POWER ELECTRONICS EUROPE

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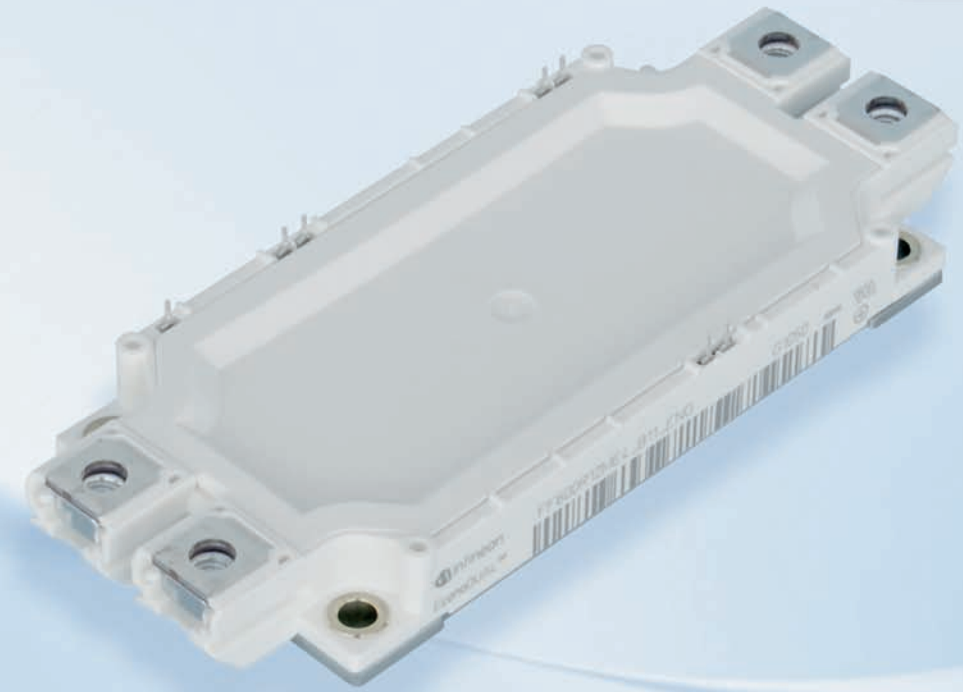
LIGHTING POWER
LED Replacements
for Fluorescent Tubes

THE EUROPEAN JOURNAL
FOR POWER ELECTRONICS
AND TECHNOLOGY

Also inside this issue



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

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

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

Circulation Manager Anne Backers
Tel: +44 (0)208 647 3133
Fax: +44 (0)208 669 8013
Email: anne@abdatalog.co.uk

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

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

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

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

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

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

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

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COVER STORY

LED Replacements for Fluorescent Tubes

Since high brightness LED technology has reached efficiency levels comparable with those of fluorescent lamps, many retrofit products have appeared on the market designed to replace the popular 4 foot fluorescent tube. Due to the directional nature of LEDs a 32W T8 replacement product can produce a similar light intensity measured at floor level consuming less than 20W thereby offering significant energy savings over fluorescent. The different approaches used in LED tube design can be broken down into two main categories; those with external drivers and those with internal drivers. The external driver approach is based on the fluorescent concept where a single external LED driver runs one or more LED tubes which contain a string or array of LEDs with little or no additional electronics. The internal driver approach however requires that all the electronics be housed within the confines of the LED tube, which creates many restrictions on components sizes and form factors, particularly for inductors. The article discusses the pros and cons in more detail. Full story on page 23.

Cover page supplied by International Rectifier


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The LED Revolution Comes

General lighting, automotive lighting and backlighting are the three largest sectors in the lighting industry, and general lighting accounts for approximately 75 % of the world market, according to McKinsey. Legislation regarding lighting efficiency is forcing the phasing out of incandescent bulbs. Compact fluorescent lamps are the other incumbent and cheaper competing lighting technology, but these are now regarded as being less green because they use mercury vapor. Now that the necessary brightness and efficiency levels are competitive, we are close to the tipping point for the adoption of high-brightness LEDs for most general illumination applications. However, adoption may be hampered by concerns over their longevity and the high initial cost of LED-based lighting solutions. Some early compact fluorescent lamps had shorter than expected lifetimes as a result of reliability issues with the ballast and ignition circuitry. This experience may act as a barrier to the adoption of LEDs in domestic lighting until longevity of the LED plus driver electronics as an integrated system is proven. The wide adoption of LEDs is facing two particular challenges. Too many technical trade-offs have to be made for LEDs to replace incandescent bulbs in luminaires originally designed for incandescent. Ultimately, new luminaires are needed that are specifically designed for LEDs, for which no compromise has to be made with regard to thermal management. However, the bare LEDs that are to be used in such LED-specific designs are not interchangeable (plug-in compatible) with each other because of a lack of standards. Good thermal designs that work well for unspecified thermal environments will be essential if LED-based retrofit products are to achieve anything close to the potential 40,000 hour useful lifetime, which is the level of consumer acceptance needed for LEDs to replace incandescent bulbs at anticipated rates.

Nevertheless, almost all sectors of the lighting industry are undergoing an unprecedented change to solid state lighting solutions based on LEDs. A number of factors have contributed to this change, including legislation, greater efficiency, and rapidly reducing prices. The U.S. Energy Independence and Security Act of 2007 requires general-purpose light bulbs that produce 310-2600 lumens to be 30 % more efficient than incandescent bulbs, with the aim of replacing 100 W incandescent bulbs in 2012 and 40 W bulbs in 2014. Many other legislative efforts around the world also will effectively ban incandescent light sources. LEDs are increasingly being used in daytime running lamps, which are mandated for new car production in the European Union. OEMs also are increasingly using LEDs as a competitive edge in branding their products. The Compounded Annual Growth Rate of revenues from >300 lumen LEDs between 2009 and 2016 will be more than 40 %, and high brightness LEDs is according to IMS Research the fastest growing subsector. This growth is anticipated in spite of a projected significant decrease in unit costs.

More efficient and brighter LEDs are finding new applications that have severe thermal challenges, such as LED car headlights, where product longevity is a must if excessive future warranty costs are to be avoided and the vehicles' safety requirements are to be maintained. The market for LED light sources in general lighting is still at an early stage and it is expected be several years before use of fluorescent tubes declines significantly. LED tube replacement sales are still modest, being sold only to early adopters at this time.

The different approaches used in LED tube design can be broken down into those with external drivers and those with internal drivers. The external driver approach is based on the fluorescent concept where a single external LED driver runs one or more LED tubes which contain a string or array of LEDs with little or no additional electronics. This approach makes a lot of sense in terms or optimizing performance and minimizing costs, however it seems the market may be going more towards the internal driver approach. The reason for this is most likely because it makes retrofitting of existing fluorescent fixtures more straightforward. The contractor simply needs to remove existing fluorescent control gear and wire the lamp end caps directly to the AC line rather than having to mount and wire up a new LED driver module as well. As LED technology continues to improve and mass production brings down the costs, the use of LEDs in general lighting applications will ramp up. As a result, the need for accurate metrics, and hence standardization, is growing rapidly.

In this issue we have published two articles dealing with these issues. I hope these will be of interest for the majority of our readers.

Achim Scharf
PEE Editor

First GaN LED Chips on Silicon

Researchers at OSRAM Opto Semiconductors have succeeded in manufacturing prototypes of blue and white LEDs, in which the light-emitting gallium-nitride layers are grown on silicon wafers with a diameter of 150 millimeters (6”). The silicon replaces the sapphire commonly used until now without a loss in quality. Already in the pilot stage, the new LED chips are to be tested under practical conditions.

“Our investments in years of research are paying off, because we have succeeded in optimizing the quality of the gallium-nitride layers on the silicon substrates to the point where efficiency and brightness have reached competitive market levels. Stress tests we’ve already conducted demonstrate the high quality and durability of the LEDs, two of our traditional hallmarks,” says project manager Peter Stauss. The company has acquired comprehensive expertise over the last 30 years in the process of epitaxy crystal growth, the foundation for this milestone in the development of new manufacturing technologies.

This is a pioneering development for several reasons. On account of its widespread use in the semiconductor industry, the availability of large wafer diameters and its very good thermal properties, silicon is an attractive and low-cost option for the lighting markets of the future. Quality and performance data on the fabricated LED silicon chips match those of sapphire-based chips: the blue UX:3 chips in the standard Golden Dragon Plus package achieve a record brightness at 58 percent efficiency. These are outstanding values for 1 mm_ chips at 350 mA. In combination with a conventional phosphor converter in a standard housing - in other words as white LEDs - these prototypes correspond to 140 lm at 350 mA with an efficiency of 127 lm/W at 4500 K. “For these LEDs to become widely established in lighting, the components must get significantly cheaper while maintaining the same level of quality and performance,” Stauss emphasizes. “We are developing new methods along the entire technology chain for this purpose, from chip technology to production processes and housing technology.” Mathematically speaking, it is already possible today to fabricate over 17,000 LED chips of one square millimeter in size on a 150 millimeter wafer. Larger silicon wafers could increase productivity even more; researchers have already demonstrated the first structures on 200 millimeter substrates (8”).

www.osram-os.com

First gallium-nitride LED chips on 6” silicon wafers in pilot stage at Osram Semiconductors

LED Manufacturing Capacity to Increase

Following a massive 36 percent increase in equipment spending in 2011 (up to $ 2.42 billion), worldwide LED manufacturing equipment spending is projected to decline 18 percent in 2012 to $1.97 billion, according to SEMI Opto/LED FabWatch and Forecast. But worldwide LED manufacturing capacity is expected to reach two million wafers in 2012 (4” equivalent per month), a 27 percent increase over 2011.

After several years of rapid capacity expansion driven by high-brightness LEDs used in TV backlighting applications- reinforced by lucrative government incentives and economic development funding in China- a 40 percent decline in world metal organic chemical vapor deposition (MOCVD) purchases in 2012 will reduce overall LED equipment spending for the first time in over five years. Spending for LED equipment is expected to increase in Taiwan and Korea. Spending for non-MOCVD equipment, however, particularly in lithography, etch, test and packaging equipment will increase in 2012, as manufacturers optimize their production lines and improve their product designs.

While HB-LED demand continues to grow in solid state lighting, HB-LEDs used in liquid crystal display (LCD) TV backlighting units- presenting approximately 40 percent of the total HB-LED market- failed to reach growth expectations in 2011. Total TV unit sales missed growth targets and the penetration of LED backlighting as part of total LCD TV unit sales did not reach the levels that many experts predicted. LEDs used in solid state lighting, currently totaling approximately $2.5 billion, may exceed $30 billion by 2020, according to many estimates.

“Similar to other microelectronics industries, LED manufacturing capacity and technology investments will vary year-over-year, but will correspond with the long-term demand driven by key applications; in LEDs, this will be primarily solid state lighting,” said Tom Morrow, executive vice president, Emerging Markets Group, at SEMI. "Future equipment and capital spending will drive LED cost reduction through larger wafers, automation and dedicated equipment specifically designed to improve to LED manufacturing yield and throughput."

Regional equipment spending shows China continuing to lead with an expected $719 million planned for 2012, followed by Taiwan ($321M), Japan ($300M) and Korea ($260M). Taiwan will continue to lead in capacity at 25 percent of the world LED capacity, followed by China at 22 percent of world LED capacity. In regards to new fabs, SEMI recorded 29 new LED fabs in 2011. For 2012, SEMI forecasts 16 new fabs coming online next year.

Looking at the back-end of the LED market, the recent Global Semiconductor Packaging Materials Outlook by SEMI and TechSearch Inc. shows very strong growth in LED leadframe shipments. Following the 69 percent unit shipment growth in 2010, LED leadframe shipments are estimated to increase by another 10 percent in 2011. In 2012, shipments are forecasted to reach almost 83 billion units shipped. Data are based on shipments reported by sixteen leadframe suppliers.

www.semi.org

Digital Power Management Patent License

Power-One and TDK-Lambda announced a license agreement for Digital Power Technology (DPT) patents from Power-One.

Power-One's Digital Power Technology applies to DC/DC Board Mount Power applications in the server, storage, networking, and telecom industries, where board densities are increasing and the power management solutions required to drive FPGAs, ASICS, DSPs and other semiconductor devices are becoming more and more complex. DPT drives increased system efficiency, improved design flexibility, faster time to market, decreased footprint size and lower system costs. It also enables telemetry capability, providing access to critical information including current, temperature and voltage. Telemetry allows the system to accurately monitor its power consumption and thermal performance, enabling designers to easily engineer key features such as system optimization, fault detection and predictive maintenance features into their end products.

www.power-one.com, www.tdk-lambda.com

Vicor and Digi-Key Announce Global Distribution Agreement

Vicor offers a portfolio of power architectures that enable to convert and manage power from the wall plug to point-of-load and address a broad range of power system requirements including performance-critical applications. "Our relationship with Digi-Key represents an important element of our global growth strategy," said VP Richard Begen. "We expect that Digi-Key's market reach will expand our global footprint, while increasing our presence and revenue in critical growth markets worldwide."

www.digikey.com

The World of Power Electronics

APEC 2012
February 5-9, 2012
Orlando, Florida

The Applied Power Electronics Conference and Exhibition (APEC) to be held from February 5-9 in Orlando/Florida again turns out to be a successful event with around thousand delegates. APEC is now considered to be one of the leading conferences for practicing power electronics professionals. The program addresses a broad range of topics in the use, design, manufacture and marketing of all kinds of power electronics equipment. The Exposition has grown from about 30 exhibitors in 36 booths in 1991 to more than 165 exhibitors filling 260 booths today.

Already on Sunday (Febr. 5) and Monday Professional Education Seminars will be held covering "Topologies and Control", "Digital Control", "Battery Management", "Components", "EMI and Surge Protection", and "Sustainable Energy". The Technical Sessions will start on Tuesday (Febr. 7) 8.30 am until Thursday (Febr. 9) 5.30 pm and will cover all important aspects of power electronics, from power semiconductors over DC/DC converters to vehicular electronics. Industry Sessions will run in parallel covering Energy Harvesting, HEV Applications, Reliability Testing, LED Lighting, Magnetics, Nanotechnology, and the Grid 2020. Rap Sessions or panel discussions on Smart Grids, Outsourcing Engineering, or Solar Energy are scheduled for Tuesday afternoon (5.00 - 6.30 pm). Finally, Dialogue Sessions will be held on Thursday from 11.30 am to 1.30 pm.

Plenary session covering trends

An important part of the APEC conference is the Plenary Session on February 6 beginning at 1.30 pm. It will be opened by Fred Lee, University Distinguished Professor at famous Virginia Tech. His presentation is entitled **"Current Mode Control and Modeling- 3 Decades of Progress".**

In light of recent surge of interest in constant on-time variable frequency control for improved light load efficiency and V2 control for its fast transients and simplicity, the existing modeling tools were not quite suitable for these popular controls. The desire for more unified approach of modeling has motivated researchers to attack this difficult modeling task with an entirely different approach, i.e. from a continuous time framework using the extended describing function techniques. The developed modeling is accurate beyond switching frequency and is applicable to constant frequency peak current/valley mode control, average current mode, charge control as well as variable frequency constant on and off control. Furthermore, a reduced-order model was presented with accuracy up to the switching frequency. The model was further simplified into a unified equivalent circuit model, namely "three-terminal current-mode control cell" which accurately characterizes the terminal properties of the three-terminal switch cell embodied the current feedback loop. This three-terminal cell can be applied to a large class of converter topologies employing a current mode control of one form or another, much the same way as the "three-terminal switch cell" average model that characterizes the nonlinearity of the active-switch and diode pair in a converter. This modeling approach has been further extended to V2 control employing various forms of modulation techniques with pin-point accuracy beyond switching frequency.

Tektronix' CTO Kevin Ilcisin will talk about the **"Challenges and Opportunities of Power Engineering Instrumentations".**

The current global focus on energy-related applications has sparked a new wave of creativity and innovation in the design of power devices, modules, and systems. New semiconductor materials such as SiC and GaN, and new battery technologies are beginning to be deployed. Improved topologies for converter and inverter designs are being evaluated to improve conversion efficiency. Wind and PV systems continue to mature and hybrid and electric vehicles are no longer just a curiosity. These development activities have driven changes in the tools needed to validate designs and verify performance. The adoption of higher voltages, currents, and switching frequencies coupled with increasing certification requirements, has resulted in engineers facing unexpected design, verification, and test challenges. In this talk, he will review response to these challenges which has been parallel innovation in measurement and characterization tools and approaches.

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John Oenick, Director of Power Electronics at Phoenix International, a John Deere company specializing in vehicle electronics, will cover **"The Challenges of Developing Electric Traction Drives for Heavy Duty Work Vehicles".**

This presentation will focus on the on the specific technical challenges of developing Power Electronics for Heavy Duty work vehicle applications. The process of power module selection based on the intended vehicle drive load profile, continuous and peak current requirements and vehicle manufacturers Power Electronics cooling media and system configurations. Life requirements and methods for demonstrating required durability via advance product verification and validation methods. Extreme vehicle ambients, performance requirements and durability effects with detail on the special methods developed to mitigate the detrimental effects of operation under extreme conditions. Special considerations for existing and future standards compliance requirements and power inverter design considerations. Fault detection monitoring best practices and capabilities.

It will close with the many benefits of electric drive application to vehicles for traction and auxiliaries. The potential to provide a win - win solution for vehicle drives that takes advantage of the inherent low speed torque advantages of electric machines over Internal Combustion Engines to improve vehicle performance and productivity while reducing fuel consumption, emissions and overall environmental impact. For HD work vehicle hybridization, the key is for the industry to choose initial applications wisely to provide multiple advantages to overcome price premiums and enable larger scale adoption and reduce cost.

Fairchild Semiconductor's CTO Dan Kinzer will follow on this subject with a presentation entitled **"Maximizing Fossil Fuel Saving Through Power Electronics".**

Power electronics technologies are fundamental to reducing energy consumption in many applications, and to developing cost effective energy alternatives to fossil fuels. The total fuel savings opportunities will be analyzed in applications like HVAC, industrial drives, lighting, automotive, appliances, power grid, energy storage, internet, communications, computing, and entertainment. New power electronic technologies will be compared for their impact. Examples will be drawn from wide band gap and silicon power device performance improvement, module and component level packaging, power distribution architecture, and advanced power control techniques.

Babak Fahimi, Professor of Electrical Engineering University of Texas again addresses E-Mobility with his presentation **"Fault Tolerant and Efficient Electric Drive Technologies for E-Mobility".**

Power electronic driven adjustable speed motor drives play a central role in electrification of the transportation industry. It is in this context that development of fault resilient, highly efficient, compact, and cost effective electric traction systems can catalyze a seamless transition to e-mobility. To address these challenges innovative magnetic design, power electronic design, sensors and control mechanisms, and novel integrations methods are required. An evaluation of the-state-of-the-art indicates that research and development in all of the above categories are far from exhausted. Furthermore, given the size of the automotive market, issues such as supply chain of components, quality control, manufacturing, and the use of cyber systems ought to be taken into account for future. This talk will highlight the opportunities and challenges related to the electric traction, its current status, and future priorities.

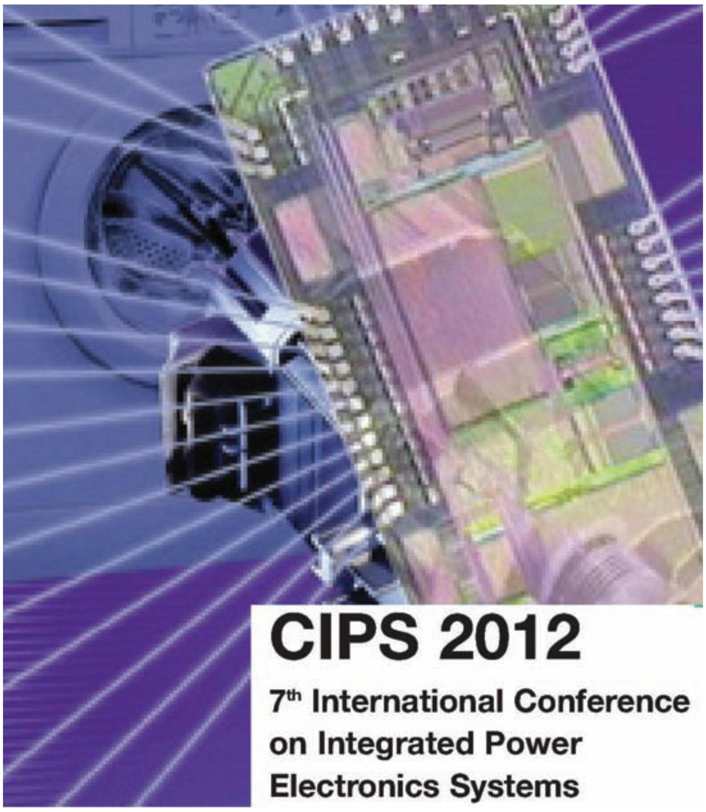
Finally, Vlatko Vlatkovic, GM of Engineering and Technology at GE Converteam, will talk about **"Power Electronics for Energy and High Power".**

Power electronics is rapidly displacing mechanical means of propulsion and motion control, and is moving upstream in the process of electricity use, distribution and generation. The talk will focus on trends in high power applications and use of power electronics in electricity generation and distribution. He will examine examples of advanced power electronics applications in oil and gas industry in renewable power generation and in electricity transmission and distribution.

Afterwards, on 5.00 pm, the APEC exhibition will be opened. We will report about the event in our next issue.

www.apec-conf.org

7th International Conference on Integrated Power Electronics Systems



Higher power efficiency, density, reliability, and lower volume and cost: How to reach these goals and what solutions are feasible? These topics will be discussed at the 7th CIPS Conference to be held from 6 - 8 March 2012 in Nuremberg's Maritim Hotel.

Power electronics will remain a key technology in the years to come: Energy saving to protect our climate can be done only by using power electronics systems. Those systems can be found in electronic ballasts for fluorescent and discharge lamps, in efficient induction cookers and variable frequency motor drives. Especially the production of wind and solar energy without power electronics is not possible. Also the e-mobility relies on efficient and reliable power electronics systems for driving and charging batteries.

Higher efficiencies can be gained by applying system integration based on advanced materials and joining as well as on active and passive components. Due to improved cooling technologies and reduced use of materials, system costs can be reduced and by applying the "building-in reliability" concept the total system reliability will be improved. Computer aided design and test tools are necessary to achieve a "first right" and robust design. The conference will address all these issues.

CIPS 2012 is organized by VDE ETG and ECPE and technically co-sponsored by the IEEE PELS and ZVEI. The conference papers undergo a peer review process which allows their introduction to the IEEE Xplore digital data base. The Technical Programme Committee selected 85 out of 105 abstracts. 45 of them will be oral and 28 will be poster presentations. The best poster as well as the best young engineer's presentation will be awarded.

The frame of these presentations is given by three keynote papers and nine invited papers which will provide an overview on the state-of-the-art of the most important topics:

Keynote Papers:

1. Extreme Efficiency Power Electronics: Johann W. Kolar, ETH Zurich, Switzerland
2. Reliability of Power Electronics Under Thermal Loading: Patrick McCluskey, University of Maryland, USA
3. SiC Device and Power Module Technologies for Environmentally Friendly Vehicles: Kimimori Hamada, Toyota Motor Corporation, Japan

Invited papers:

1. Advanced Cooling for Power Electronics: Sukhvinder Kang, Aavid, USA
2. Analysis of Innovative Packaging Technologies and Trends for Power Modules: Alexandre Avron, Yole, France
3. Electromagnetic Modeling of EMI Input Filters: Andreas Muesing, Gecko Research GmbH, Switzerland
4. On-chip System Integration: Ashraf Lofti, Enpirion Inc. USA
5. Combined Reliability Testing: An Approach to Ensure Reliability Under Complex Loading Conditions: Olaf Wittler, Fraunhofer IZM, Germany
6. Integrated High Power Modules: C Mark Johnson, University of Nottingham, UK
7. SiC and GaN Devices - Competition or Coexistence? Nando Kaminski, University of Bremen, Oliver Hilt, FBI Berlin, Germany
8. Planar Interconnect Technology for Power Module System Integration Norbert Seliger, University of Applied Sciences Rosenheim, Karl Weidner, Siemens CT, Germany
9. Reliability of the Planar Skin Interconnect Technology: Uwe Scheuermann, Semikron, Germany

More information and registration:
www.cips-conference.de, etg@vde.com

On the Road Towards Ideal Power Semiconductors

PCIM Europe (May 8 - 10) is the ideal event for the introduction of newly developed or improved power semiconductors. In particular PEE's Special Session on May 9 will underline this statement.

Mitsubishi Electric will introduce its 6th generation of 600 V/20 A CSTBT IGBTs featuring reduced Eoff compared to the 5th generation of devices. Although the new generation adapts trench MOS gate structure with CS layer and PT (Punch Through) structure like the 5th generation, the 6th generation has about 25% larger N+ Emitter area in the MOS part. As a result of chip shrink, the current density is 1.35 times larger and of the forward voltage drop $V_{CE(sat)}$ decreases by 0.2 V.

With TrenchStop 50µ Infineon Technologies introduces a new fast switching 650 V IGBT generation and presents application test results for high frequency resonant and hard switching applications. The device is an optimization of Infineon's TRENCHSTOP™ technology towards lowest E_{off} losses and low V_{CEsat}. Application tests in resonant converters show that the IGBT is optimized for either parallel or series resonant converters that require high frequency switching. With the increase in frequency cost/performance optimized solutions are possible. Also a snubberless operation up to a frequency of 144 kHz is achievable. In applications that do not require short-circuit robustness such as solar inverters or active boost converters the device offers a significant reduction of the output filter size due to the increase of the switching frequency from 20 kHz to 44 kHz.

Toshiba developed new generation 600 V-class superjunction (SJ) MOSFETs - DTMOS-IV series, which have lower on-state resistance by deep-trench filling process. The 30 % reduction of specific on-state resistance ($R_{DS(ON),SP}$) was attained by 27 % of SJ pitch narrowing as compared with the DTMOS-III. With this DTMOS-IV technology, the lowest $R_{DS(ON)}$ was updated in each package class. In addition, better power efficiency was shown in PFC application by adjustment of $R_{DS(ON)}$ x QGD designed to become compatible with DTMOS-III aiming at switching noise reduction, and 12 % of output capacitance reduction.

From these results, the DTMOS-IV showed better efficiency in a 120-W PFC circuit not only at high output power but also light power compared with conventional DTMOS-series.

Rohm will present SiC Schottky diodes and MOSFETs with trench structures. SiC Schottky diodes with newly developed trench structure show lower forward voltage drop than conventional SiC diodes while keeping the leakage current at acceptable level. SiC MOSFETs with double-trench structure was developed. The new structure effectively reduced the highest electric field at the bottom of the gate trench which caused oxide destruction, thus robustness of the device has improved. The threshold voltage of the trench Schottky diode is by 0.48 V smaller than that of the planar structure. Also, the lowest on-resistance in SiC MOSFETs was achieved by employing the double-trench structure.

Infineon introduces the new thinQ! 5th generationof SiC Schottky diodes. Based on a new production process, both the capacitive charge, and the forward voltage have been minimized. Resulting devices present better performance with respect to 2nd and 3rd generations, under both light and heavy load operations. Samples of this new family have been tested in a PFC stage circuit, together with devices from ThinQ! 2G and ThinQ! 3G, and have demonstrated significant improvement on the system efficiency.

PEE Special session

Our Special Session "High Frequency Switching Technologies & Devices for Green Applications" is scheduled for Wednesday morning (May 9, 10.00 - 12.00 am) and will focus on WBG (SiC and GaN) power applications. The papers will cover The Status of HV GaN based Power Device Development at International Rectifier, Efficient Power Electronics for the price of Silicon - 3D-GaN Technology for GaN-on-Silicon, Comparative High Frequency Performance of SiC MOSFETs Under Hard Switched Conditions, Silicon Carbide BJT's in boost applications, and finally Opportunities and Challenges for Wide Bandgap Power Devices in Megawatt PE Applications. More in our next issue.

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MicroSMD 2A Step-Down Voltage Regulator

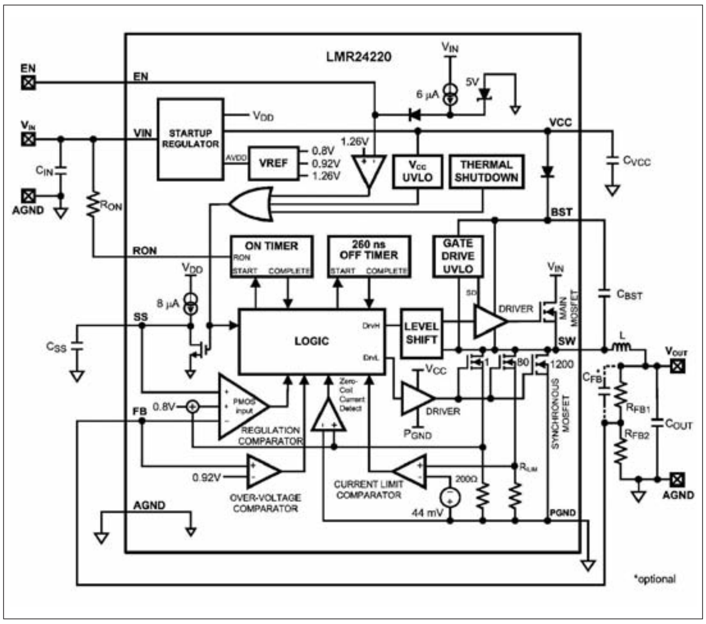
After the acquisition of National Semiconductor Texas Instruments continues to enhance the Simple Switcher family with the LMR24220 Step Down Switching Regulator which features all required functions to implement a buck power converter capable of supplying 2 A to a load. The LMR24220 can be applied in numerous applications and can operate efficiently for inputs as high as 42 V.

The device contains a N-Channel main MOSFETs (see block diagram) and an associated floating high voltage main MOSFET gate driver. The gate drive circuit works in conjunction with an external bootstrap capacitor C_{BST} and an internal high voltage diode. CBST connecting between the BST and SW pins powers the main MOSFET gate driver during the main MOSFET on-time. During each off-time, the voltage of the SW pin falls to approximately -1 V, and C_{BST} charges from V_{CC} through the internal diode. The minimum off-time of 260 ns provides enough time for charging C_{BST} in each cycle.

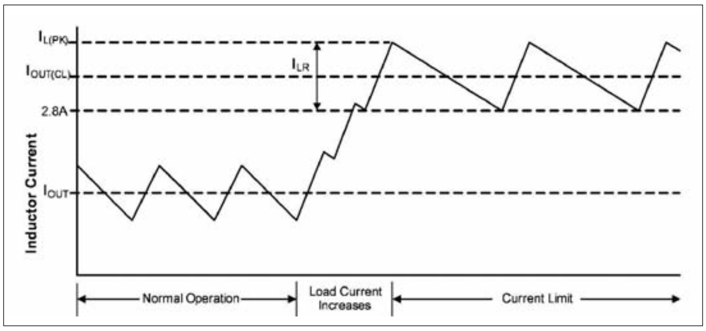
The Constant ON-Time (COT) regulation scheme requires no loop compensation, results in fast load transient response and simple circuit implementation. The regulator can function properly even with an all ceramic output capacitor network, and does not rely on the output capacitor's ESR for stability. The operating frequency remains constant with line variations due to the inverse relationship between the input voltage and the on-time. The valley current limit detection circuit, with the limit set internally at 2.8 A, inhibits the main MOSFET until the inductor current level subsides. Protection features include output over-voltage protection, thermal shutdown, VCC under-voltage lock-out and gate drive under-voltage lock-out.

Control circuits

COT control is based on a comparator and a one-shot ontimer, with the output voltage feedback (feeding to the FB pin) compared with an internal reference of 0.8 V. If the voltage of the FB pin is below the reference, the main MOSFET is turned on for a fixed on-time determined by a programming resistor R_{ON} and the input voltage V_{IN}, upon which the on-time varies inversely. Following the on-time, the main MOSFET remains off for a minimum of 260 ns. Then, if the voltage of the FB pin is below the reference, the main MOSFET is turned on again for another on-time period. The switching will continue to achieve regulation.



LMR24220 simplified block diagram



Inductor current - current limit operation

The regulator will operate in the discontinuous conduction mode (DCM) at a light load, and the continuous conduction mode (CCM) with a heavy load. In the DCM, the current through the inductor starts at zero and ramps up to a peak during the on-time, and then ramps back to zero before the end of the off-time. It remains zero and the load current is

supplied entirely by the output capacitor. The next on-time period starts when the voltage at the FB pin falls below the internal reference. The operating frequency in the DCM is lower and varies larger with the load current as compared with the CCM. Conversion efficiency is maintained since conduction loss and switching loss are reduced with the reduction in the load and the switching frequency respectively. The operating frequency in the DCM can be calculated approximately according to equation 1:

$$fSW = \frac{V_{OUT}\,(V_{IN} - 1) \times L \times 1.18 \times 10^{20} \times IOUT}{(V_{IN} - V_{OUT}) \times RON^2} \qquad (1)$$

In the continuous conduction mode (CCM), the current flows through the inductor in the entire switching cycle, and never reaches zero during the off-time. The operating frequency remains relatively constant with load and line variations. The CCM operating frequency can be calculated according to equation 2:

$$f_{SW} = \frac{V_{OUT}}{1.3 \times 10^{-10} \times R_{ON}} \qquad (2)$$

The output voltage is set by two external resistors RFB1 and RFB2. The regulated output voltage is according to equation 3

$$V_{OUT} = 0.8\ V \times (R_{FB1} + R_{FB2}) / R_{FB2}. \qquad (3)$$

Startup regulator

A startup regulator is integrated within the LMR24220. The input pin VIN can be connected directly to a line voltage up to 42V. The V_{CC} output regulates at 6 V, and is current limited to 65 mA. Upon power up, the regulator sources current into an external capacitor C_{VCC}, which is connected to the VCC pin. For stability, C_{VCC} must be at least 680 nF. When the voltage on the VCC pin is higher than the under-voltage lock-out (UVLO) threshold of 3.75 V, the main MOSFET is enabled and the SS pin is released to allow the soft-start capacitor C_{SS} to charge.

The voltage at the FB pin is compared to a 0.92V internal reference. If it rises above 0.92 V, the on-time is immediately terminated. This condition is

		I_C	1200V	1700V	3300V AlSiC Baseplate
1-Pack	 130 x 140 mm	800A			●
		1000A			●
		1200A	●	●	
		1600A	●	●	
	 140 x 190 mm	1200A			●
		1500A			●
		2400A	●	●	
		3600A	●	●	
2-Pack	 130 x 140 mm	600A	●	●	
		800A	●	●	
		1200A	●	●	
	 89 x 172 mm	600A	●		
		650A		●	
		900A	●		
	 89 x 250 mm	1000A		●	
		1400A	●	●	

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e-Front runners

Fuji Electric Europe GmbH
Goethering 58 · 63067 Offenbach am Main · Germany
Fon +49 (0)69 - 66 90 29 0 · Fax +49 (0)69 - 66 90 29 56
semi-info@fujielectric.de . www.fujielectric.de

known as over-voltage protection (OVP). It can occur if the input voltage or the output load changes suddenly. Once the OVP is activated, the main MOSFET remains off until the voltage at the FB pin falls below 0.92 V. The synchronous MOSFET will stay on to discharge the inductor until the inductor current reduces to zero, and then switches off.

The on-time of the LMR24220 main MOSFET is determined by the resistor RON and the input voltage V_{IN}. It is calculated according to equation 4:

$$t_{on} = \frac{1.3 \times 10^{-10} \times R_{ON}}{V_{IN}} \quad (4)$$

The inverse relationship of t_{on} and V_{IN} gives a nearly constant frequency as V_{IN} is varied. R_{ON} should be selected such that the on-time at maximum V_{IN} is greater than 150 ns. The on-timer has a limiter to ensure a minimum of 150 ns for t_{on}. This limits the maximum operating frequency, which is governed by equation 5:

$$f_{SW(MAX)} = \frac{V_{OUT}}{V_{IN(MAX)} \times 150\ ns} \quad (5)$$

The LMR24220 can be remotely shutdown by pulling the voltage of the EN pin below 1 V. In this shutdown mode, the SS pin is internally grounded, the on-timer is disabled, and bias currents are reduced. Releasing the EN pin allows normal operation to resume because the EN pin is internally pulled up.

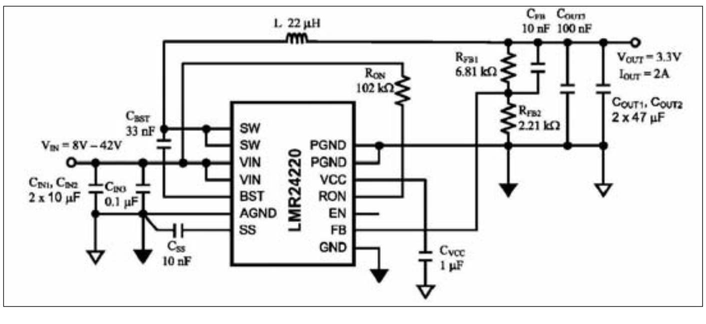
Current limit

Current limit detection is carried out during the off-time by monitoring the re-circulating current through the synchronous MOSFET. Referring to the functional block diagram, when the main MOSFET is turned off, the inductor current flows through the load, the PGND pin and the internal synchronous MOSFET. If this current exceeds 2.8 A, the current limit comparator toggles, and as a result disabling the start of the next on-time period. The next switching cycle starts when the recirculating current falls back below 2.8 A (and the voltage at the FB pin is below 0.8 V). The inductor current is monitored during the on-time of the synchronous MOSFET. As long as the inductor current exceeds 2.8 A, the main MOSFET will remain inhibited to achieve current limit. The operating frequency is lower during current limit due to a longer off-time.

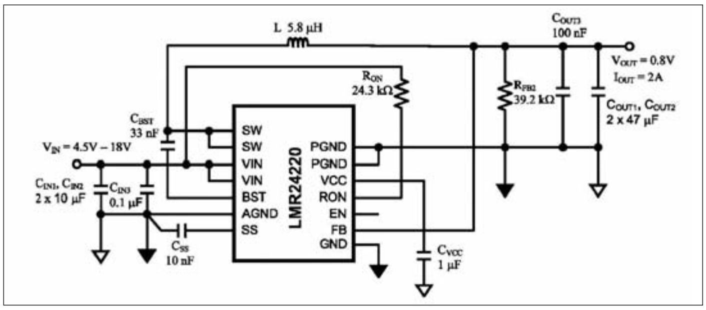
On average, the output current IOUT is the same as the inductor current IL, which is the average of the rippled inductor current. In case of current limit (see inductor current waveform figure, current limit portion), the next on-time will not initiate until the current drops below 2.8 A (assume the voltage at the FB pin is lower than 0.8V). During each on-time the current ramps up an amount equal to:

$$I_{LR} = \frac{(V_{IN} - V_{OUT}) \times t_{on}}{L} \quad (6)$$

During current limit, the LMR24220 operates in a constant current mode with an average output current $I_{OUT(CL)}$ equal to 2.8 A + I_{LR} / 2. However, due to



Typical application schematic for 3.3 V output voltage



Typical application schematic for 0.8 V output voltage

thermal limitations, the device may not support load currents greater than 2 A for extended periods.

External components

The following guidelines can be used to select external components for application circuits.

The resistors R_{FB1} and R_{FB2} should be chosen from standard values in the range of 1.0 kΩ to 10 kΩ, satisfying the ratio $R_{FB1}/R_{FB2} = (V_{OUT}/0.8\ V) - 1$.

For V_{OUT} = 0.8 V, the FB pin can be connected to the output directly with a pre-load resistor drawing more than 20 µA. This is needed because the converter operation needs a minimum inductor current ripple to maintain good regulation when no load is connected.

Equation 2 can be used to select R_{ON} if a desired operating frequency is selected. But the minimum value of R_{ON} is determined by the minimum on-time.

The main parameter affected by the inductor is the amplitude of inductor current ripple (I_{LR}). If the output current IOUT is determined, by assuming that $I_{OUT} = I_L$, the higher and lower peak of I_{LR} can be determined. Beware that the higher peak of I_{LR} should not be larger than the saturation current of the inductor and current limits of the main and synchronous MOSFETs. Also, the lower peak of ILR must be positive if CCM operation is required.

The capacitor on the V_{CC} output provides not only noise filtering and stability, but also prevents false triggering of the V_{CC} UVLO at the main MOSFET on/off transitions. C_{VCC} should be no smaller than 680 nF for stability, and should be a good quality, low ESR, ceramic capacitor. C_{OUT} should generally be no smaller than 10 µF. Experimentation is usually necessary to determine the minimum value for C_{OUT}, as the nature of the load may require a larger value. A load which creates significant transients requires a larger C_{OUT} than a fixed load.

C_{OUT3} is a small value ceramic capacitor located close to the LMR24220 to further suppress high frequency noise at V_{OUT}. A 100 nF capacitor is recommended. The function of C_{IN} is to supply most of the main MOSFET current during the on-time, and limit the voltage ripple at the VIN pin, assuming that the voltage source connecting to the VIN pin has finite output impedance. If the voltage source's dynamic impedance is high (effectively a current source), C_{IN} supplies the average input current, but not the ripple current. At the maximum load current, when the main MOSFET turns on, the current to the VIN pin suddenly increases from zero to the lower peak of the inductor's ripple current and rampsm up to the higher peak value. It then drops to zero at turn-off. The average current during the on-time is the load current. C_{IN3}'s purpose is to help avoid transients and ringing due to long lead inductance at the VIN pin. A low ESR 0.1 µF ceramic chip capacitor located close to the LMR24220 is recommended.

A 33 nF high quality ceramic capacitor with low ESR is recommended for $_{CBST}$ since it supplies a surge current to charge the main MOSFET gate driver at turn-on. Low ESR also helps ensure a complete recharge during each off-time. The capacitor at the SS pin determines the soft-start time, i.e. the time for the reference voltage at the regulation comparator and the output voltage to reach their final value. The time is determined by $t_{ss} = C_{SS} \times 0.8\ V / 8\ \mu A$.

If the output voltage is higher than 1.6V, C_{FB} is needed in the Discontinuous Conduction Mode to reduce the output ripple. The recommended value is 10 nF.

www.ti.com/product/lmr24220

Efficient Thermal Design for Power LEDs and Semiconductors

Legislation regarding lighting efficiency is forcing the phasing out of incandescent bulbs. Compact fluorescent lamps (CFLs) are the other incumbent and cheaper competing lighting technology, but these are now regarded as being less green because they use mercury vapor. Now that the necessary brightness and efficiency levels are competitive, we are arguably close to the tipping point for the adoption of high-brightness (HB) LEDs for

T3Ster and TERALED together provide a comprehensive solution for LED testing

most general illumination applications. The article describes novel thermal design approaches for Power LEDs and semiconductors.

Currently, the wide adoption of LEDs is facing two particular challenges. Too many technical trade-offs have to be made for LEDs to replace incandescent bulbs in luminaires originally designed for incandescent. Ultimately, new luminaires are needed that are specifically designed for LEDs, for which no compromise has to be made with regard to thermal management. However, the bare LEDs that are to be used in such LED-specific designs are not interchangeable (plug-in compatible) with each other because of a lack of standards.

Heat is enemy for LEDs

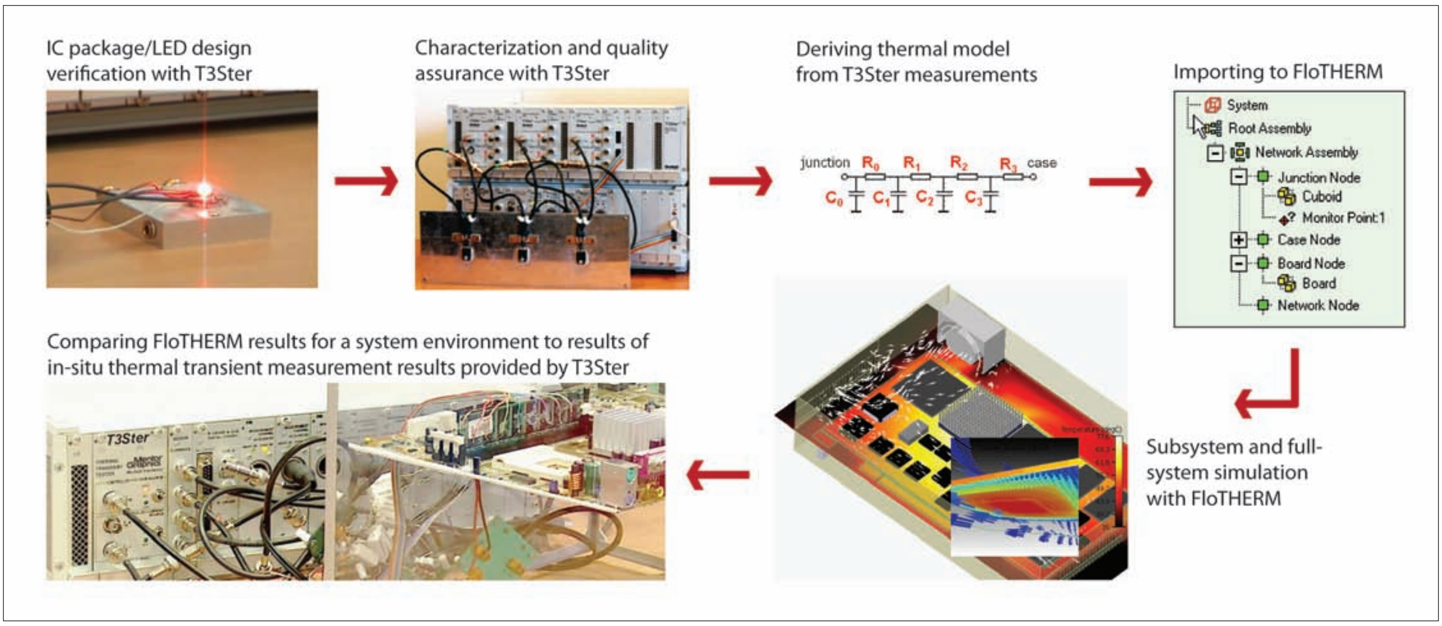
Good thermal designs that work well for unspecified thermal environments will be essential if LED-based retrofit products are to achieve anything close to the potential 40,000 hour useful lifetime, which is the level of consumer acceptance needed for LEDs to replace incandescent bulbs at anticipated rates.

Unlike incandescent lighting that relies on heat to cause a filament to glow and produce light as hot black body, light emitting diodes (LEDs) are semiconductors and as such must be kept cool. When LEDs produce light, heat is a by-product ineasing its temperature. As the LED's temperature increases, the light output decreases, the light changes color, and the lifetime of the LED reduces. As a consequence, thermal management has become the most predominant issue in solid state lighting (SSL) design.

Importance of accurate thermal metrics

Purchasing parts with poor thermal performance is a false economy because, in the end, a more efficient and costly cooling solution will be required. Selecting the best part for a particular application is critical to producing a commercially successful product, and thermal metrics are a key consideration when making that selection. Because these are the primary inputs to thermal design, the metrics must be accurate.

Thermal performance of an electronic part is usually reported as a thermal resistance, which is an indication of how difficult it is for heat to flow



Design flow combining T3Ster in-situ thermal measurement and FloTHERM simulation software

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The UK's leading exhibition for Drives, Automation, Power Transmission and Motion Control Equipment

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- **IPE&E** (Independent Power Energy Europe)
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We've been very impressed. We had set a target for the number of enquiries we wanted from the show and had exceeded it by the end of the second day. We look forward to 2012.
Simon Goodwin, General Manager, B&R Automation

It's been really, really good for us. It's our 25th Anniversary in the UK and we wanted to make an impact, and I think we've done that. We've had some really good leads, and good quality people coming onto our stand.
Becky Smith, Phoenix Contact Ltd

Drives & Controls 2010 surprised us once again with a fantastic quality of visitors. We had 65 quality enquiries over the three days, with the majority coming from new potential clients. We have ready secured orders on the back of the show. The resounding consensus is that we can not wait for the next show in 2012.
Carl Krajewski, HMK Technical Services Ltd

It's been an invaluable show to get our new technology in front of new and existing customers...The leads have been very directed, and a purpose to them…About 80% of the leads are projects or those looking to migrate…You get the footfall at Drives and Controls.
Mike Loughran, Rockwell Automation

We're really pleased with the show. In terms of the number and quality of leads, its been up with SPS/IPC/Drives and Hannover. People have been coming with real projects and looking for solutions. We've had some very strong leads.
Mark Crocker, Marketing Director, Baldor

Drives & Controls 2010 was a successful exhibition for us, which resulted in many new and existing customers making the effort to turn out to look at the latest technologies steute had to offer in the field of explosion protection and Wireless Automation. Looking forward to 2012.
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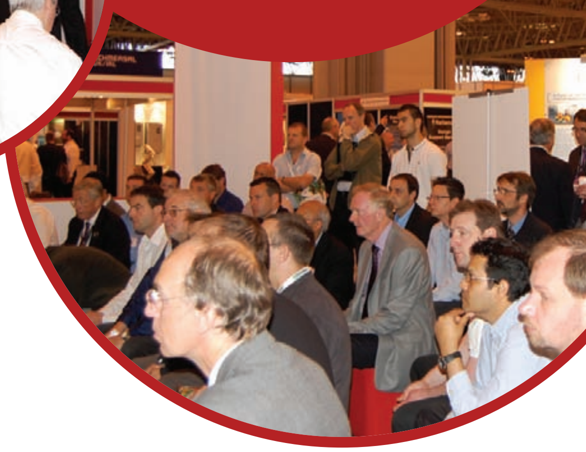

If you wish to discuss any aspect of the Exhibition please contact:

Doug Devlin
| T: 01922 644766 | M:07803 624471
| E: doug@drives.co.uk

Simon Langston
| T: 01353 863383 | M: 07900 095826
| E: simon@dfamedia.co.uk

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We were overwhelmed by the response we had at the 2010 Drives and Controls Exhibition. The excellent quality and sheer number of leads were outstanding. In comparison with other similar events around the world the Drives and Controls is at the very top. We look forward to 2012.
John Wilkins, Rittal Marketing Services

The most positive effect we've had in 30 years of exhibiting.
Bob Halls, System Control Solutions

The quality of UK based leads was up, Drives & Controls is a serious business show rather than a 'jolly.
Geoff Spear, Lenze

The most promising and successful show we have experienced in Europe to date.
Amit Magnani, Rotomag Motors

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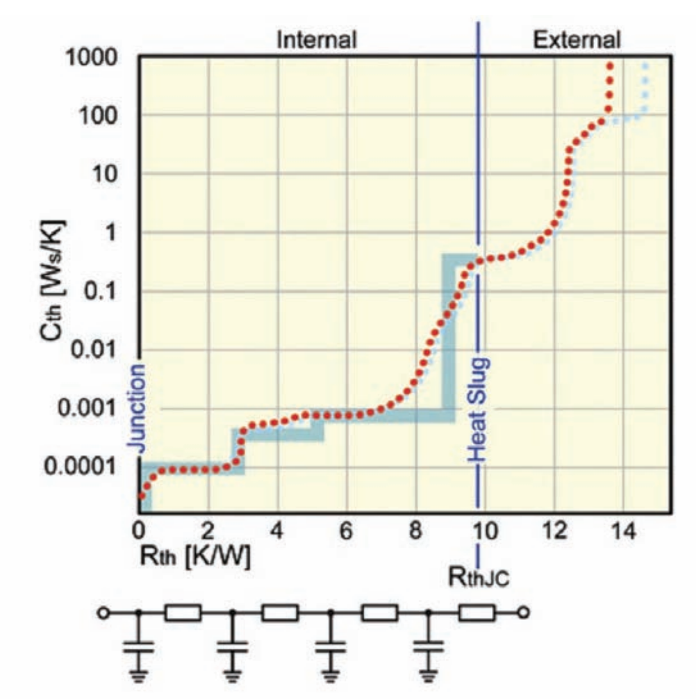


Dynamic compact thermal model (DCTM) ladder when used in dynamic thermal simulations accurately reproduces the thermal response of the LED as a function of time

out of the package. Thermal resistance is calculated as the temperature rise of the junction divided by the power heating the junction. LEDs are complex because their thermal, optical, and electrical operations are interdependent. For example, the amount of electrical power that produces heat varies with temperature. Thermal metrics should be based on the actual heat dissipated in the LED rather than the supplied electrical power, which requires accurate measurement of the light output as a function of temperature and applied electrical current. If the supplied electrical power is used, the calculated thermal resistance is far too low; and the more efficient the LED, the more the error increases. If the published metrics are optimistic, the likely result is either that an inadequate cooling solution will be designed or that a far more expensive cooling solution is required will be realized late in design, which increases the costs and lengthens the timescale of the design process.

Benefits of thermal measurements

More efficient and brighter LEDs are finding new applications that have severe thermal challenges, such as LED car headlights, where product longevity is a must if excessive future warranty costs are to be avoided and the vehicles' safety requirements are to be maintained. As a result, the need for accurate metrics, and hence standardization, is growing rapidly. If vendors are not using accepted standards to ensure their metrics are both correctly based, and accurately measured, SSL designers are placing themselves at considerable business risk unless they verify the thermal metrics provided by vendors.

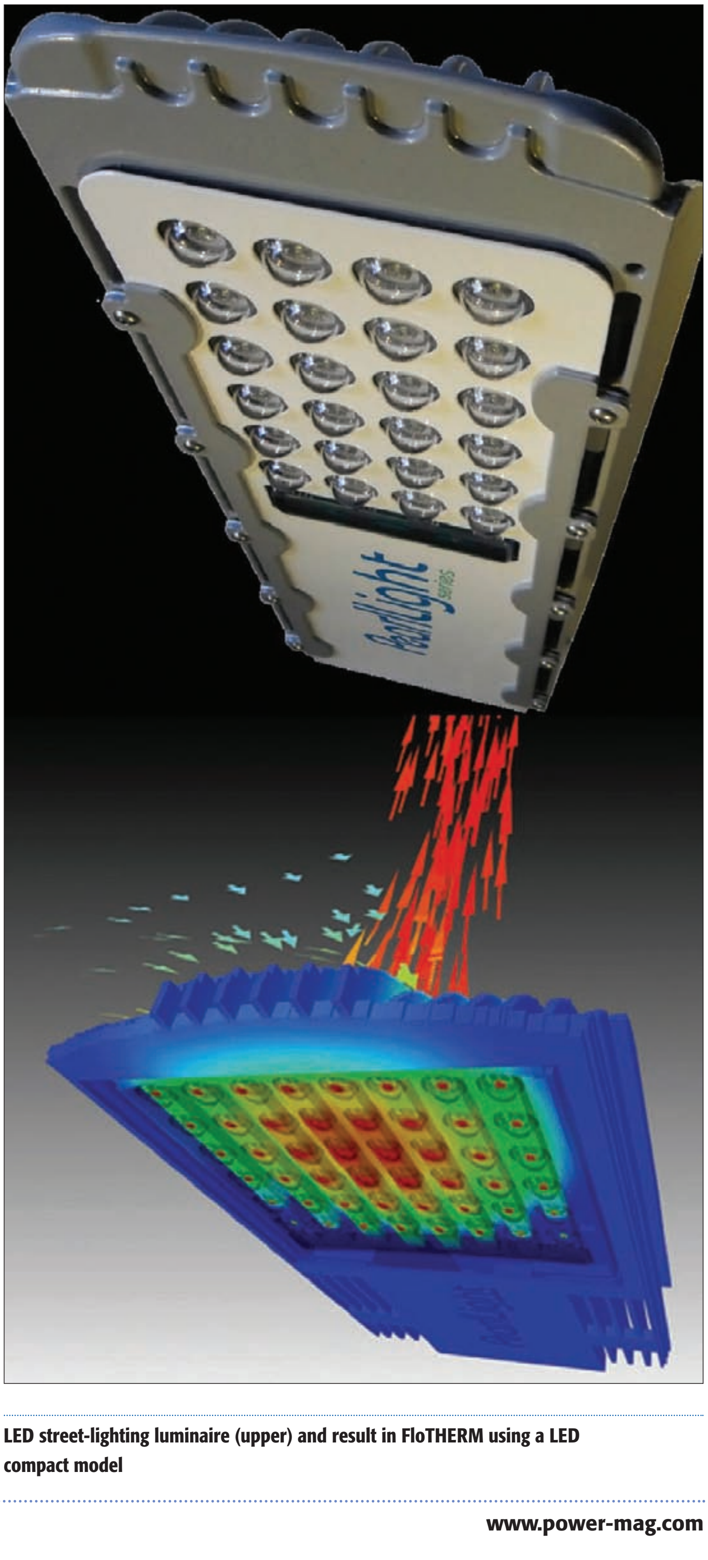
Fortunately, T3Ster's high measurement throughput enables systems integrators (for example, automotive lighting manufacturers, automotive OEMs, and customers in other safety-critical industries such as aerospace), to verify a vendor's thermal resistance data during design and to test incoming COTS parts before they are introduced into production.

A long-established division of responsibility in the electronics thermal supply chain is that vendors should provide information that characterizes their part independent of any application environment in which they are used, and their customers are responsible for building products that provide an application environment in which the part can operate within specification.

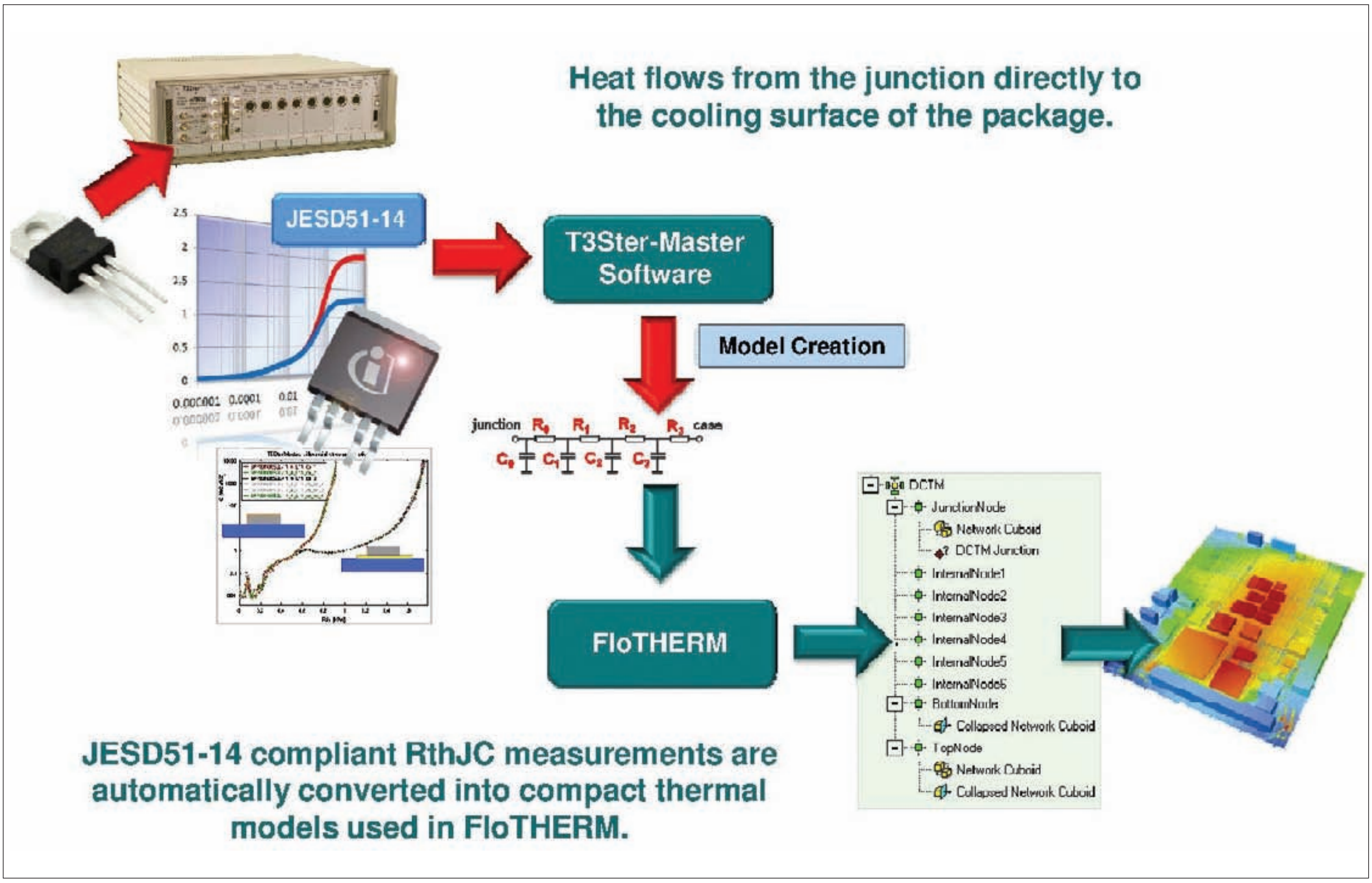
The latest JEDEC standard covering junction-to-case thermal resistance measurement, JESD51-14 [1], is now regarded as the way to thermally characterize power semiconductor devices, including power and high-brightness (HB) LEDs. Correctly measured, with allowance made for the power emitted as light, the junction-to-case thermal resistance measured in accordance with JESD51-14 conforms to the above principle.

The Mentor Graphics thermal transient tester T3Ster uses a "smart" implementation of the JEDEC JESD51-1 static test method. Using T3Ster together with TERALED, a CIE127:2007-compliant total flux measurement system with temperature control, provides LED vendors a comprehensive LED testing station that enables them to perform self-consistent thermal and radiometric/photometric characterization of LEDs. The system is fully automated, allowing an LED to be characterized at approximately 50 operating points (forward current and temperature combinations), in an hour.

LED vendors often report thermal metrics at only one temperature; for example, for a junction temperature of 25°C, which is far from the temperature at which LEDs normally operate. This data is supplemented by diagrams showing the relative light output as a function of junction



LED street-lighting luminaire (upper) and result in FloTHERM using a LED compact model



Measurement-based modeling of power semiconductor packages

temperature, but again no standardized method is used for obtaining these curves.

Using a junction-to-case thermal resistance at 25°C to design a product is valid, but the lower efficiency caused by the higher temperature during operation must be factored in, recognizing that the light output will be lower. As the forward voltage also drops with temperature, light output and power consumption vary until LED reaches a stable operating temperature.

With care, metrics can be used for early design calculations. Their use becomes more problematic the more complex the product. Placed close together, LEDs interact, each heating its neighbors as well as itself. Light generation, electrical power consumption, and heating have a complex, mutual interdependence. The junction-to-case resistance describes how self-heating affects the junction temperature, but does not capture the effect of heating from other LEDs, so this metric alone is unsuitable for designing complex multiple heat source products such as LED headlights.

Thermal models for successful SSL design

Thermal models don't replace metrics, but within dedicated thermal design software such as FloTHERM from Mentor Graphics, they are far more useful in product design. Models allow designers to investigate the thermal interaction between multiple LEDs and to arrive at a product that delivers the desired light output at the anticipated operating temperature, while dissipating the heat produced.

The T3Ster post-processing software allows the temperature versus time curve obtained during the JESD51-14-compliant transient junction-to-case thermal resistance measurement of a single LED to be re-cast as "structure functions" described in JESD51-14 Annex A. These graphs show the magnitude of all the partial thermal resistances in the heat flow path.

The structure function can be represented by a piecewise linear fit, separating the curve into a number of discrete thermal resistance and thermal capacitance steps. The resistance and capacitance values within the package provide a measurement-based thermal model that is computationally efficient and accurately captures the heat flow path. These dynamic compact thermal models (DCTMs), as they are known to thermal designers, can capture the thermal response of the LED as a function of time.

When generated with T3Ster and TERALED, the models are consistent with the measured light output properties. Measurements that use the older "dynamic" test method are much slower to perform, do not provide the accuracy needed for JESD51-14-compliant thermal resistance measurements and to construct DCTMs, and, in the case of LEDs, are fundamentally incorrect.

Accurate thermal metrics are essential if the correct LED is to be selected for a particular application. They are also used in early pre-design sizing calculations. Accurate thermal models are needed to produce the optimal thermal design for a product, and they are available directly from measurements using T3Ster and TERALED. SSL designers can use these measurement-generated models in detailed design by importing them directly into FloTHERM, as indicated in the street lighting example.

In the past when accurate thermal models were needed for design, a detailed thermal model of the package that included all the thermally significant internal geometry and material properties would be needed. Today, measurement-based thermal models are reducing this need. Where they are still required, for example to represent LED light engines or street-lighting luminaires, these detailed models can be validated by vendors using T3Ster and tuned to give near-perfect accuracy, increasing confidence in their use during product design.

The same procedure may be applicable for power semiconductors.

Literature

[1] JESD51-14 "Transient Dual Interface Test Method for the Measurement of the Thermal Resistance Junction to Case of Semiconductor Devices with Heat Flow through a Single Path," November 2010, http://www.jedec.org/sites/default/files/docs/JESD51-14_1.pdf.

www.mentor.com/mechanical

LED Replacements for Fluorescent Tubes

Since high brightness LED technology has reached efficiency levels comparable with those of fluorescent lamps, many retrofit products have appeared on the market designed to replace the popular 4 foot fluorescent tube. Due to the directional nature of LEDs a 32W T8 replacement product can produce a similar light intensity measured at floor level consuming less than 20W thereby offering significant energy savings over fluorescent. **Peter B. Green, LED Group Manager, International Rectifier, El Segundo, USA**

Fluorescent tubes have been and continue to be used in vast numbers worldwide. These offer much greater efficiency in terms of lumens (light output) per watt (electrical power) than incandescent light bulbs. The most widely used linear fluorescent tube is the 4 foot long 32W T8 tube. These are used in offices, hospitals, schools and homes in light fixtures often containing two or more tubes. In the past electro-mechanical starters and iron cored magnetic ballast inductors have been used as an inexpensive means of ignition and current limitation enabling several years of tube life. More recently high frequency electronic ballasts have been introduced that offer increased efficiency, extended lamp life and improved line power factor and harmonics.

Magnetic ballasts used with fluorescent lamps will be phased out by government legislation in many countries over the next few years. This will force the market to use more the expensive electronic ballasts where the payback will be in reduced replacement costs as well as lower emissions and less waste. Used fluorescent tubes, many of which contain toxic mercury are generally dumped in landfills contributing to long term environmental damage.

Alternatives to fluorescent lamps

Although there are several different approaches to the design of LED replacement tubes, these all currently cost more than a fluorescent alternative even when the fluorescent lamp is combined with an electronic ballast. This is due to the much higher cost of LEDs, which is expected to reduce significantly in the coming years.

The market for LED light sources in general lighting is still at an early stage and it is expected be several years before use of fluorescent tubes declines significantly. LED tube replacement sales are still modest, being sold only to early adopters at this time.

The different approaches used in LED tube design can be broken down into two main categories; those with external drivers and those with internal drivers. The external driver approach is based on the fluorescent concept where a single external LED driver runs one or more LED tubes which contain a string or array of LEDs with little or no additional electronics. This approach makes a lot of sense in terms or optimizing performance and minimizing costs however it seems the market may be going more towards the internal driver approach. The reason for this is most likely because it makes retrofitting of existing fluorescent fixtures more straightforward. The contractor simply needs to remove existing fluorescent control gear and wire the lamp end caps directly to the AC line rather than having to mount and wire up a new LED driver module as well. Figure 1 shows a fluorescent fixture fitted with LED tubes.

The internal driver approach however requires that all the electronics be housed within the confines of the LED tube, which creates many restrictions on components sizes and form factors, particularly for inductors. It is also more difficult to incorporate smart features such as 0-10V or DALI controlled dimming as used in architectural lighting control systems. Many of these products are non-dimmable or rely on inefficient triac based phase cut dimming approaches not normally preferred for office lighting.

External LED driver

Going back briefly to describe the external driver type system, the LED driver can comfortably include any dimming and smart features required. These might include fault protection, power factor and THD optimization and even lamp life monitoring.

An external LED driver could consist of a single stage Flyback converter delivering a regulated output current to one or more lamps. Such a driver can operate over a wide line voltage input range while providing a high power factor and low THD. Multi stage designs consisting of a PFC boost front end followed by an isolated back end regulating stage offer even better efficiency and controllability. The back end stage could be a Flyback or resonant converter if galvanic isolation is required. In non-isolated systems a Buck regulator could be used provided some form of safety interlock is built into the light fixture to avoid potential electric shock. Figure 2 shows a multi stage LED driver example schematic.

Since there is less restriction on size and form factor combined with the fact that better efficiency and heat transfer from the circuitry is possible, the external LED driver approach should offer better reliability.

Internal LED driver

Out of the several products on the market taken apart and examined several cheaper products contained nothing more that low current standard white LEDs with a very simple current limiting circuit containing a

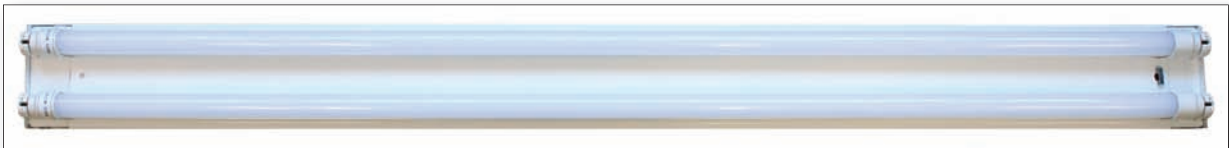
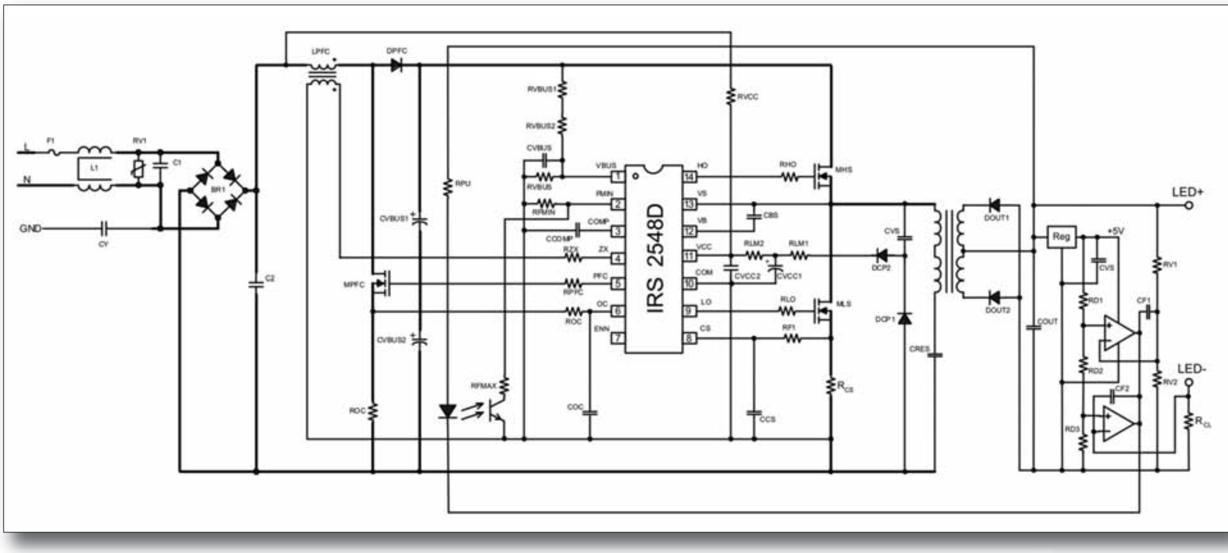
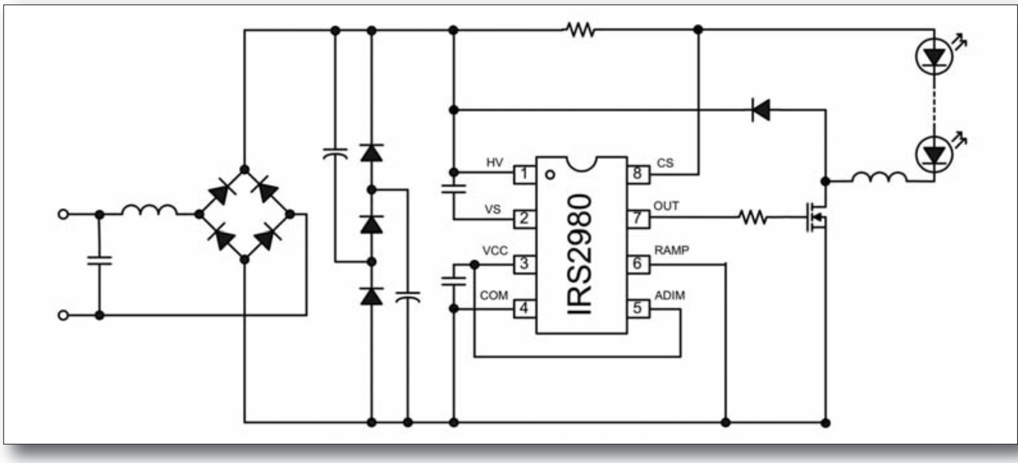


Figure 1: A fluorescent fixture fitted with LED tubes





ABOVE Figure 2: Multi stage LED driver example schematic

LEFT Figure 3: Buck circuit with passive valley fill

bridge rectifier, a resistor, and a few capacitors. This type of product though cheap does not offer high efficiency, has a low power factor and high harmonics. The low power LEDs used are better suited for indication rather than illumination and in any case are being driven with high peak currents, all of which is likely to contribute to reduced operating life.

Of the tubes containing an active power converter, most are based on a simple Buck regulator using a passive "valley fill" PFC correction circuit. This would seem to be an adequate low cost approach to making a non-dimmable tube replacement. Power factor of 0.9 can be accomplished with line current THD at around 50%. This would meet US Department of Energy (DOE) Energy Star requirements for commercial lighting. Products using this type of system often use peak current regulation, which is sufficient to compensate against variations in LED output voltage but may not be adequate in providing current control over a wide AC line input range. For this reason some LED tube replacements may be limited to 100-120VAC line operation or 220 to 240VAC line operation.

Hysteretic average current regulation is used in the latest generation of Buck LED controller ICs such as the recently launched IRS2980. This method is able to provide tight current control over a wide input range. Figure 3 shows a Buck circuit with passive valley fill.

Some products however, have gone beyond the Buck approach to use a single stage Flyback converter operating from an unsmoothed DC bus. This method requires more components in order to provide a higher power factor and lower THD. It seems that the market may be being driven by the introduction of new performance standards for LED lighting that mandate very high performance levels going beyond the requirements imposed on electronic ballasts used in fluorescent and other forms of lighting. Introduction of such strict standards with its added cost penalty is likely to slow down the adoption of LED lighting while fluorescent alternatives are available. Figure 4 shows a Flyback LED driver schematic.

Most of the products tested were not dimmable. Since triac based phase cut dimmers do not work with fluorescent tubes this form of dimming should not be necessary in LED tube replacements, however 0-10V dimming is widely used with electronic ballasts which so far has only been seen in external driver systems.

To further optimize energy usage it is also desirable to incorporate 0-10V or DALI dimming in the driver electronics. It would be more practical to incorporate this into an external driver system but internal driver systems offer easier retrofitting in non-dimming applications therefore both types are likely to continue being produced.

Retrofitting of existing fluorescent light fixtures with LED tubes makes a lot of environmental sense and since the number of fixtures already in existence runs into hundreds of millions the potential market for LED tube replacements is enormous.

Successful adoption on a large scale will depend on the future availability of very low cost high brightness LEDs in conjunction with low cost driver electronics. The LED driver whether housed within the tube or externally will need to provide the best possible efficiency and conform to reasonable standards for power factor and harmonics. Many LED drivers currently being sold are based on existing power supply and PFC control ICs. It is expected that the next generation of drivers will incorporate controllers designed specifically for the LED application with optimized functionality designed to conform to standards while at the same time keeping cost and component count to a minimum.

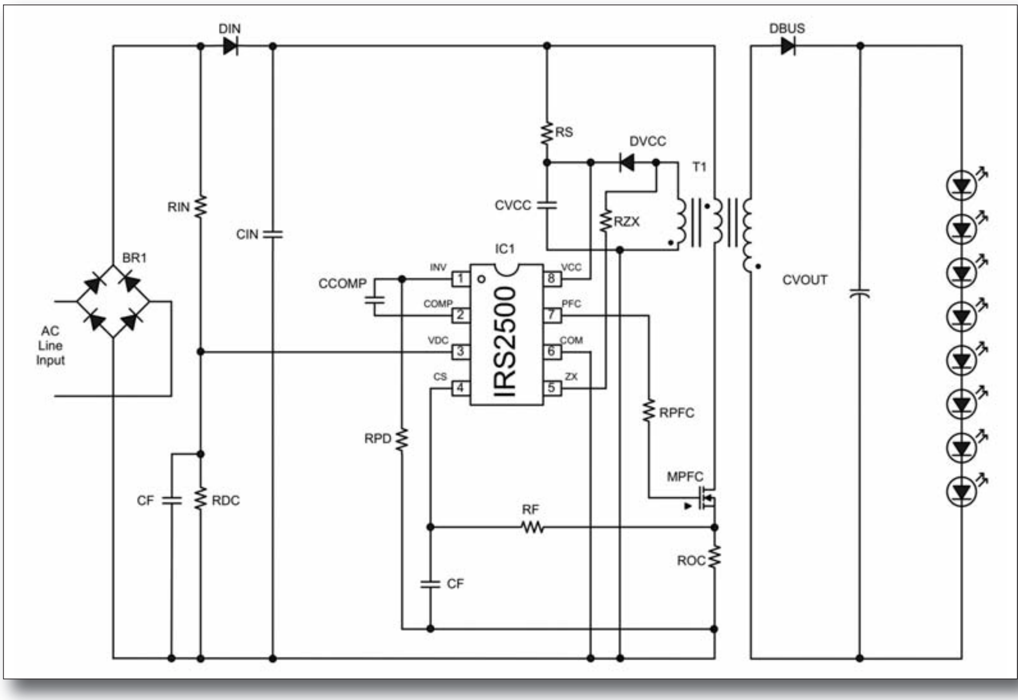


Figure 4: Flyback LED driver schematic

Conclusion

In conclusion the adoption of LED tube replacements saves energy and produces less waste, however the initial investment is high and the payback period can be up to 20 years. As LED technology continues to improve and mass production brings down the costs, the use of LEDs in general lighting applications will ramp up. This would be greatly aided by raising consciousness to the environmental impact from incandescent and fluorescent light sources. At this time the majority of consumers prefer to ignore environmental considerations in favor of reducing initial outlays as much as possible. There is also considerable political opposition to the introduction of new laws that outlaw inefficient light sources, largely supported by the fossil fuel lobby.

Using Trench Power MOSFETs in Linear Mode

If we think about applications for modern Power MOSFETs using trench technology, running them in linear mode may not be top of the priority list. Yet there are multiple uses for Trench Power MOSFETs in linear mode. In fact, even turning the device on and off in switching applications is a form of linear operation. Also, these components can be run in linear mode to protect the device against voltage surges. This article will illustrate the factors that need to be considered for linear operation and show how Trench Power MOSFETs are suited to it. **Felix Hüning, Principal Engineer Automotive Business Group, Renesas Electronics Europe, Düssedorf, Germany**

Modern Trench Power MOSFETs are mainly used in switching applications such as DC/DC converters and motor control using pulse width modulation (PWM). In other words, the Power MOSFET is alternately switched on and then switched off completely. To maximize efficiency and minimize losses when the components are switching, the technology needs to be optimized to cope with static and dynamic power dissipation. This is why development of new technologies focuses on parameters like on-resistance ($R_{DS(on)}$), gate charge (Q_G) and capacities (C_{iss}, C_{oss}, C_{rss}).

Requirements for linear mode operation

But how can modern Trench Power MOSFETs be used in linear mode? What we mean by linear in this context is a mode of operation in which the Power MOSFETs are neither completely switched on nor completely switched off. Small changes to the gate-source voltage (V_{GS}) can have a significant effect on the drain current (I_D) and higher drain-to- source voltages (V_{DS}) might coincide with large drain currents.

Many Power MOSFET datasheets show diagrams indicating the safe operating area (SOA) and these are very helpful when deciding whether or not linear mode is feasible. Figure 1 shows an example of the maximum drain voltage (ID) in relation to the drain source voltage (V_{DS}), when the Power MOSFET is run in linear mode (in this case, DC). Trench Power MOSFETs can operate below the SOA curve with no constraints, as long as the curve's limiting factors have been correctly indicated in the datasheet parameters as shown below:

1. On-resistance limit ($R_{DS(on)}$ limit): the maximum current for the relevant VDS is limited by the component's $R_{DS(on)}$, so its intrinsic properties will stop it from exceeding this limit.
2. Package limit ($I_{D(DC)}$): the maximum current is limited by package constraints.
3. Power dissipation limit: the PowerMOSFET's maximum channel temperature (usually 175°C) must not be exceeded. As the power dissipation causes an increase in the channel temperature, it should be kept in check to ensure that the temperature does not rise above this level.
4. Hotspot, also known as the Spirito limit (secondary breakdown limit): tiny flaws, like inhomogeneities in the chip's cell structure or small solder cavities, can cause an uneven distribution of the current over the chip. As a result, some of the chip's cells may carry more current and become hotter than the surrounding cells. This thermal instability can lead to the temperature of the affected cells increasing to well above the maximum permitted channel temperature level, which in turn will destroy the component. This is known as the Spirito effect [1] and can occur in larger I_D/V_{DS} combinations. It is vital to take this into account when putting together the SOA. The Spirito effect can occur at levels above the line, but no hotspots will occur below it, avoiding thermal instability and the destruction of the component.
5. Breakdown voltage: this is the component's specified breakdown voltage.

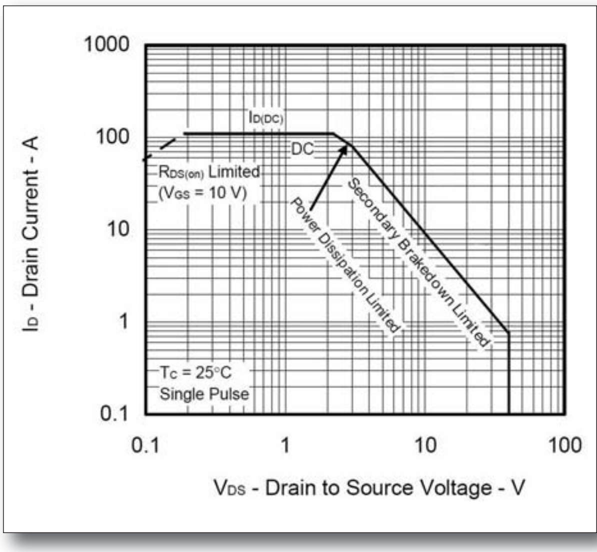


Figure1: DC SOA of the NP109N04PUJ

There are additional parameters that have a major influence on the SOA curve, including the time that the component is operating in linear mode and the ambient temperature (T_A).

The left side of Figure 2 shows the whole SOA diagram of the NP109N04PUJ Trench Power MOSFET at room temperature and for various linear mode timescales. It is clear from the diagram that the SOA increases for short periods, allowing for higher I_D-V_{DS} combinations. As a result, the package can tolerate short pulses of higher currents in Region 2, and short pulses shift the power dissipation

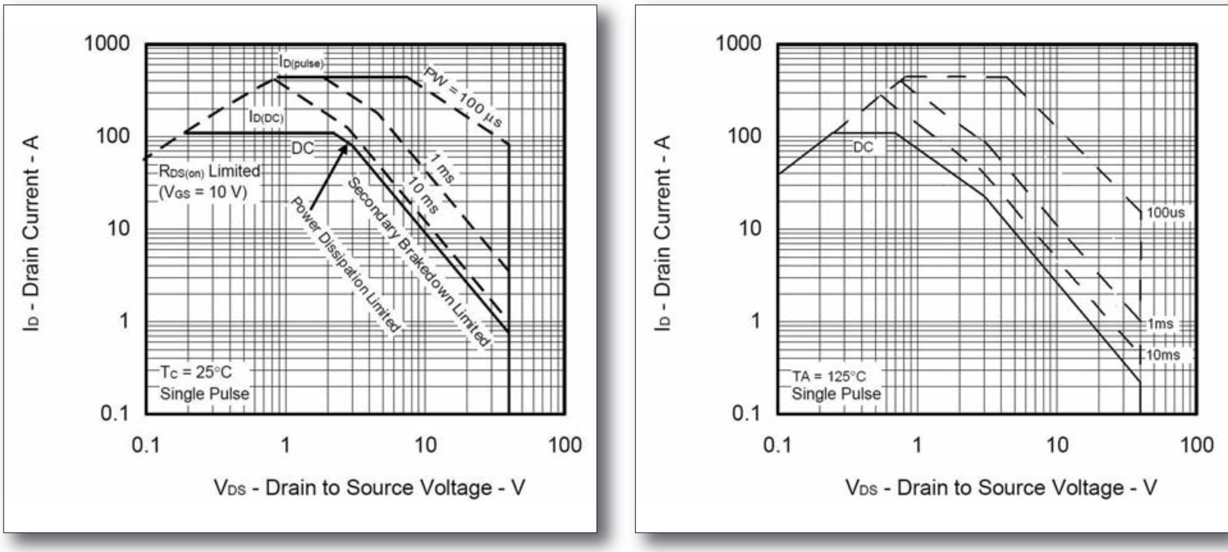


Figure 2: Whole SOA of the NP109N04PUJ at room temperature (left) and at 125°C (right)

and Spirito limits to higher levels.

Conversely, the SOA becomes smaller at higher surrounding temperatures because the maximum power dissipation level decreases as the temperature increases. This effect is shown in Figure 2 (right) for a temperature (T_A) of 125°C. The maximum power dissipation limit shifts the curves down to lower levels.

Time and temperatures are decisive factors for operation in linear mode, and the following examples (switching, active clamp and linear regulator) include a variety of timescales and temperatures.

Switching application

Switching is by far the most common application for Power MOSFETs, which are used in DC/DC converters as well as in PWMs for motor controllers. Strictly speaking, the Power MOSFET is running in linear mode when it is being switched on as well as off. The switching times vary from a few hundred ns up to the ms range or even longer. The left diagram in Figure 3 shows a typical switch-on procedure with a PWM at 20 kHz, often used for the control of brushless DC (BLDC) motors. Within about 1 µs, the I_D increases to the maximum level of 70 A, while the VDS decreases to the on-state value $V_{DS}=R_{DS(on)}xI_D=120$ mV. The right-hand diagram in Figure 3 shows that the current-voltage characteristic of this switching operation has been added to the room-temperature SOA of the NP109N04PUJ. Here we can see clearly that the data values are located above the DC curve but still well within the SOA for short periods. As a result, this type of switching operation is feasible with no constraints.

Active clamp operation

During switching of inductive loads, high voltage peaks occur during the Power MOSFET's switch-off process because the inductance is trying to maintain the flow of current. The active clamp operation is used to stop the Power MOSFET from avalanching (see Figures 4/5/6). This involves using a Zener diode and a conventional diode between the drain and gate connectors, where the Zener voltage is lower than the Power MOSFET's breakdown voltage. If there is a voltage peak at the drain, the Zener diode will maintain the Zener voltage and the gate potential will be increased, putting the Power MOSFET into linear mode. In this way, the inductive energy can be dissipated safely. In the example shown below, the drain current (I_D) of 5 A is switched off. The Zener diode limits the drain voltage to about 30 V and the Power MOSFET goes into linear mode (V_{GS} ~4 V). The duration of this linear operation is about 0.4 ms and the current-voltage characteristic is still below the 1 ms curve.

Linear voltage regulator

Along with DC/DC converters - which are increasingly being used as voltage

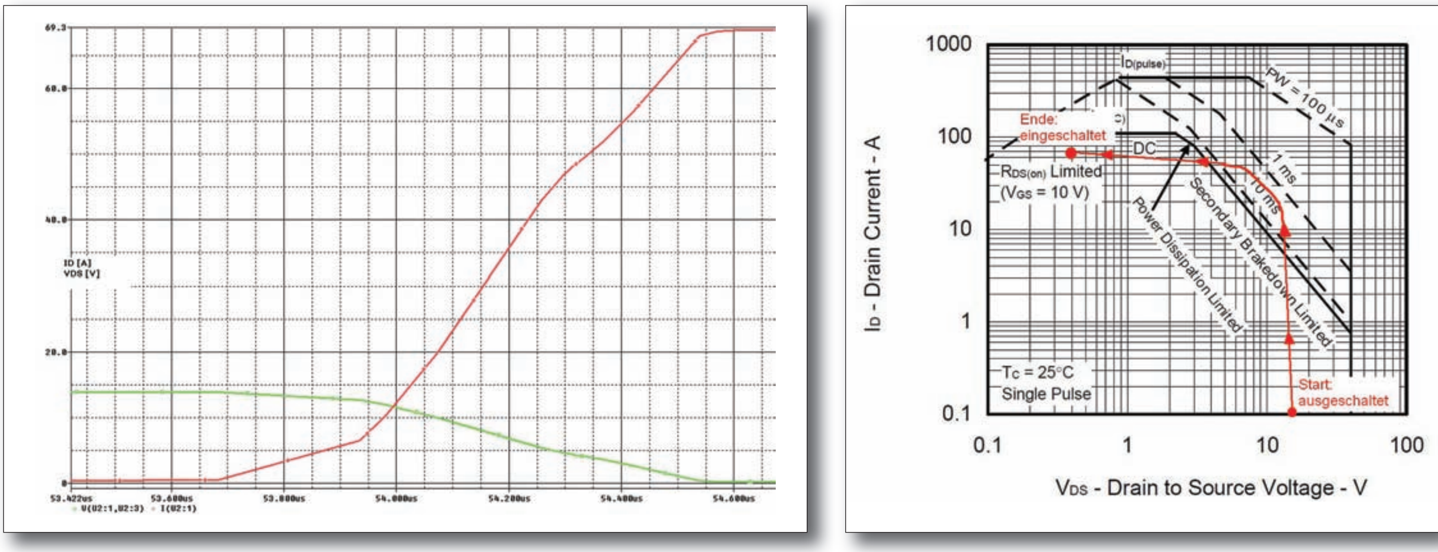


Figure 3: Activation process of the NP109N04PUJ, showing drain-source voltage V_{DS} (green) and drain current I_D (red) on the left. On the right, the SOA diagram with I_D crossing over V_{DS}

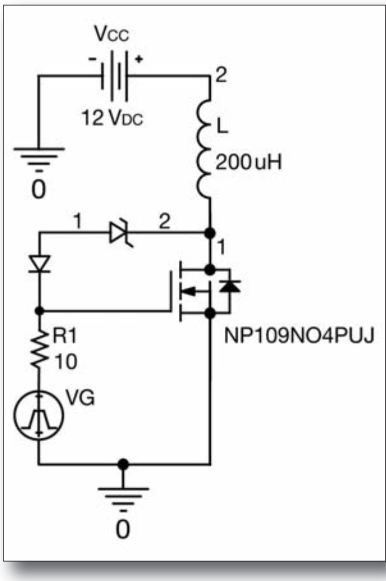


Figure 4: Simplified circuit for active clamp operation

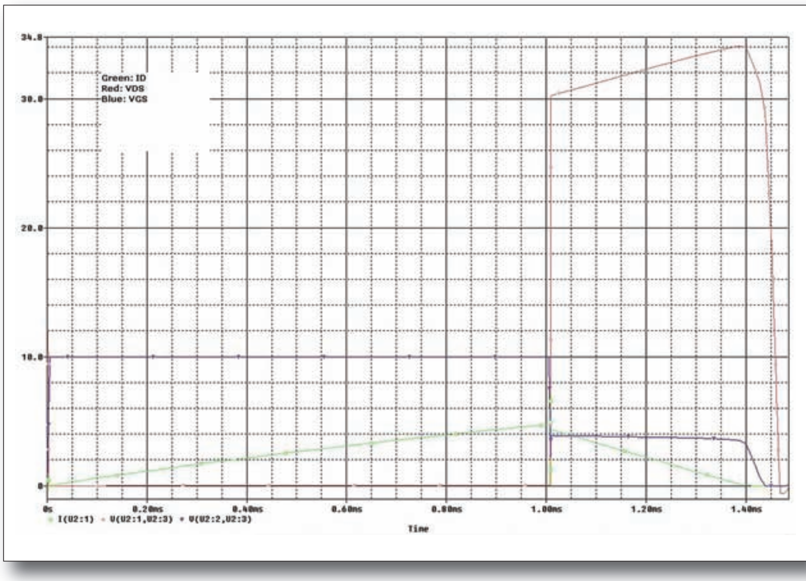


Figure 5: Active clamp time response of the drain current I_D (green), drain-to-source voltage V_{DS} (red) and the gate-source voltage V_{GS} (blue)

converters due to their high efficiency levels - linear voltage regulators are also being used in automotive applications. Here, the PowerMOSFET is used to transfer the input voltage into a lower output voltage. By varying the gate voltage, the voltage drop V_{DS} can be regulated, putting the Power MOSFET into DC linear mode.

With a surrounding temperature of 125°C, the exemplary linear regulator changes the input voltage of 6.5 V to 1.2 V, providing output current of 5 A. Accordingly, the drain-to-source voltage V_{DS} is 5.3 V. Figure 7 shows the SOA diagram at 125°C, demonstrating that the NP109N04PUJ can be used as a linear regulator with no constraints because the current/voltage levels are all below the 125°C DC curve.

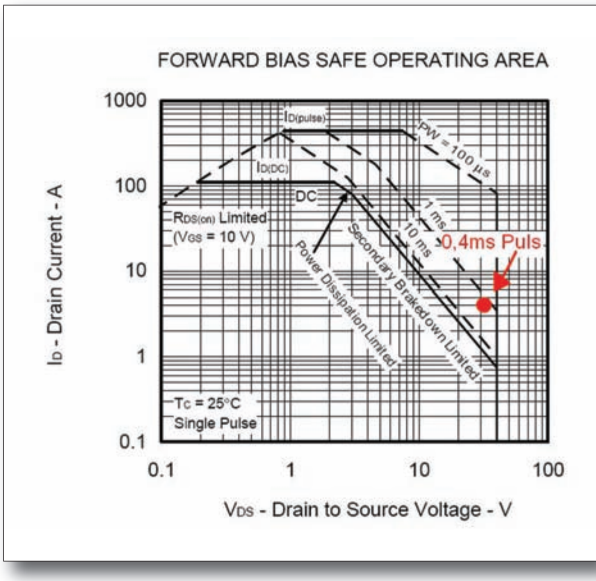


Figure 6: Active clamp SOA with the pulse's V_{DS}/I_D combination

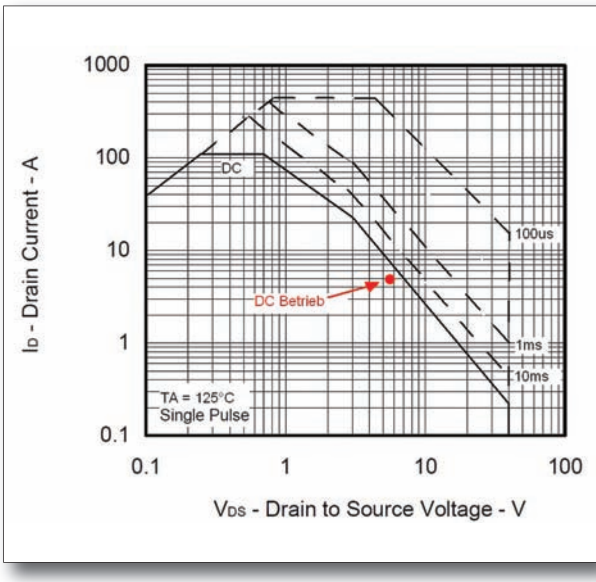


Figure 7: Operating parameters of a linear regulator from 6.3 V -> 1.2 V, 5 A at a surrounding temperature of 125°C

Conclusion

There is nothing to stop using Trench Power MOSFETs in applications with linear operation, they are also suitable for DC applications. To decide whether or not a component can be used in a specific use case, the SOA diagrams provided in the Power MOSFETs' datasheets should indicate all limiting factors and the Spirito effect, in particular, must be taken into account. In the SOA curves of Renesas' Trench Power MOSFETs, all factors are indicated, enabling customers to make an accurate judgement as to whether the Power MOSFETs can be used for linear operation.

Literature

[1] Breglio G.; Frisina, F.; Magri, A.; Spirito, P.: "Electro-Thermal Instability in Low-Voltage power MOS: Experimental Characterization", 1999 IEEE ISPSD 1999, p. 233-236

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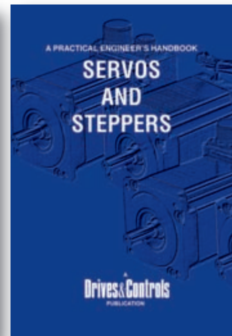

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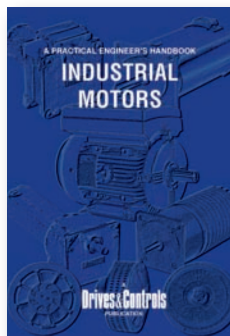

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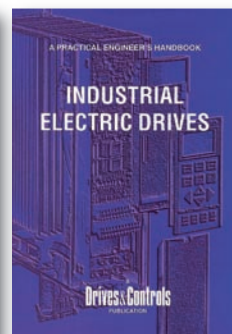

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Automotive Environments Demand Robust Power Conversion

Automotive and heavy equipment vehicle environments are very demanding for any type of power conversion devices. Wide operating voltage ranges coupled with large transients and wide temperature excursions combine to make reliable electronic system design difficult. To further complicate design considerations, the number of rails within an electronic system is also increasing. The new LTC3890 provides features that make it an good choice for a high input voltage power supply. It brings a new level of performance in terms of needing to operate safely and efficiently in a demanding high voltage transient environment. **Bruce Haug, Senior Product Marketing Engineer, Linear Technology Corp., USA**

For example, a typical navigation system can have six or more rails including 8.5 V, 5 V, 3.3 V, 2.5 V, 1.8 V and even 1.5 V. At the same time, as the number of components increases, space requirements continue to shrink, making high efficiency conversion critical due to the space limitations and high temperature conditions.

As a result, a good automotive and truck switching DC/DC regulator needs to be specified to work over a wide input voltage range. A 60 V rating gives good margin for a 12 V system, which is usually clamped in the 36 V to 40 V range. In addition, double battery applications found in trucks and heavy equipment require an even higher operating voltage due to their 24 V nominal battery voltage. Most are clamped to 58 V, so a 60 V rating is usually sufficient. The on-board automotive and truck over-voltage clamp is required to maintain a maximum transient voltage caused by the inductive kick back voltage from the starter motor, which can cause a much higher transient voltage when left unclamped.

Low quiescent current required

There are many automotive and truck systems that require continuous power even when the vehicle's motor is not running, such as remote keyless entry and alarm systems. It is essential for these types of "always-on" systems to have a DC/DC converter with low quiescent current in order to maximize the battery run time when in sleep mode. In such circumstances, the regulator runs in normal continuous switching mode until the output current drops below a predetermined threshold of around 30-50 mA. Below this level, the switching regulator must go into Burst Mode® operation to lower the quiescent current into tens of microamps, thereby lowering the power drawn from the battery in order to extend the battery run time.

With 60 V input DC/DC converters in short supply, designers have resorted to a transformer-based topology or external high side drivers to operate from up to 60 V. Others have used an intermediate bus converter, requiring an additional power stage. Both of these alternatives increase the design complexity and, in most cases, reduce the overall efficiency. However, the LTC3890 is the latest part in a growing family of 60 V input capable step-down switching regulator controllers that addresses many of the key issues required in automotive and truck applications as outlined above. Figure 1 shows a schematic of the LTC3890 operating in an application that converts a 9 V to 60 V input into 3.5 V/5 A and 8.5 V/3 A outputs.

The LTC3890/-1 is a high voltage dual

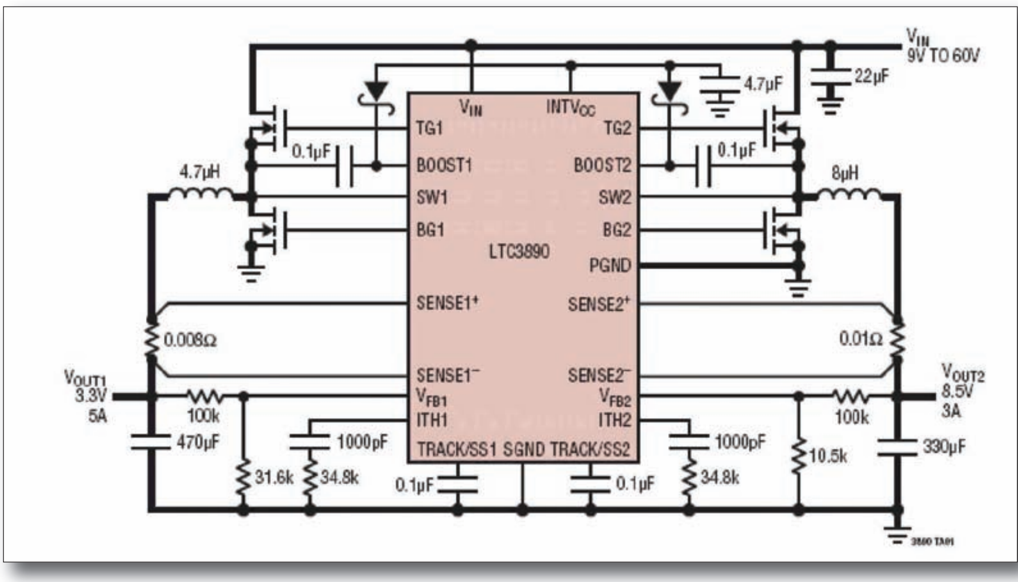

Figure 1: LTC3890 schematic with 9 V to 60 V input to 8.5 V/3 A and 3.3 V/5 A outputs

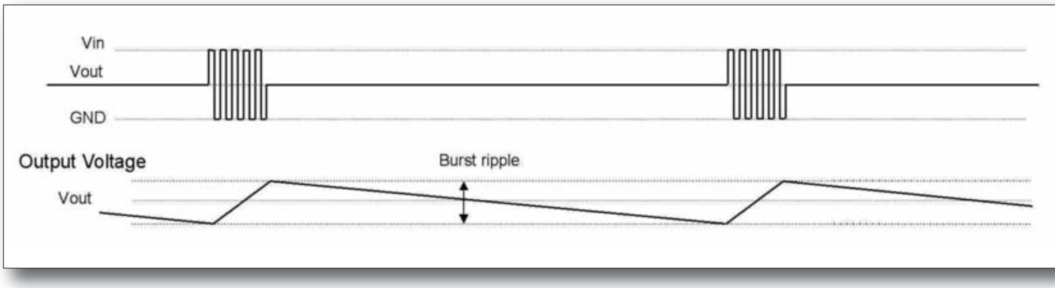

Figure 2: Burst Mode operation voltage diagram for the LTC3890

output synchronous step-down DC/DC controller that draws only 50 µA when one output is active and 60 µA when both outputs are enabled. With both outputs shut down, the device draws only 14 µA. The 4 V to 60 V input supply range is designed to protect against high voltage transients, continue operation during automotive heavy equipment and truck cold cranking along with covering a broad range of input sources and battery chemistries. Each output can be set from 0.8 V to 24 V at output currents up to 20 A, with efficiencies as high as 98 %, making it well suited for 12 V or 24 V automotive, truck, heavy equipment and industrial control applications.

The LTC3890/-1 operates with a selectable fixed frequency between 50 kHz and 900 kHz, and can be synchronized to an external clock from 75 kHz to 850 kHz with its phase-locked loop (PLL). The user can select from continuous operation, pulse skipping and low ripple Burst Mode operation during light loads. The LTC3890's 2-phase operation reduces input filtering and capacitance requirements. Its current mode architecture provides easy loop compensation, fast transient response and excellent line regulation. Output current sensing is accomplished by measuring the voltage drop across the output inductor (DCR) for the highest efficiency or by using an optional sense resistor. Current foldback limits MOSFET heat dissipation during overload conditions. These features, combined with a minimum on-time of just 95 ns, make this controller suitable for high step-down ratio applications.

The device is available in two versions; the LTC3890 is the fully featured part with functions including a clock out, clock phase modulation, two separate power good outputs and adjustable current limit. The LTC3890-1 does not have those extra features and is available in a 28-pin SSOP package. The LTC3890 is available is a 32-lead 5 mm x 5 mm QFN package.

Choice of operation modes

The LTC3890/-1 can be enabled to enter high efficiency Burst Mode operation, constant frequency pulse skipping, or forced continuous conduction mode at low load currents. When configured for Burst Mode operation and during a light load condition, the converter will burst out a few pulses to maintain the charge voltage on the output capacitor. It then turns off the converter and goes into sleep mode with most of its internal circuits shut down. The output capacitor supplies the load current and when the voltage across the output capacitor drops to a programmed level, the converter starts back up delivering more current to replenish the charge voltage. The action of shutting down and turning off most of its internal circuits significantly reduces quiescent current, thereby helping to extend the battery run-time in an "always-on" system when the system is not running. Figure 2 shows the conceptual timing diagram of how this works.

The Burst Mode output ripple is load independent so only the length of the sleep intervals will change. In sleep mode, much of the internal circuitry is turned off except for the critical circuitry needed to respond quickly, further reducing its quiescent current. When the output voltage drops low enough, the sleep signal goes low and the controller resumes normal Burst Mode operation by turning on the top external MOSFET. Alternatively, there are instances when the user will want to operate in forced continuous or constant frequency pulse skipping mode at light load currents. Both of these modes are easily configurable but will have a higher quiescent current and a lower peak to peak output ripple.

In addition, when the controller is enabled for Burst Mode operation, the inductor current is not allowed to reverse. The reverse current comparator, IR, turns off the bottom external MOSFET just before the inductor current reaches zero, preventing it from going negative. Thus, the controller also operates in discontinuous mode when configured for Burst Mode operation.

Furthermore, in forced continuous operation or when clocked by an external clock source, the inductor current is allowed to reverse at light loads or under large transient conditions. Continuous operation has the advantage of lower output voltage ripple and results a higher quiescent current.

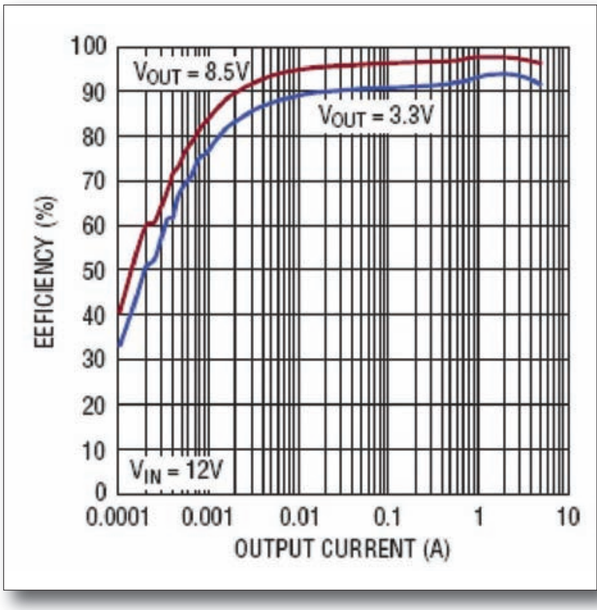

Figure 3: LTC3890 efficiency curves for 8.5 V and 3.3 V outputs from a 12 V input

Protection and efficiency

Fast accurate over-current limit protection is essential in a high voltage power supply. Because of the high voltage across the inductor when the output is shorted, the inductor of either using a sense resistor in series with the output or using the voltage drop across the output inductor to sense the output current. Either way, the output current is monitored continuously and provides the highest level of protection. Alternative designs might use the on-resistance of the top or bottom MOSFET to sense the output current. However, this creates a time frame within the switching cycle where the controller is blind with regards to what the output current is and can cause a failure of the converter.

Switching losses are proportional to the square of the input voltage and these losses can dominate in high input voltage applications with an inadequate gate driver. The LTC3890/-1 has powerful 1.1 Ω on-board N-channel MOSFET gate drivers that minimize transition times and switching losses thereby maximizing the efficiency. In addition, it is capable of driving multiple MOSFET's in parallel for higher current applications.

The LTC3890 efficiency curves in Figure 3 are representative of the Figure 1 schematic with a 12 V input voltage. As shown, the 8.5 V output produces a very high efficiency at up to 98%. The 3.3 V is also over 90 % efficient. In addition, this design is still over 75 % efficient for each output with a 1 mA load, this due to its Burst Mode operation.

Fast transient response

The LTC3890 uses a fast 25 MHz bandwidth operation amplifier for voltage feedback. The high bandwidth of the amplifier, along with high switching frequencies and low value inductors, allow for a very high gain crossover frequency. This allows the compensation network to be optimized for a very fast load transient response. Figure 4 illustrates the transient response of a 4 A step load on a 3.3 V output with a less than 100 mV deviation from nominal.

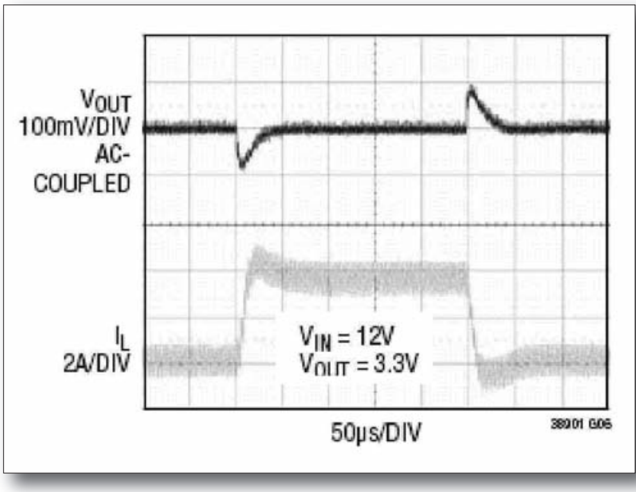

Figure 4: Transient response curve for a 4 A load step

Conclusion

A 60V input capability make the described DC/DC converter well suited for automotive double battery, truck and heavy equipment applications. Its low quiescent current preserves battery energy during sleep mode allowing for increased battery run-time, a very useful feature in "always-on" bus systems. Furthermore, the device is easily applied to a wide variety of output voltages with up to a 24 V output voltage. Alternatively, its low minimum on-time enables the LTC3890 to be used in high step-down ratio applications. The ability to directly step-down input voltages from 60 V without requiring a bulky transformer, or external protection, makes for a cost effective, compact and reliable solution.

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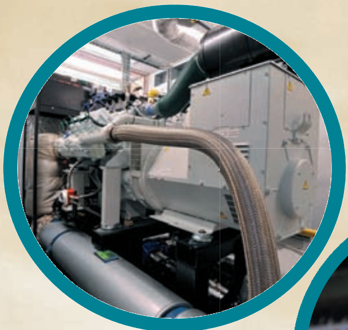

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How to Define the Adequate Reliability Requirement for a Power Electronic System?

Reliability is a key design factor for the vast majority of power electronic systems. Lifetimes of 20 years and more are often required for power applications, while low failure rates during the useful life of a system are implicitly presumed. **Uwe Scheuermann, Product Reliability Manager, SEMIKRON Elektronik, Nuremberg, Germany**

System designers thus request component manufacturers to supply a Mean-Time-To-Failure (MTTF) values for power electronic components in the early design phase, often even before specific operational conditions are defined. The following discussion illustrates that an MTTF value can only be specified on the basis of all relevant application parameters on the one hand and that such a single value is not sufficient to describe the reliability of a system on the other.

The bathtub curve

As an example for the following discussion, we will use the common graphical representation of system reliability: the 'bathtub curve' (Figure 1). Such a bathtub curve is found in every textbook on reliability, however usually not with scaled axes. The bathtub curve is describing the reliability of a hypothetical power electronic system, constructed as the sum of three statistical Weibull distributions. The parameters of the Weibull distributions are for this hypothetical system are selected according to field experience according to equation 1:

$$f(t)=\frac{b}{T}\cdot\left(\frac{t}{T}\right)^{b-1}\cdot\exp\left(-\left(\frac{t}{T}\right)^{b}\right) \quad (1)$$

The probability density function f(t) of a Weibull distribution is determined by two parameters: the scale factor T and the shape factor b. The survival probability R(t) and the failure rate λ(t) can then be calculated by:

$$R(t)=\exp\left(-\left(\frac{t}{T}\right)^{b}\right) \quad (2) \quad \text{and} \quad \lambda(t)=\frac{f(t)}{R(t)}=\frac{b}{T}\cdot\left(\frac{t}{T}\right)^{b-1} \quad (3)$$

The construction of the bathtub curve by parameterized statistical distributions thus allows the calculation of the survival rates for each contribution as well as for the sum of all failure rates.

Contributions to the total failure rate

For the early life failures, the Weibull shape factor is <1 which results in a decreasing failure rate over time. Early life failures are related to process and assembly errors,

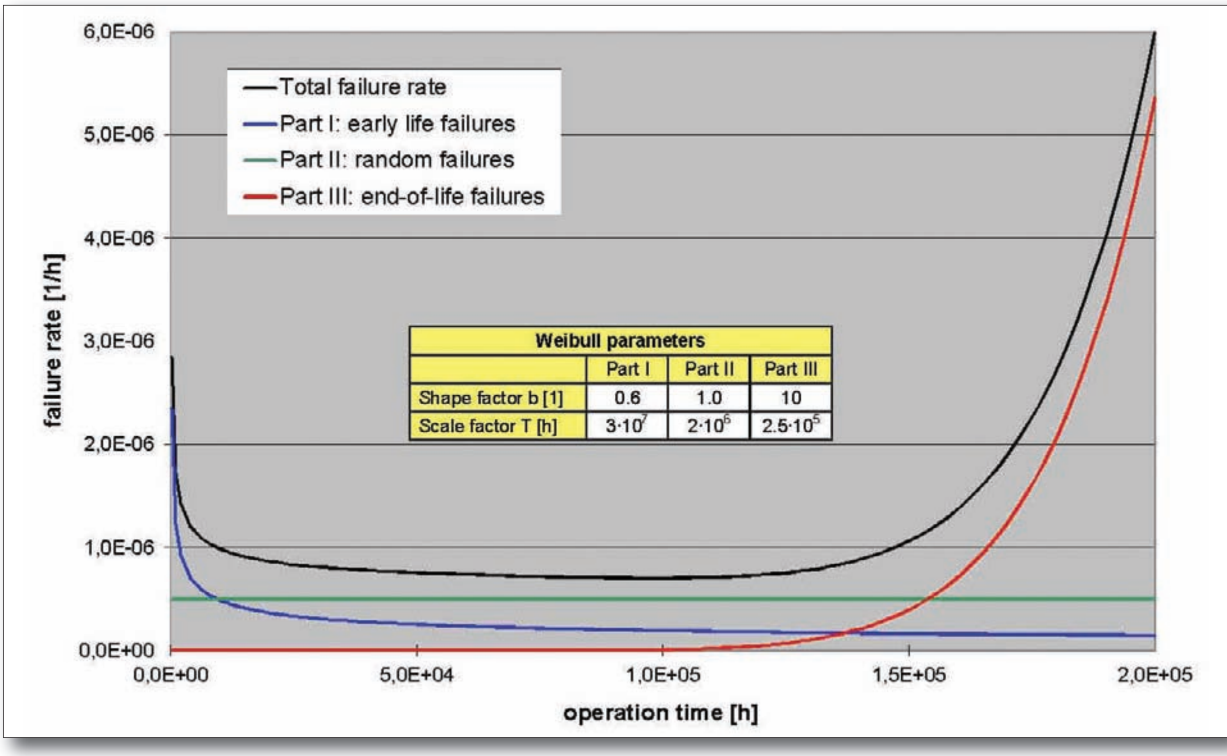


Figure 1: **'Bathtub curve' for a hypothetical power electronic system constructed as the sum of three Weibull distributions representing early life failures (blue), random failures (green) and end-of-life failures (red)**

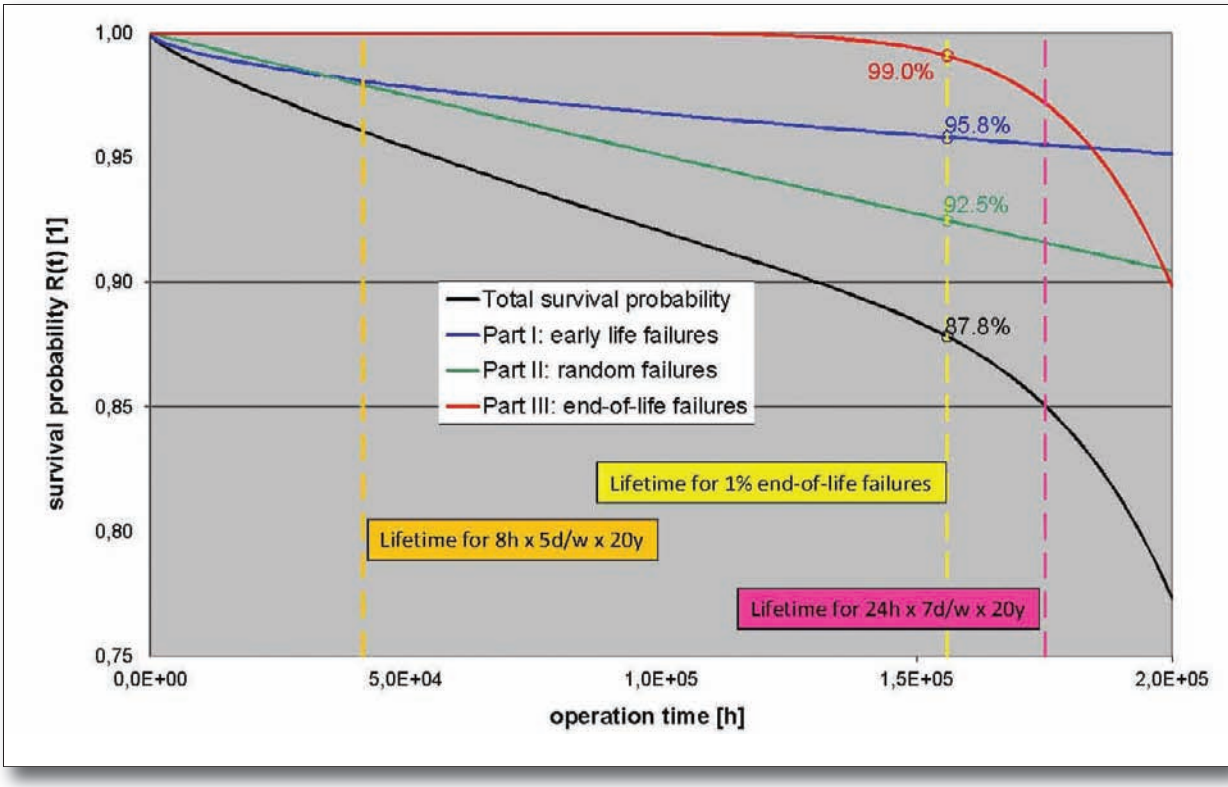


Figure 2: Total survival probability for the hypothetical system together with the contributions of the three Weibull distributions representing early life failures (blue), random failures (green) and end-of-life failures (red)

material defects and application related overstress, which result in a fatal destruction of the component. Since weak components are selected out of the population the failure rate associated to weakness of components decreases over time.

The second contribution represents random failures with a Weibull shape factor of 1. The root causes of these random failures are handling and maintenance errors and statistical physical failure causes. The cause of failure has its origin outside of the system and therefore generates a constant failure rate during the system lifetime.

The third contribution is describing end-of-life failures by a Weibull distribution with a shape factor >1. It comprises degradation, wear-out mechanisms and corrosion effects and thus increases towards the end of the useful life of the system. Since these aging mechanisms are generated by stress, the conditions of operation determine this failure rate.

On the commonly accepted assumption that these individual contributions are independent we can add up the failure rates and obtain the well-known bathtub curve shown in Figure 1.

The survival probability

Since we have constructed the bathtub curve for this hypothetical system by statistical distributions, we can now calculate the survival rate over time as shown in Figure 2. Using a common definition for the end of the useful life as the point in time when the end-of-life failures reach 1 % of the population, we find that for this hypothetical system the early life failures accumulate to 4.2 % and the random failures contribute with 7.5 %, thus resulting in a total survival rate of 87.8 % after an operational interval of 156,000h.

Figure 2 visualizes the impact of time of operation on the survival rate. If the application is operating 24 hours, 7 days a week for 20 years, a useful life of 175,000 hours is required which would result in a total survival probability of 85 %. If, however, the system is operating 8 hours, 5 days a week for 20 years, this would require only 41,000 hours with a survival probability of 94 % for the hypothetical system.

End-of-life failures

End-of-life failures result from the repetitive stress generated in a component by the application conditions. Considerable effort has been invested in the investigation of the physical failure modes and technology improvements to increase the component lifetime are continuously developed. Lifetime models, which are derived by extrapolation from highly accelerated laboratory tests, are used to estimate the useful lifetime of a system.

The strong focus on these end-of-life failures resulted in the proposal of health monitoring facilities, which will warn the user before a failure occurs by evaluating parameter shifts caused by degradation. However, even if such a facility would be able to detect all end-of-life failures before occurrence, no early life failures and no random failures would be detected. For our hypothetical system, less than 10 % of the total system failures would be detected by a health monitoring system, which would hardly be acceptable.

Random failures

Besides handling and maintenance errors, which can potentially be avoided by appropriate measures, the random failure rate includes statistical physical failure modes. A significant contribution to this group of failure modes is the 'single event burn-out' (SEB) caused by cosmic rays. The theoretical description of this effect, which was first identified in the early 1990s, is well understood today. A high energy particle that hits the silicon device in blocking mode can destroy the device without any precursor. Therefore, it is impossible to detect these SEB events by health monitoring. The DC-link voltage has a major impact on this failure rate. A state-of-the-art 1200 V IGBT exhibits a failure rate in the range of 1..10 FIT/cm^2 for a blocking voltage of 840 V at sea level and room temperature, it will rise by an order of magnitude for a blocking voltage of 900 V. The unit FIT is equivalent to 1 failure in 10^9 hours.

Especially for high power applications

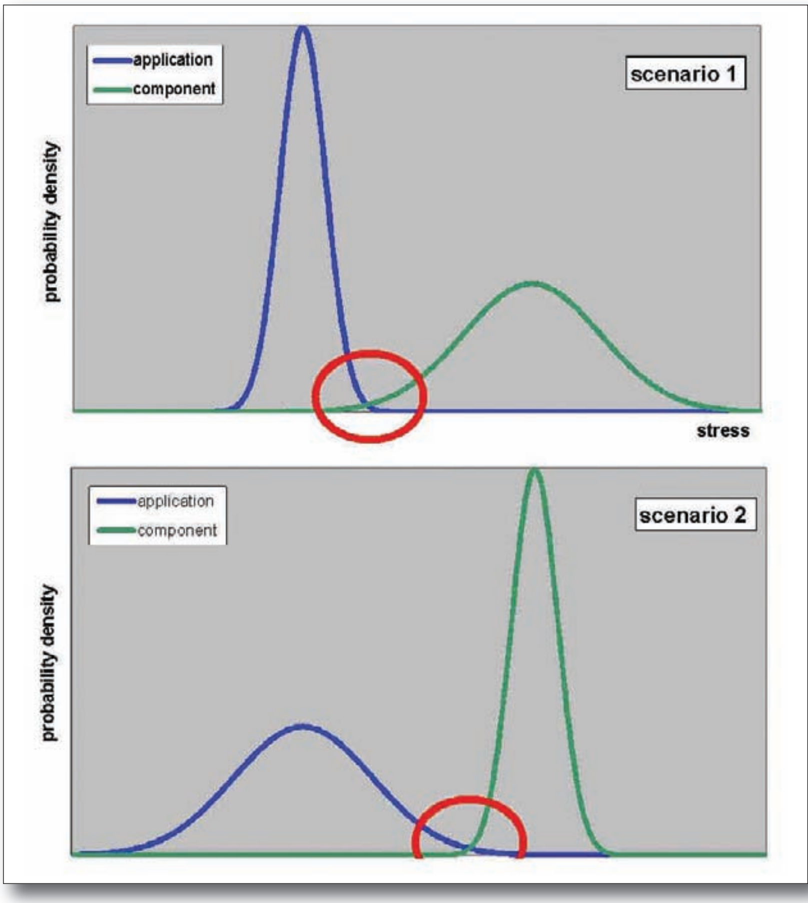


Figure 3: Comparison of application stress demand and component stress capability: Scenario 1 (top) shows a well-defined application and a component with a large variation of stress capability, while scenario 2 illustrates a well-defined component with a wide distribution of stress for individual instances of the application

containing 100 chips and more, the constant failure rate can easily reach values of 500 FIT or 0.5 ppm as in our hypothetical system. Since cosmic rays cannot be shielded by any practical means, the only way to reduce this failure rate is to reduce the DC-link voltage.

Early life failures

Early life failures are also a significant contribution to the total failure rate. While continuous improvement programs can reduce tolerances and process flaws, these failures cannot be completely eliminated. A burn-in test is necessary to further reduce this failure mode for high reliability applications. Such a test is stressing the component under worst case operational conditions for a limited time interval. Since the stress applied during burn-in testing is imperatively reducing the useful operational life of the component, its duration must be limited. The trade-of between lifetime reduction and reduction of the early life failures prevents the elimination of all early life failures.

The MTTF value

The MTTF value combines all the previously discussed failure modes into a single parameter that specifies the component reliability. It is by definition the expectation value for a component failure, reflecting both the component capability and the application stress demand. Therefore, it is not possible to determine a specific MTTF value for a component without taking into account the application conditions.

The detailed discussion of the different contributions to the failure rates shows, that this single value contains only limited information. It can be shown, that different bathtub curves with diverging failure contributions can result in the same MTTF value. Moreover, a bathtub curve with a smaller MTTF value can result in higher failure rates of the application. Therefore, the statement of a single MTTF value is not sufficient to characterize the reliability of a system.

Relation between application demand and component capability

So far, we have focused the discussion on the component stress capability in a system application. However, application related overstress is also contributing to the total failure rate. It can contribute to early life failures in case of a fatal stress condition - for example if the blocking voltage is exceeded - or it will affect the end-of-life failure rate if the impact is not fatal, for example by an increased temperature swing. Therefore, the relation between statistical distribution of stress capability of components and the statistical distribution of stress requirement by the individual application are fundamentally relevant.

This is illustrated in Figure 3 which shows the statistical distribution of component stress capability together with the statistical distribution of stress requirement by the application. Whenever a component with a low stress capability will be operating in an application with a high stress demand, indicated by the overlap of both distributions, an impact on the system reliability must be expected.

Often, scenario 1 is implicitly associated with such failures: The application conditions are clearly defined, but a fraction of the component population will not fulfill the requirement.

However, the same result must be expected when the component stress capability is statistically well defined, but the application stress demand shows a wide variation as depicted in scenario 2.

The knowledge of the statistical distribution of stress demand by an application is part of the core competence of the system designer. The better the knowledge about the stress demand, the higher the potential of designing systems with a well-defined reliability. If the distribution of stress demand is known, then the system designer can decide on the stress level that should be required over the useful operational life. A system designer can chose to fulfill the stress demand even for the highest demanding application, but this will possibly impact the commercial success of his product. Imagine a car manufacturer, which will design his car for a twenty years lifetime as a taxi. Of cause, all taxi drivers will be very happy with such a high reliability, but the other 95 % of the customers will have to pay for a reliability level they do not need. The decision of the reliability level is thus a genuine task of the system designer.

A well-defined reliability is of fundamental importance for a successful system design. It comprises much more than a simple statement of MTTF values; it is achievable only by close cooperation between the system designers and the component manufacturers. It must bring together the knowledge on stress demand by the applications and the stress capability of the components in a close relationship between system and component manufacturers. And it must finally be validated by field experience.

Compact Half-Bridge Power Modules

Vincotech has added a new family of power modules to its portfolio of baseplate-less half-bridges ranging up to 1200 V/150 A and 600 V/200 A. With the new flowPHASE 0 2nd generation power modules baseplate-less half-bridges now encompasses a line of products ranging from 50 to 150 A and 75 to 200 A for 1200 and 600 V, respectively. Alongside the standard types with low saturation voltage, Vincotech also offers fast modules with 1200 V/100 A. The overall portfolio of flow 0 half-bridges comprises ten different bases available in 66-by-33 mm housings measuring 12 and 17 mm in height, with a standard or an AlN DCB for improved thermal resistance. Optional solder or Press-Fit pins enable cost-effective assembly. The flowPHASE 0 2nd generation is also available with pre-applied thermal interface material. This highly conductive, 3.4 W/mK material simplifies assembly and further improves thermal impedance.

www.vincotech.com

Automotive Qualified Lead-Free Power MOSFETs

Infineon Technologies introduced automotive qualified 100 percent lead-free power MOSFETs for TO package types. The new 40 V/160 A OptiMOS(tm) T2 power MOSFETs uses a diffusion soldering die attach approach to produce the lead-free packages that include TO-220, TO-262 and TO-263. Because of specific requirements in terms of package geometry, die pad thickness and chip size the diffusion soldering die attach approach is today only suitable for these three package types. With the new MOSFET series, Infineon exceeds current RoHS (Restriction on Hazardous Substances) directives related to lead-based solder used to attach silicon chips to packages. Stricter ELV RoHS directives pending implementation after 2014 may require 100 percent lead-free packaging. The patented lead-free die attach (the interconnection between chip and leadframe of the package) uses a diffusion soldering approach, which allows improved electrical and thermal performance, manufacturability and quality. Matching this die attach technology with the thin wafer processes (60µm compared to standard 175µm) enables several improvements for power semiconductors, such as reduced on-resistance (2.0mΩ), and improved thermal resistance (0.9K/W), as the conventional lead-based soft solder material has poorer thermal conductivity and acts as a thermal barrier for the heat generated on the junction of the MOSFET. The devices IPB160N04S4-02D (160 A in TO-263 package), the IPB100N04S4-02D (100A, TO-263), the IPP100N04S4-03D (100A, TO-220) and the IPI100N04S4-03D (100A, TO-262) are already available.

www.infineon.com/automotivemosfet

6-A Power Module with Integrated Inductor

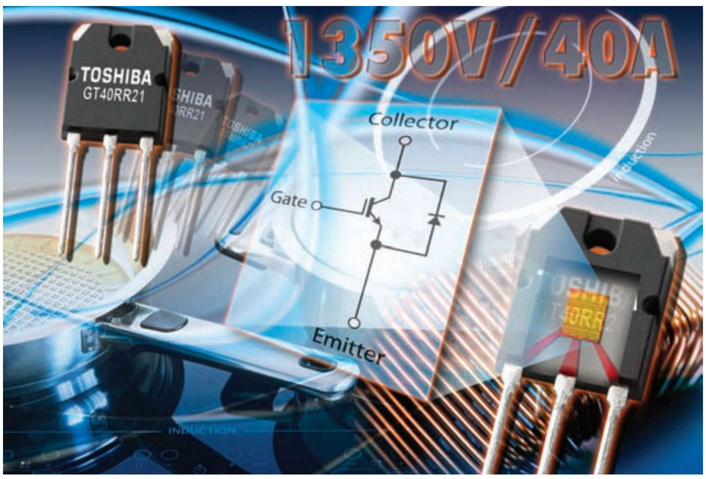
Texas Instruments introduced a 6-V, 6-A synchronous power module with integrated inductor, which achieves peak power efficiency up to 97 percent. The TPS84610 provides excellent thermal performance of 12 K/W. The device simplifies telecom power designs for DSPs and FPGAs by combining the inductor and passives onto one lead frame, requiring only three external components for a complete, easy-to-design 150-mm_ solution. The TPS84610 supports input voltages from 2.95 V to 6 V, generates a low 0.8-V output and has an adjustable switching frequency from 500 kHz to 2 MHz. The 9-mm x 11-mm x 2.8-mm low-noise module meets EN55022 Class B electromagnetic emissions, allowing it to support noise-sensitive applications, such as broadband communications equipment.
In addition to the TPS84610, TI also introduced four additional power modules with integrated inductors, including the pin-compatible 2-A TPS84210 and 4-A TPS84410, which support input voltages from 2.95 V to 6 V. The 3-A TPS84320 and 6-A TPS84621 modules support input voltages from 4.5 V to 14.5 V and output voltages down to as low as 0.6 V.

www.ti.com/tps84k-preu

Co-Packed IGBT and Reverse Recovery Diode for Industrial Heating

Toshiba Electronics Europe (TEE) has announced its first high-speed, integrated IGBT to feature a voltage rating up to 1350V. Designed for voltage resonator inverter switching, the new device will address growing demands for IGBTs with higher voltage withstand capabilities. The N-channel 'enhancement mode' GT40RR21 saves space and component count by combining an IGBT and a reverse recovery freewheeling diode into a single, compact monolithic device. Suitable for high-temperature operation, target applications for the IGBT include induction heating and induction cooking appliances. The new device supports very high-speed operation and can handle peak pulse currents as high as 200 A for 3 µs. Low turn-off switching losses - typically 0.30 mJ at a case temperature of 25°C and 0.54 mJ at 125°C - ensure high-efficiency operation. The 1350V GT40RR21 is designed to operate with junction temperatures up to 175°C. At 25°C maximum collector current is 40 A, and this falls by 5A at a temperature of 100°C. Typical saturation voltage at 25°C is 2.0 V. Maximum diode forward voltage/current is rated at 3.0 V/20 A. Supplied in a TO-3P(N), TO247-equivalent package, the GT40RR21 measures 15.5 mm x 20.0 mm x 4.5 mm. Engineering samples are available now and mass production is scheduled for Q3 2012.

www.toshiba-components.com



40 A Buck Stage

International Rectifier announced the expansion of its PowIRstage® family of integrated devices with the introduction of the 40 A IR3553, optimized for next-generation servers, consumer and communication systems. The IR3553 integrates a synchronous buck gate driver, synchronous MOSFETs and Schottky diode into a 6 mm x 4 mm x 0.9 mm PQFN package to deliver a high current density and high efficiency power stage solution that simplifies the design and implementation of high current, high performance multiphase buck regulators. IR PowIRstage® products provide an integrated current sense amplifier that achieves superior current sense accuracy and noise immunity compared to controller based inductor DCR sense methods. The IR3553 and IR3550 are fully PWM compatible with IR's CHiL digital power control products, as well as most industry standard PWM controllers on the market.

www.irf.com

Flat Wire Inductors Excel At High Temperatures

Featuring a "flat wire" design that is coiled and mounted directly to the circuit board to allow efficient heat dissipation, the new DR79892 and DR79893 Flat Wire Inductors from Datatronic Distribution are designed for performance in power supplies, industrial controls and instrumentation applications. Their compact flat wire design provides for better thermal management, which results in superior performance and reliability. The inductors are insulated to a minimum of 100 MΩ at 500VAC between coil and core. Rated to Insulation Class E, they are operable to a high temperature of 120°C (248°F). The Model DR79892 features an inductance up to 4.0 μH, 45 A rated current, and a 0.8 mΩ DC resistance. The DR79893 features an inductance of 45 μH and 30 A rated current.

www.datatronics.com

New Common Mode Inductors Offer Superior EMI Suppression

With advanced magnetics designed to eliminate common noise to all lines in power supply designs, the new CMT-8100 Series Common Mode Inductors from Triad Magnetics feature rugged construction and materials for high-temperature applications in demanding electronics operating environments. The inductors can be used in various types of power supplies to eliminate noise common to all lines. They offer excellent EMI suppression over a wide frequency spectrum and a high current capacity. Meeting VDE, IEC, UL, and CSA requirements, they minimize AC line transmitted interference often created by high frequency switching power supplies. CMT-8100 Series Inductors feature high dielectric strength of 1500 V RMS between windings. They operate at a temperature range of -55° to +105°C, with the rated current yielding a temperature rise of approximately 35°C. Inductors in the series offer a minimum inductance per winding ranging from 1 to 50 mH, a current rating ranging from 1.7 to 20 A and a DCR range from 0.006 to 0.45 Ω.

www.triadmagnetics.com

Automotive Grade High-Current LED Driver ICs

The A6265, A6266 and A6267 from Allegro MicroSystems Europe are a new family of automotive-grade (fully qualified to the AEC-Q100 Grade 0), high-current LED driver ICs with extensive diagnostics and protection features. The A6265/A6267 are configurable as either boost or buck-boost converters and the A6266 as a boost converter only. All the new driver ICs provide a programmable constant current output for driving high power LEDs in series, ensuring identical currents and uniform brightness. Each is capable of driving up to 15 LEDs at currents of 1 A or higher based on the external logic-level MOSFET. The maximum LED current is set with a single external sense resistor and can be modified using a current reference input. Direct PWM control is possible via the "enable" input, which also provides a shutdown mode. The dimming schemes for the A6265 and A6267 differ slightly, offering flexibility with a choice of drop-in devices. Integrated diagnostics and two fault outputs give indication of under-voltage, chip over-temperature, output open circuit, LED short circuit and LED under-current, and can be configured to provide short-circuit to supply and short-circuit to ground protection for the LED connections. The ability to detect one or more short-circuited LEDs is a unique feature of all the devices.

www.allegromicro.com

Trench Low Forward Voltage Schottky Diodes

ON Semiconductor offers a new family of 100 V and 20/30 A trench-based low forward voltage Schottky rectifiers (LVFR) for applications such as switching power supplies or DC/DC converters. The new NTST30100CTG, NTST20100CTG and NTSB20U100CTG family utilizes a trench MOS structure that enables an enhanced conduction zone under forward bias, resulting in significant reduction in forward voltage drop. Under reverse bias, this structure creates a "pinch-off" effect resulting in reduced leakage current. Unlike planar Schottky rectifiers, the LVFR's switching performance is strong across their entire operating junction temperature range of -40°C to +150°C. Data measured in a 65 W power adapter showed a 1 % efficiency improvement using LVFR versus planar Schottky.

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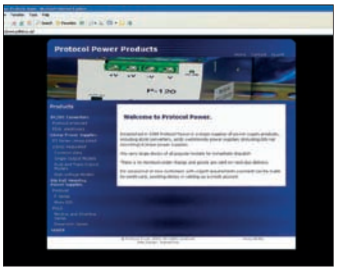

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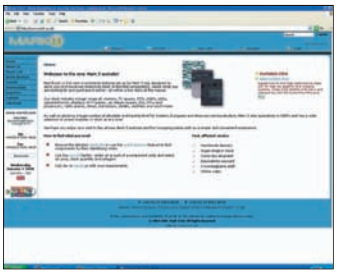

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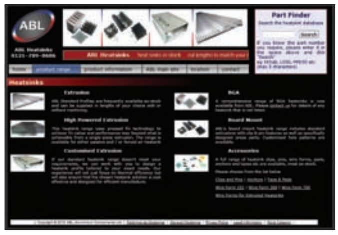

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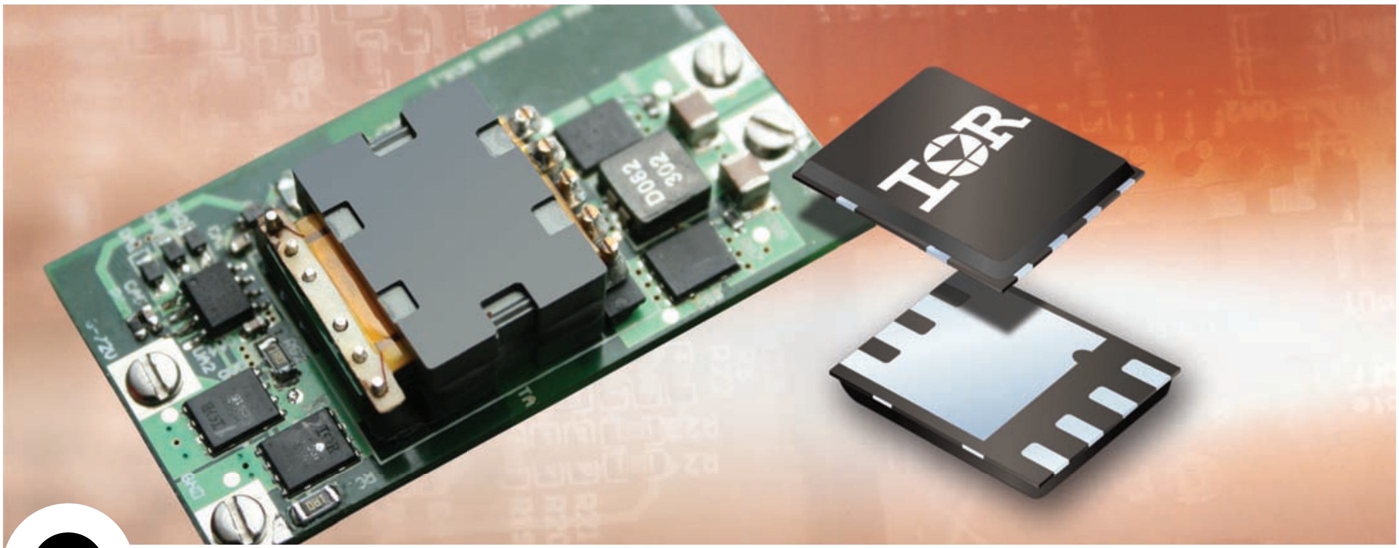

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IRFH5104TRPBF	PQFN 5x6mm	40 V	100 A	3.5 m	53 nC
IRFH5204TRPBF	PQFN 5x6mm	40 V	100 A	4.3 m	42 nC
IRFH5006TRPBF	PQFN 5x6mm	60 V	100 A	4.1 m	67 nC
IRFH5106TRPBF	PQFN 5x6mm	60 V	100 A	5.6 m	50 nC
IRFH5206TRPBF	PQFN 5x6mm	60 V	89 A	6.7 m	40 nC
IRFH5406TRPBF	PQFN 5x6mm	60 V	40 A	14.4 m	21 nC
IRFH5007TRPBF	PQFN 5x6mm	75 V	100 A	5.9 m	65 nC
IRFH5207TRPBF	PQFN 5x6mm	75 V	7 A	9.6 m	40 nC
IRFH5010TRPBF	PQFN 5x6mm	100 V	100 A	9.0 m	67 nC
IRFH5110TRPBF	PQFN 5x6mm	100 V	63 A	12.4 m	48 nC
IRFH5210TRPBF	PQFN 5x6mm	100 V	55 A	14.9 m	40 nC
IRFH5015TRPBF	PQFN 5x6mm	150 V	56 A	31 m	33 nC
IRFH5215TRPBF	PQFN 5x6mm	150 V	27 A	58 m	20 nC
IRFH5020TRPBF	PQFN 5x6mm	200 V	43 A	55 m	36 nC
IRFH5220TRPBF	PQFN 5x6mm	200 V	20 A	100 m	20 nC
IRFH5025TRPBF	PQFN 5x6mm	250 V	32 A	100 m	37 nC

Logic Level Gate Drive

Part Number	Package	Voltage	Current	$R_{DS(on)}$ Max. @4.5V	Q_G Typ @4.5V
IRLH5034TRPBF	PQFN 5x6mm	40 V	100A	3.2 m	43 nC
IRLH5036TRPBF	PQFN 5x6mm	60 V	100A	5.5 m	44 nC
IRLH5030TRPBF	PQFN 5x6mm	100 V	100A	9.9 m	44 nC

Features

- Low thermal resistance to PCB (down to <0.5°C/W)
- High Current Package – up to 100A continuous
- 100% RG tested
- Low profile (<0.9 mm)
- Industry-standard pinout
- Compatible with existing surface mount techniques
- RoHS compliant containing no lead, no bromide and no halogen
- MSL1, industrial qualification

The IR Advantage

- Increased power density
- Increased reliability
- Multi-vendor compatibility
- Easier manufacturing
- Environmentally friendlier

For more information call +49 (0) 6102 884 311
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