can be tailored for communication over 100 meters of cable and reject high interference levels. The LTC6804 includes a 15-bit cyclic redundancy check (CRC) to ensure the integrity of the data.

The performance of isoSPI has been confirmed with Bulk Current Injection (BCI) testing. BCI measures systems immunity to electromagnetic interference. RF energy is injected through a probe clamped around the cable while another probe measures the resulting RF current. Data is sent through the cable and the CRC is analyzed for data corruption. The test is repeated with several strengths of isoSPI data pulses. The 20 mA isoSPI data pulses are immune to 200 mA of RF injection.

Cell balancing control

Controlling the SOC for each cell in a system requires balancing each cell in the system. Balancing refers to adding or removing charge on individual cells, as needed, to keep each within a controlled SOC range. Passive balancing, which is primarily used today, involves discharging any cell that reaches its maximum State-of-Charge limit during the charge process. This allows the rest of the cells in a string to continue being charged without damaging this weaker cell. This extends the amount of charging and allows more of the full capacity of each cell. The LTC6804 includes onboard FETs that can provide modest passive balancing, or can control external power FETs for higher current passive balancing.

Passive balancing is energy inefficient and relatively slow. Typical balancing currents range from 1 to 5 % of the cell capacity. To dissipate 10 % of the charge from a 40 Ah battery requires 10 hours at I=400 mA, or generates 8 W of heat per cell at I=2 A. For large capacity packs, the balancing time or heat generation can become unacceptable; a high efficiency, high current active balancer may be the only viable solution. Active balancing refers to moving charge between cells, both during the charge and discharge cycles, to keep the SOCs within range. This can extend both the charge and discharge phases, allowing for further extension of the usable battery capacity. It also has the potential to reduce heat generation, reduce battery charging time, increase energy efficiency and extend the life of the cells (by ensuring cells age in unison).

New IC's are anticipated in the near future, such as Linear Technology's LTC3300 with balancing currents up to 10 A. The LTC3300 can be controlled via a serial port on the LTC6804, offering an accurate, easy to use cell monitor and balancing system (Figure 5).

More Battery Management Systems

Charge and discharge cycles have an impact on the longevity of lithium ion batteries used in electric vehicles and the ultracapacitors used for energy storage in photovoltaic systems. For this reason, it is necessary for battery safety and longevity to be able to establish the state of charge (SoC) and the state of function (SoF). As electric mobility becomes more popular, more vendors are entering the market.

At Electronica Maxim Integrated Products (**www.maximintegrated.com**) introduced the MAX17823, a high-voltage battery sensor for mission-critical automotive and industrial LiIon battery and fuel cell applications. Offering a suite of proprietary integrated ISO-26262 diagnostic features, the MAX17823 maximizes electric and hybrid electric vehicle driving range while ensuring battery and fuel cell safety and reliability.

A proprietary, differential UART communications link (5 m) is automotive EMC-hardened, enabling uninterrupted cell monitoring during battery pack service disconnect and eliminating costly digital isolators. An innovative shutdown feature safely enters all daisy-chain devices into sleep mode when a host microcontroller loses 12V power. ASIL-D (Automotive Safety Integrity Level "D", per ISO-26262) compliance is achieved and maintaines accurate 96-cell, 100 measurements-per-second performance. The 96-cell hot-plug immunity ensures highest reliability during battery management system manufacturing.

Maxim's high-voltage battery sensor manages 96 cells

Also Toshiba Electronics Europe (**www.toshiba-components.com**) has announced it will launch a LiIon battery monitor chipset for automotive applications.

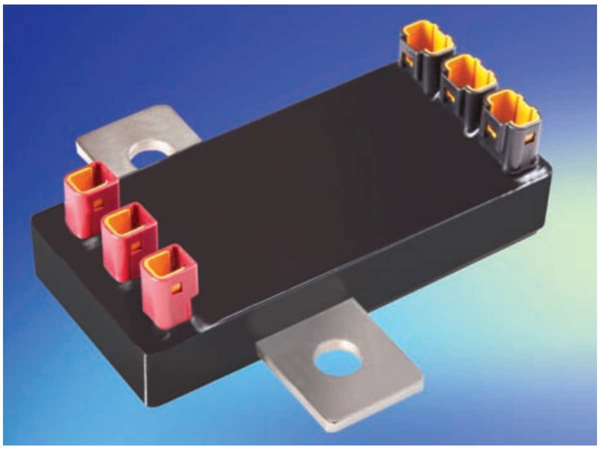
Designed for Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs), the Li-ion battery chipset monitors up to 16 cells and comprises the TB9141FG monitoring IC and the TMPM358FDTFG microcontroller. The chipset detects remaining battery level, equalizes battery levels (cell balancing) and can detect abnormal battery status. Typical measurement accuracy is ±2mV cell voltage, improving the accuracy of battery state of charge (SOC) detection and contributing to more effective battery usage. The TB9141FG incorporates a cell balance switch and is able to measure battery voltage while cell balancing.

Furthermore, the TB9141FG is able to communicate in a noisy environment by differential signals using daisy chain communication with neighbouring TB9141FGs. The TMPM358FDTFG is a 32-bit RISC microcontroller built around an ARM CortexTM-M32 core and compliant with functional safety levels (IEC61508 / ISO26262).

Sample shipments of this chipset will start in February 2013, and mass production in April 2014. The company will prepare a software library to be compliant with the IEC61508 and ISO26262 functional safety standards and is also planning reference models. These tools will simplify the implementation of battery monitoring systems.

Chipset for monitoring 16 LiIon battery cells

Isabellenhütte (**www.isabellenhuette.de**) offers for LiIon battery management the tried-and-trusted IVT sensor module for measuring current, voltage and temperature, which is now available in a modular design enabling customers to select individual components and configure their own made-to-measure IVT in accordance with their specific needs. A customer might choose communication between SPI or CAN interfaces, between a sensor module with or without galvanic separation or many other configuration possibilities. As well as the current input, up to three voltage inputs are possible; these can be fitted with input filters. Likewise, customers can choose from three different power supplies. The IVT can be equipped with an optional overcurrent detection facility. As well as the off-the-shelf products, customers can order specific solutions upon request. Current range is up to 1,500 A, extended up to 5,600 A with 0.1 % tolerance.



Shunt-based battery measurement system for high currents

High-Speed TRENCHSTOP 5 IGBT

IGBTs are historically known for having long tail currents with focus on drive applications and anything switching up to 30 kHz was known as "High Speed", where conduction losses were penalized to get switching losses down. In 2008, Infineon launched a ground breaking technology called the HighSpeed3, which is the highest efficiency IGBT capable of switching up to 100 kHz with a MOSFET-like turn-off switching behavior. Now Infineon's TRENCHSTOP™ 5 technology is capable of switching well beyond 100 kHz. **Mark Thomas, Discrete IGBT Product Marketing, Infineon Technologies AG, Villach, Austria**

The TRENCHSTOP™5 technology is an optimization of the TRENCHSTOP™ concept combining Trench gate and Field Stop structures. In order to minimize total power losses, the chip thickness is reduced to 50 µm and an optimization of the carrier profile has been carried out to provide a reduction of charge carriers within the drift zone that have to be removed during the turn-off phase. These two measures allow for a significant reduction in conduction losses ($V_{CE(sat)}$) and turn-off switching losses (E_{off}). Despite the chip thickness reduction, a 650 V blocking capability is achieved, 50 V higher than the previous generation. Additionally, thanks to a new transistor stripe cell structure the gate charge (Q_g) is reduced and current density is increased.

The combination of all the above mentioned innovations result in an IGBT with the lowest combination of conduction losses ($V_{CE(sat)}$) and total switching losses (E_{ts}), thus producing the highest efficiency IGBT.

TRENCHSTOP 5 is the name for the base technology and from this two device families are being initially released to address different application requirements and fulfill designers' needs. The designer has the opportunity to select between the HighSpeed5 (H5) and HighSpeed5 Fast (F5) versions. The H5 family is characterized by an optimized field-stop design and is aimed to complement the HighSpeed3 IGBT family; it allows for the "plug-and-play" replacement of IGBTs without any special effort in adjusting the board design. It provides soft voltage rise during hard commutation at turn-off even with low gate resistor (Rg) values and very high di/dt.

The F5 meanwhile, is the extended performance solution. It provides higher efficiency, but more design effort is required to harvest the benefits. The driver stage should be equipped with split turn-on ($R_{g,on}$)/ turn-off ($R_{g,off}$) gate resistors to maximize efficiency and control voltage overshoot during turn-off. It is the best fit for optimized PCB design with low stray inductance both in the commutation loop and packages and used in combination with Silicon Carbide diodes (SiC)

Comparison with Infineon's HighSpeed3 Technology

Compared to the HighSpeed3 (HS3) family, the TRENCHSTOP 5 shows a significant improvement in all static and dynamic parameters. It provides

* 50 V higher blocking voltage to allow for bus voltage increases without compromising reliability. Also for solar applications, cosmic radiation robustness in increased,

- 250 mV lower conduction losses (Vce(sat)) and a factor of 2 lower turn-on/-off switching losses (Eon and Eoff), resulting in the highest efficiency high speed IGBT ever released,
- drastic reduction of Coss, Cres ensures benchmark light load efficiency,
- 50% reduction in gate charge (Qg) allows for lower power driver ICs to be used without sacrificing performance and enables a system cost reduction.

Mild positive temperature coefficient of the conduction and switching losses mean efficiency is not sacrificed when devices are driven with higher junction temperatures and thermal run away during paralleling is not a problem.

The TRENCHSTOP 5 uses the new Rapid Silicon diode as the free-wheeling diode (FWD), which offers 50 ns reverse recovery time (t_{rr}) and temperature stable forward voltage (V_F). This ensures turn-on losses are minimized and overall efficiency is optimized.

Dynamic behavior

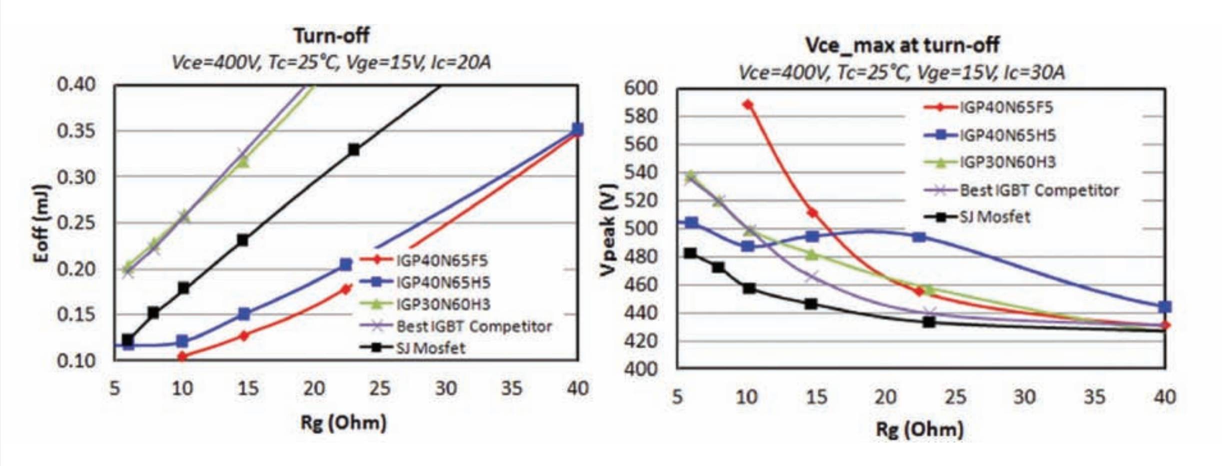
In order to highlight a new technology it is important to explain the gate resistor controllability of the switching behavior. On the left hand side of Figure 1, the turn-off controllability as function of Rg during a standard double pulse test circuit is highlighted, with stray inductance of 45 nH in the commutation loop. The E_{off} curve of both H5 and F5 are drastically lower compared to traditional fast IGBTs, and in the same range of Superjunction MOSFETs at low R_g of 5 Ω.

The right hand plot of Figure 1 shows the collector-emitter voltage at turn-off as function of Rg. The plot helps to underline the difference between H5 and F5, thus the need for the two families. The H5 shows a smooth switching behavior, with voltage overshoot of the same order as the HighSpeed 3. The F5 meanwhile, is characterized by higher voltage overshoot at turn-off, but exhibits higher efficiency. The typical waveforms are also shown in Figure 2, where the F5 shows much faster current drop during turn off, translating unavoidably in higher voltage overshoot (L*di/dt).

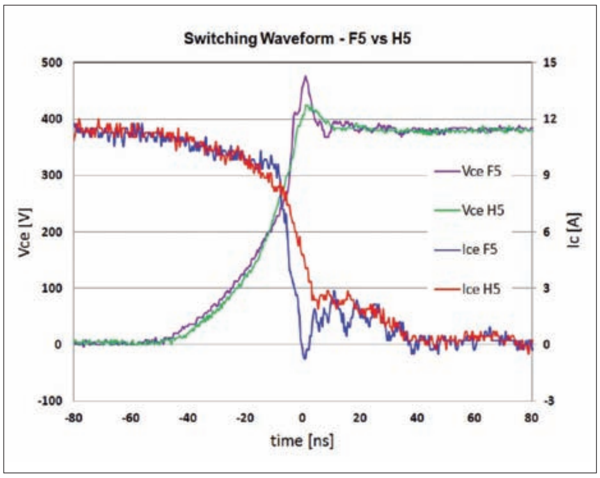
Figure 3 shows the relationship between the turn-on losses (E_{on}) and turn-on gate resistor value ($R_{g,on}$) for both F5 and H5. From Figure 3 it can be seen that the TRENCHSTOP 5 shows very similar behavior to a superjunction MOSFET of equivalent rating, and significantly lower losses compared to previous IGBTs. It can also be concluded that the turn-on behavior of the F5 and H5 is controllable via the turn-on gate resistor ($R_{g,on}$) over a wide range.

What can be concluded from Figures 3, 4 and 5 is as follows:

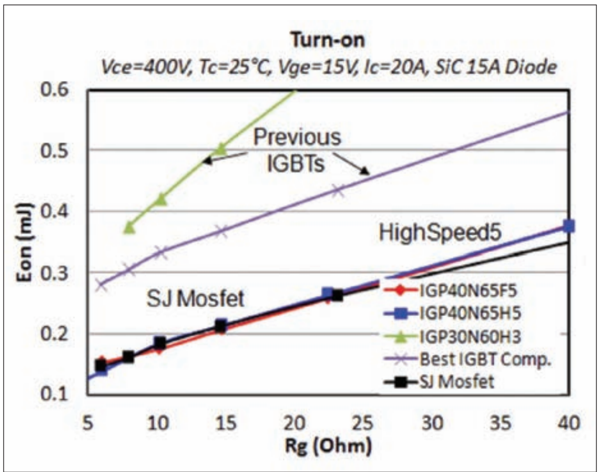
- Two families are required to provide



ABOVE Figure 1: Turn-off dependence of gate resistor: turn-off Energy (left) and voltage overshoot (right)



RIGHT Figure 2: Typical turn-off waveform H5 vs F5



LEFT Figure 3: Effect of $R_{g.on}$ on turn-on energy

designers with either an IGBT that is easy to handle and thus can be easily implemented (H5) or an IGBT that is snappy, needs care during implementation to reduce commutation loop inductance, but offers extended higher efficiency (F5).

- Turn-off controllability of the voltage overshoot and the switching losses is possible.
- Turn-on controllability is possible and turn-on switching losses are on par with superjunction MOSFETs.
- Ultimately there is a trade-off between switching losses and voltage overshoot. F5 needs to be driven with higher ohmic gate resistors compared to the H5, to limit the voltage overshoot.
- F5 has the highest efficiency due to the higher di/dt and is recommended for low inductance commutation loops and in combination with Silicon Carbide (SiC) diodes.
- H5 can be driven with gate resistors down to 5 Ω due to the softer turn-off behavior compared to F5.

Application measurements

For this industrial application measurement example, the H5 has been analyzed compared to the HighSpeed3 equivalent products.

Due to the dramatic improvement in efficiency seen by the H5 in the application test, designers have to make one of two fundamental decisions:

1. Do I maintain the traditional switching frequency of 20 kHz seen in state-of-the-art photovoltaic inverters to get the highest efficiency out of the TRENCHSTOP™ 5? or
2. Do I drive the switching frequency higher, keeping the same level of efficiency seen with the HighSpeed3 or the same case temperatures, but concentrate on system costs by reducing the size of the passive components?

To provide information to help answer questions 1 and 2 a very simple test condition of a 20 A square wave with 50 % duty cycle and maximum junction temperature 100°C was used. This was defined to show the power loss improvement the H5 offers compared to Infineon's HighSpeed 3 in terms of switching frequency. The results of this simple test where the curves of total power loss per IGBT vs. switching frequency are shown in Figure 4.

Relating to question 1, at 20 kHz switching frequency, the total power loss per IGBT dropped from 32.80 W, when the HighSpeed3 was used, to 25.04 W, when the H5 was implemented. What the results show is that just by implementing the new H5 (with no changes to driver circuit or board layout), power losses were reduced by more than 23 %. Furthermore, when the IKW40N65H5, which has the Rapid Silicon diode as the free-wheeling diode, was replaced with the IGW40N65H5 in combination with Infineon's 2nd generation Silicon Carbide (SiC) diode, provided a further 11 % power loss reduction.

Just by implementing the H5, immediate IGBT loss reduction was

Figure 4: P_{tot} vs switching frequency

observed, resulting in higher efficiency. Concentrating on systems offering higher efficiency allows designers to differentiate their designs and add extra value, which in turn can be sold at higher market prices.

Relating to question 2 and the affects of switching frequency versus power losses are now considered.

Let's first consider maintaining the same level of switching losses as the HighSpeed3 when the H5 is used. Under the simple test condition described above and again as shown in figure 4, switching frequency could be increased by more than 42%, to 35 kHz, when the HighSpeed3 was replaced by the H5. The switching frequency could be extended a further 28%, to 48 kHz, when the H5 was used in combination with a SiC diode.

Having the opportunity to increase the frequency, whilst maintaining the same thermal performance, brings about a cost and reliability benefit. This can be realized by using smaller and lighter magnetic components, and reducing or even eliminating the use of electrolytic capacitors. Although increasing the switching frequency increases the design complexity, clear benefits can be achieved for applications like solar and UPS, where the costs of the passive components dominate the bill of material.

When reverting to the examination of junction temperature versus switching frequency, the assumption is made that the junction temperature of all the power devices fulfill the derating requirement e.g. 80 % of the maximum junction temperature (T_{jmax}), which then allows for the maximum allowable power loss per device to be defined. Taking a practical example to demonstrate the performance of the H5, assume the specification of the maximum junction temperature is 100°C.

Taking the same test condition mentioned above (20 A square wave, 50 % duty cycle) for a 40 A device, the maximum power loss for a standard TO-247 package would be 40 W. At 40 W, the maximum operating frequency of HighSpeed 3, with respect to maximum junction temperature of 100°C, is around 28 kHz. The new H5 could however be driven up to 50 kHz, which represents nearly a 50 % increase in switching frequency, whilst maintaining the same junction temperature. This result highlights, for the same level of junction temperature (bearing in mind junction temperature is proportional to lifetime reliability) switching frequency can be dramatically increased. Of course, as in life, there are trade-offs and going beyond 33 kHz (according to this simple calculation) efficiency would be lower than when the HighSpeed3 is implemented at 20 kHz. The great thing about the TRENCHSTOP 5 is the designer really has a number of options to optimize his design to reach their design specifications.

Figure 5 shows an example of a HERIC topology which was measured at Fraunhofer Institute ISE. The H5 allows for the switching frequency to be tripled from 16 to 48 kHz compared to corresponding HighSpeed3 device by keeping the same efficiency over the entire load range.

Conversely, by maintaining the switching frequency at 16 kHz, overall system efficiency has been increased. A clear design strategy is necessary to get the best out of the new TRENCHSTOP 5 IGBTs. Further improvements in efficiency can be attained when a Silicon Carbide diode is used as the free-wheeling diode or the F5 IGBT is used. It will be those designers and companies who are able to successfully manage design strategies to be able offer differentiated systems to their end customers and increase their own market share.

Conclusion

Through application measurements it has been proven that the TRENCHTOP 5 sets a new benchmark for IGBTs switching greater than 16 kHz. As a result of the best optimization of carrier profile in combination with Infineon's further advancement of thin wafer technology, a drastic reduction in both turn-off and turn-on losses in hard switching applications, along with a low $V_{ce(sat)}$ value provide an IGBT that can achieve more than 98 % system efficiency in a photovoltaic inverter. Furthermore, the overshoot and EMI behavior is well controlled and is on the same level as the well-known HighSpeed 3 series. The H5 with the Rapid diode as the free-wheeling diode offers an ease-of-use solution for high performance industrial applications like photovoltaic inverters, UPS and welding. The H5 in combination with SiC further increases this efficiency range, while further optimisation is available when using the F5 version. The TRENCHSTOP 5 offers designers many advancements in IGBT performance. It is now up to designers to harness the full capability.

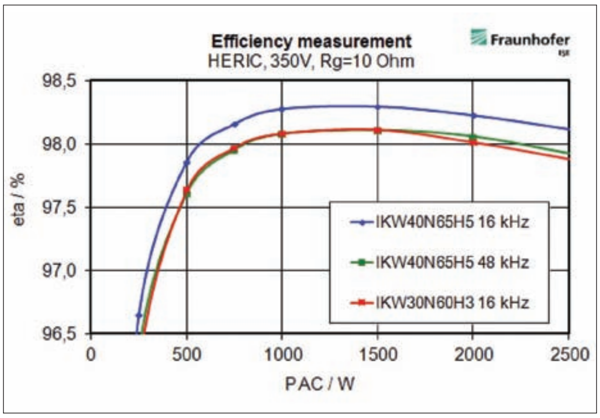


Figure 5: HERIC efficiency at different switching frequencies

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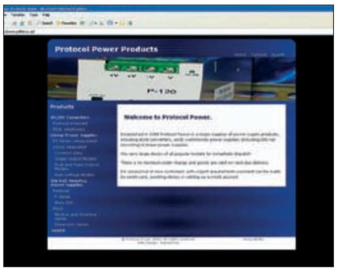

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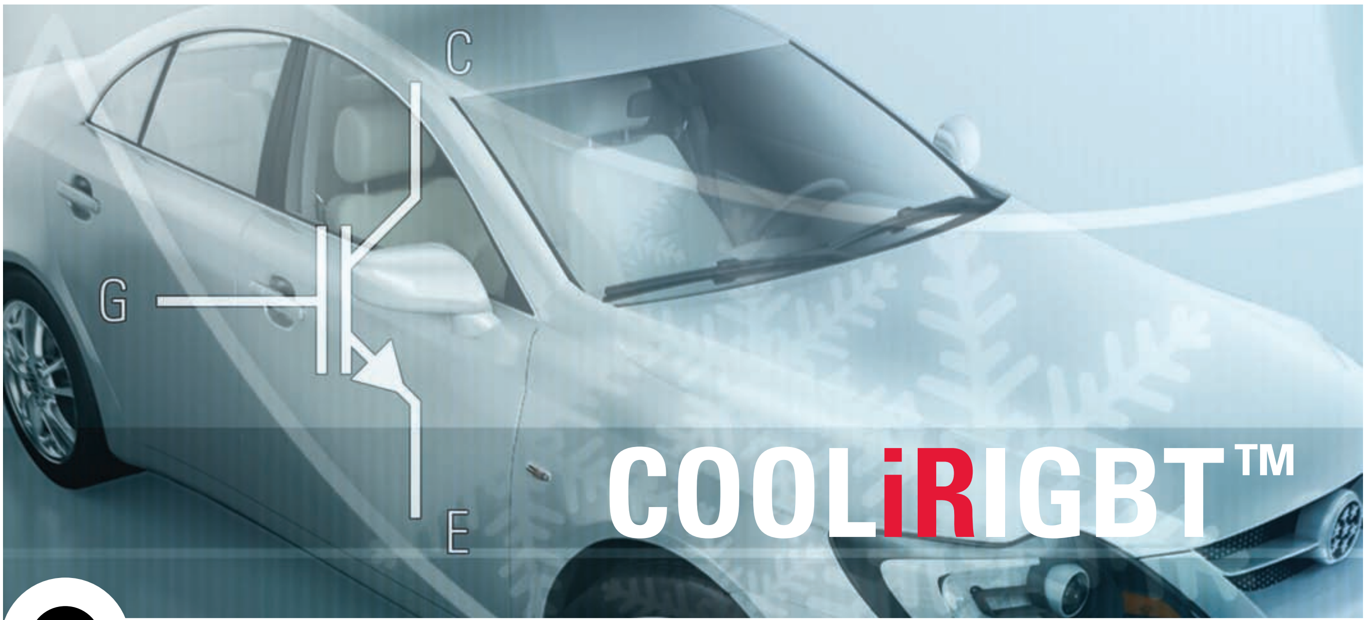

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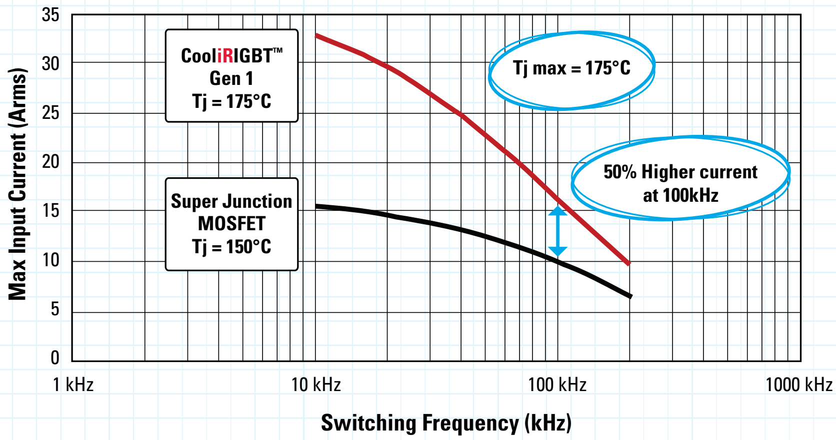

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