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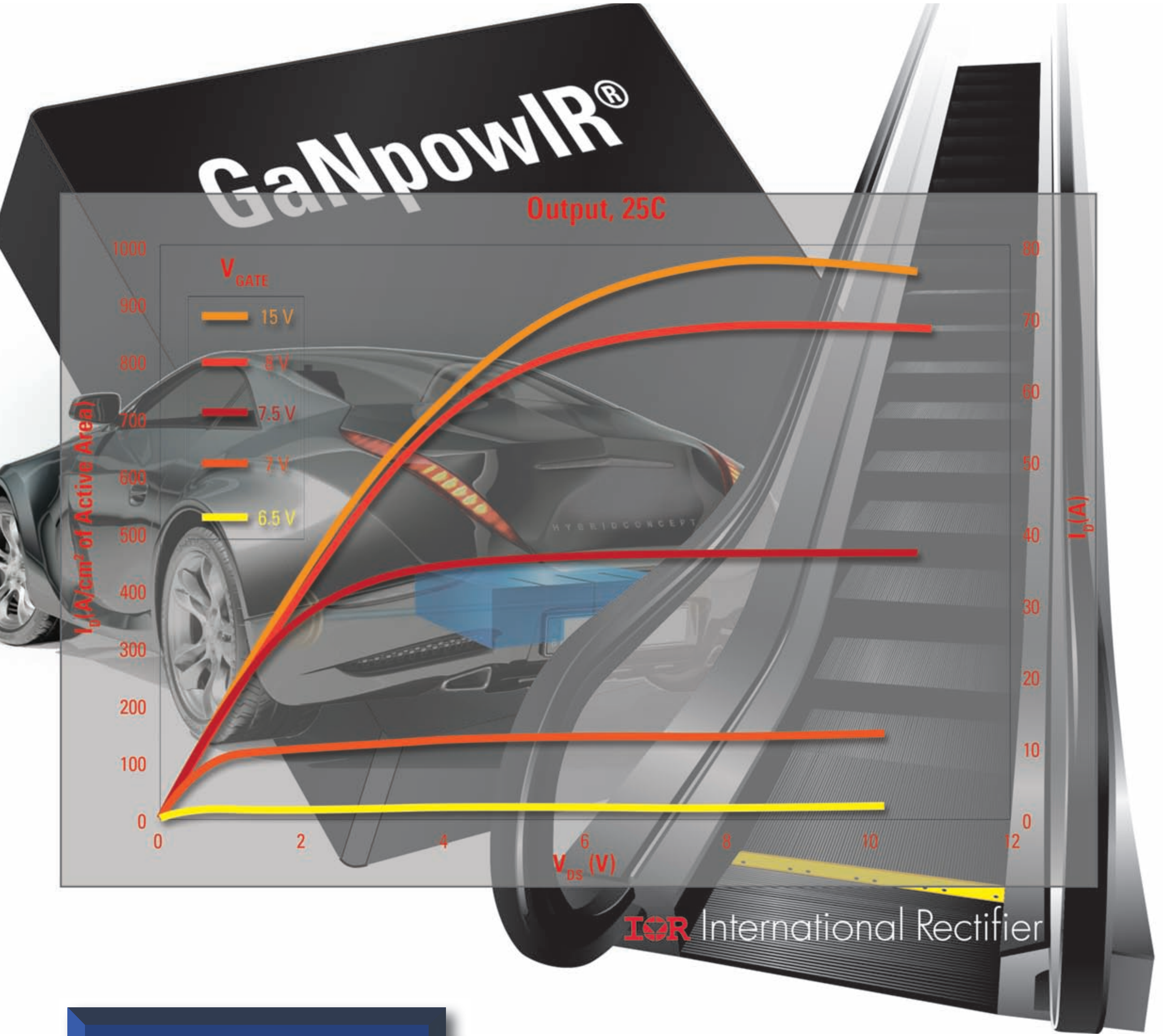
POWER SEMICONDUCTORS

Current Handling Capability of 600 V GaN High Electron Mobility Transistors



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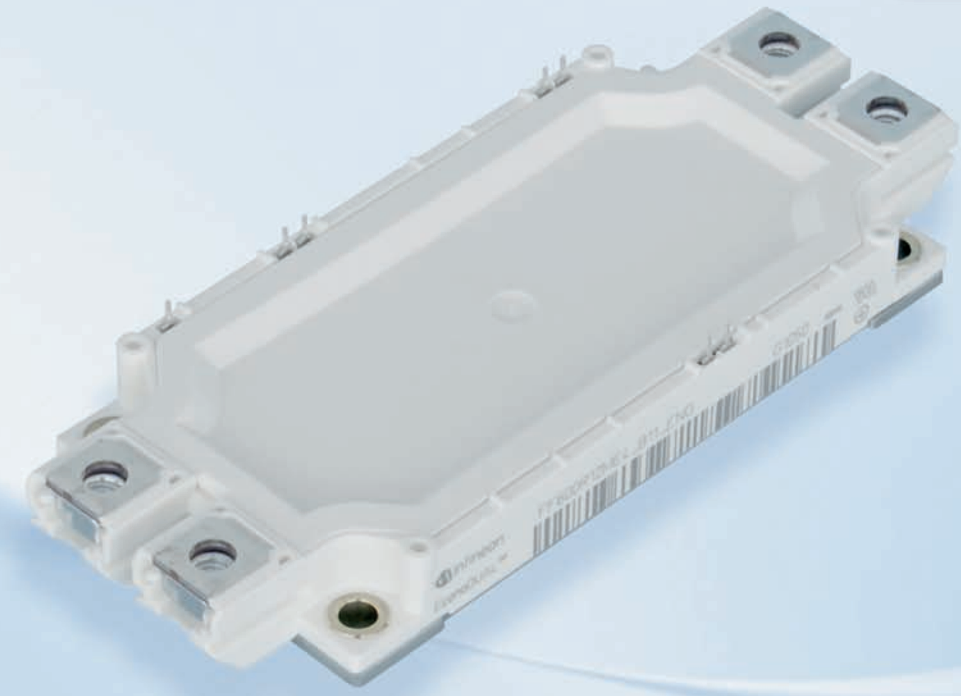

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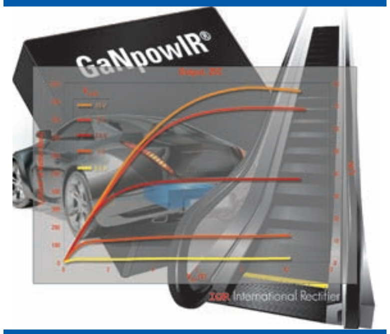
COVER STORY



Current Handling Capability of 600 V GaN High Electron Mobility Transistors

The revolutionary performance capabilities of Gallium-Nitride (GaN) based power devices compared to the incumbent Silicon based alternatives has been frequently demonstrated in a variety of power electronic applications where such GaN based High Electron Mobility Transistors (HEMTs) provide remarkably improved performance for essentially any power conversion circuit in terms of power density and efficiency. There have, however, been several members of the power electronics community who have suggested that, due to the lateral near surface nature of the GaN based power HEMTs, there is an inherent current handling limitation to less than 10 A. The development of thick, crack-free Gallium Nitride (GaN) epitaxy on standard thickness Silicon (Si) substrates, together with device fabrication in high volume silicon CMOS factories, has opened the potential for highly cost competitive, high voltage GaN devices. The simultaneous combination of advantages in efficiency, power density and cost over silicon based devices presents a compelling competitive advantage, which should help to drive rapid and widespread adoption of GaN devices throughout the power electronics industry including automotive and industrial applications. Whereas it has been previously shown that low voltage GaN-on-Si based HEMTs can process more than 150 A, even with a drain-source potential drop of 40 V, such current handling capability has not yet been shown for more recently developed 600 V rated devices. In this article, the measured current handling capability of such 600 V rated GaN-on-Si based HEMTs will be presented.

Full article on page 26

Cover supplied by International Rectifier

Smarter Power for a Smarter World

The power semiconductors market exhibits a 8.3 percent growth up to $16.2 billion in 2011. One reason for more rapid growth lies in the essential role power semiconductors have to play in the shift toward renewable energy sources. The value of the semiconductors installed per megawatt of capacity in renewable generation systems is an order of magnitude higher than the equivalent figure for conventional technologies. A conventional power station with 1,000 to 1,500 megawatts i. e. contains around Euro 250,000 worth of semiconductors, for example, whereas a wind farm of the same capacity contains semiconductors worth around Euro 7.5 million. Other areas of high growth are the smart grid, which is one of the big topics at this year's electronica fair in Munich, and innovative light sources such as LEDs and OLEDs are also on the advance. Implementation of the EU's eco-design guideline 2009/125/EG is accelerating market growth. Since 2009, light bulbs and other inefficient light sources have been gradually phased out. When it comes to these and other topics such as automotive lighting, e-signage and industrial applications, more than 170 exhibitors will present the latest technical solutions, products and components at electronica..

Smart Grids upgrade the infrastructure by adding distributed local intelligence, security across the network, enhanced efficiency and advanced control (to accommodate bi-directional power flow), flexible demand management and other new capabilities. Importantly, the chip-level building blocks of these systems must meet the highest quality standards to fulfill industry requirements for reliable, long lifetime use. The latest market data also illustrates the extent to which innovations related to smart energy solutions drive the market now and in the future. According to a forecast by the ZVEI, volume on the market for electronic components will increase by 5.7 percent to nearly $503 billion in 2012. Based on the ZVEI forecast, the most important forces that drive growth are the sectors for environmental protection and energy and resource efficiency. According to the industry association, due to increasing energy costs and guidelines to further reduce CO2 emissions, these sectors will also ensure continued growth in the years to come.

New electric automobiles such as the Smart Fortwo Electric Drive, the Renault Twizy or the Opel Ampera illustrate the progress that has been made in electromobility. Electric bicycles and pedelecs are also making advances. According to the ACE (Auto Club Europa), a total of 310,000 bicycles with electric motors were sold in 2011. However, there is still a great deal of development potential, especially in the areas of battery-charging infrastructure and vehicle safety. More than 1,000 electronica exhibitors will present technologies and products for the automotive sector. The electrification of traffic by electric cars, e-bikes, electrical transporters and pedelecs is changing mobility. New electric drive concepts are giving rise to innovations in a number of vehicle components. Besides drive units, storage solutions and battery systems, they include interfaces to the battery-charging infrastructure, power electronics and air-conditioning technology.

All these applications rely on efficient power semiconductors. Thus Gallium Nitride on Silicon power devices are gaining more attention in industry. Recently, ON Semiconductor has joined the multi-partner, industrial research and development program at imec in Belgium. Imec's research program is focused on developing GaN-on-Si technology on 200 mm wafers, as well as reducing the cost and improving the performance of GaN devices. By bringing together leading integrated device manufacturers, foundries, compound semiconductor companies, equipment suppliers and substrate suppliers, imec has been successful in achieving significant technical advancements. Last year, imec's research program successfully produced 200 mm GaN-on-Si wafers, bringing processing within reach for standard high-productivity 200 mm fabs. Moreover, a fabrication process compatible with standard CMOS processes and tools, the second prerequisite for cost-effective processing has been developed. As such, Europe is also on the forefront of this technology, though Japanese and US-based companies have one foot or even two feet in the market (see our cover story). The development of thick, crack-free Gallium Nitride epitaxy on standard thickness Silicon substrates, together with device fabrication in high volume silicon CMOS factories, has opened the potential for highly cost competitive, high voltage GaN devices. The simultaneous combination of advantages in efficiency, power density and cost over silicon based devices presents a compelling competitive advantage, which should help to drive rapid and widespread adoption of GaN devices throughout the power electronics industry including automotive and industrial applications.

Looking ahead, Power Electronics Europe will follow this progress and is preparing again a Special Session for PCIM Europe 2013.

Enjoy reading of this issue!

Achim Scharf
PEE Editor

Seventy Percent Growth for Microinverters

IMS Research's report "The World Market for Microinverters & Power Optimizers – 2012" revealed that shipments grew by more than 180 percent last year and at the same time revenues surged by 160 percent to more than $200 million. The research firm predicts that combined shipments will grow again in 2012 to almost 900 MW despite the relatively weak state of the PV industry as a whole. "Microinverter and power optimizer vendors have been somewhat insulated from the weak underlying demand and consolidation in the PV industry. The technologies are still relatively new and growth is simply coming from capturing share from existing solutions such as string inverters. Microinverters have now carved out a significant portion of the US residential market and have begun to make some inroads in Europe," explained Research Director Ash Sharma.

Looking further ahead, the outlook for microinverters and power optimizers remains positive with the report predicting that they would capture more than 10 percent of the market in 2016, generating revenues of nearly $1.5 billion. "Whilst microinverters are likely to remain limited to mainly residential and small commercial systems, optimizers will more likely be used in even larger installations, expanding their addressable market. Suppliers of the devices are also working closely with manufacturers of junction boxes, modules and inverters to offer several new routes to market that will help to further accelerate adoption," added Sharma.

Five of the most attractive markets for microinverters and power optimizers will be the U.S., Canada, U.K., Australia and Japan, which will see the disruptive technologies capturing up to a 25 percent share of the total markets by 2016. These five markets are predicted to continue to support a healthy residential and small commercial segment, be more accepting of new technologies (e.g. compared to Germany), and not enforce restrictive grid codes that may prevent microinverters or optimizers from being deployed. Despite the research identifying more than 25 suppliers of microinverters and power optimizers, in 2011 the market was dominated by three suppliers: Enphase Energy, SolarEdge and Tigo that accounted for more than 90 percent of shipments. Given the raft of partnerships announced by other suppliers including Enecsys, SolarBridge Technologies and tenKsolar, as well as the impending product releases of SMA and Power-One, the market is expect to fragment considerably.

Merchant Power Supply Market to Grow to $29 Billion in 2016

Growth in the merchant power supply market was curtailed in the second half of 2011 by continuing economic problems. Despite this, the market grew by 6.5 percent; however, this was just two-thirds of the growth initially projected in the first half of the year. IMS Research projects a strong 2012, with revenue growth forecast to reach 9.3 percent according to its latest report analysing the AC/DC and DC/DC merchant power supply markets.

The strong revenue growth forecast for 2012 will drive the market to a total of almost $23 billion. IMS Research projects positive growth annually through 2016, although at a slower rate owing to the impact that adoption of the Wired Universal Charging Solution for cell phones is predicted to have on the overall market beginning in 2014. The three fastest growing markets for power supplies over the next five years will be lighting, tablet PCs and storage (for servers). The lighting market in particular is forecast to grow rapidly due to the widespread adoption of LED lighting. "Although these three applications only account for a calculated 0.6 percent of the market in 2012, we expect that they will outperform the rest of the market by some margin. In 2016 we project they will account for 15 percent of the total market and provide an opportunity manufacturers cannot overlook," Market Analyst Jonathon Eykyn comments.

Out of the top ten suppliers, seven were Asian, two were American and one was European. GE Energy (through its acquisition of Lineage Power) and ZTE were new entries to the top ten global AC/DC and DC/DC market rankings and ZTE is the first Chinese supplier to make the list. Eykyn added, "The Chinese merchant power supply market is forecast to overtake the North American market in 2014 to become the largest market in the world. This means that it is likely that we'll see more Chinese suppliers follow ZTE into the top ten."

www.imsresearch.com

SafeBatt Makes Lithium Ion Batteries Safer

Over the next three years, 15 partners from German science and the automotive and supply industry will research how the safety of lithium ion batteries can be further improved for electric and hybrid vehicles. A focal part of the research will be new materials, test methods and semiconductor sensors for use in lithium ion batteries. The Federal Ministry of Education and Research (BMBF) is funding this research work in order to further develop Germany's top position as a center for industry, science and technology, and to accelerate the shift to more climate-friendly and cost-effective mobility. The German government has also elected SafeBatt as one of nine "lighthouse projects" of Germany's National Electric Mobility Platform (NPE). SafeBatt stands for "active and passive measures for intrinsically safe lithium ion batteries". SafeBatt was started in July 2012 and will end on June 30, 2015. The project will cost about Euro 36 million. The industry partners are putting in around Euro17 million, while the BMBF is participating in the funding of SafeBatt with about Euro 19 million.

The SafeBatt partners will investigate among other things how the cell chemistry can be optimized to increase the (intrinsic) safety of lithium ion battery cells; in particular that of the cathode material and the electrolytes. In addition, research will be done into totally new semiconductor sensors made of material never previously used in this area, such as graphene, in order to record the relevant safety parameters of the battery cell. This includes for example chemical processes, the increase in pressure and the temperature cycles inside the cell.

Another objective of the research is a "digital battery pass", which continuously records, evaluates and stores safety-related battery parameters during the battery's operational life. The SafeBatt team also wants to develop new safety models for battery cells, which ascertain the correct operating status of the battery and at the same time take into consideration all possible extreme situations. Such extreme situations include for instance the complete discharge of the battery in low temperatures or an excessive rise in operating temperature at the height

of the summer, for example when the battery temperature control fails. In addition, SafeBatt experts want to optimize and standardize the test procedure for the product approval of batteries, since the test procedure used at the moment does not cover all conceivable extreme situations.

Project partners are BASF SE, BMW AG, Daimler AG, Deutsche ACCUmotive GmbH & Co.KG, ElringKlinger AG, Evonik Litarion GmbH, Infineon Technologies AG, Li-Tec Battery GmbH, SGS Germany GmbH, Volkswagen AG, Wacker Chemie AG, the Institute for Chemical Technology ICT of the Fraunhofer-Gesellschaft, the Technical University of Braunschweig with the Institute for Particle Technology iPAT, the University of Münster with its battery research center MEET as well as the Technical University of Munich with its Department for Electrical Energy Storage. Infineon Technologies acts as the overall project coordinator.

Global Leader in Power Semiconductors

According to IMS Research Infineon held an 11.9 percent share of the total US Dollar 17.6 billion market for power semiconductors in 2011.

With a growth rate of nearly 21 percent, Infineon revenue in the segment grew faster than the 8.3 percent growth of the power semiconductors market. Also among the top 3 suppliers in 2011 were Mitsubishi with a market share of 8.3 percent and Toshiba with 6.6 percent. In 2010, Infineon held 10.7 percent of the total market of $16.2 billion."Already today about 30 percent of the electricity consumed worldwide could be saved through the consistent use of semiconductors. Innovation is key to enabling this level in industrial, automotive and consumer applications," says Dr. Reinhard Ploss, CEO of Infineon Technologies AG. "We are continuously researching new materials for power semiconductors, such as Silicon Carbide and Gallium Nitride, and developing advanced processes such as 300-millimeter thin wafer technology for power semiconductors."

One reason for more rapid growth lies in the essential role power semiconductors have to play in the shift toward renewable energy sources. The value of the semiconductors installed per megawatt of capacity in renewable generation systems is an order of magnitude higher than the equivalent figure for conventional technologies. A conventional power station with 1,000 to 1,500 megawatts contains around Euro 250,000 worth of semiconductors, for example, whereas a wind farm of the same capacity contains semiconductors worth around Euro 7.5 million.

Additionally, the Infineon CoolMOS™ team consisting of Dr. Franz Auerbach, Dr. Gerald Deboy, Dr. Hans Weber and Dr. Reinhard Ploss, is the recipient of the European SEMI Award 2012. CoolMOS technology is capable of blocking voltages of several hundred volts, while at the same time switching currents up to a hundred amperes. It is used, for instance in power supplies, enabling efficient energy usage for a wide range of

"Already today about 30 percent of the electricity consumed worldwide could be saved through the consistent use of semiconductors," says Infineon's CEO Dr. Reinhard

applications. The award was presented during the SEMICON Europa Executive Summit on October 11 in Dresden. The basic principle was described at the end of the eighties by Jenö Tihanyi, one of Infineon's first fellows. The idea was brilliant but also challenging, realization was very difficult at the outset. But belief in the product was stronger than any resistance. In March 1997 we demonstrated that the idea could be implemented in Silicon, at the end of 1998 Infineon achieved a breakthrough in the yield. Today the CoolMOS™ is one of Infineon's most successful products as well as in volume for power applications and in revenue.

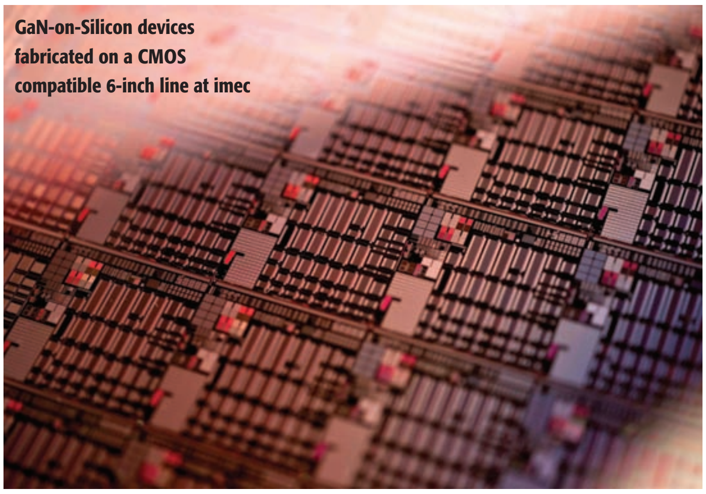
The European SEMI Award was established more than two decades ago to recognize individuals and teams who made a significant contribution to the European semiconductor and related industries.

www.infineon.com

ON Semiconductor Joins imec's GaN-on-Si Research Program

ON Semiconductor has joined the multi-partner, industrial research and development program at imec in Belgium, to collaborate on the development of next-generation Gallium Nitride (GaN) on silicon (Si) power devices.

Imec is headquartered in Leuven, Belgium, its staff of close to 2,000 people includes more than 600 industrial residents and guest researchers. Imec's research program is focused on developing GaN-on-Si technology on 200 mm wafers, as well as reducing the cost and improving the performance of GaN devices. By bringing together leading integrated device manufacturers (IDMs), foundries, compound semiconductor companies, equipment suppliers and substrate suppliers, imec has been successful in achieving significant technical advancements. Last year, imec's research program successfully produced 200 mm GaN-on-Si wafers, bringing processing within reach for standard high-productivity 200 mm fabs. Moreover, a fabrication process compatible with standard CMOS processes and tools, the second prerequisite for cost-effective processing has been developed. "Extraordinary developments continue to emerge from our GaN-on-Si Affiliation Program, creating further inroads to drive down production costs. Leveraging joint efforts will help us overcome the next hurdle toward economical volume manufacturing, ultimately bringing GaN power devices to the market", commented Imec's VP energy technology Rudi Cartuyvels. "As a top 20 global semiconductor supplier with a portfolio focused on energy efficient devices, ON Semiconductor has



GaN-on-Silicon devices fabricated on a CMOS compatible 6-inch line at imec

been researching GaN silicon technologies for several years and is presently building a GaN processing line in its Oudenaarde facility in Belgium. Partnering with imec will help strengthen our current market position", said Hans Stork, senior vice president and Chief Technology Officer (CTO) at ON Semiconductor.

On the way to 8-inch wafers

GaN and AlGaN layers are highly strained epitaxial grown layers, grown on Si substrates with <111> crystal orientation. Because of the difficulty to grow such highly strained layers, the growth is done on 4 and 6 inch wafers.

Imec has completed the development of a 6-inch depletion mode HEMT already in 2011. While typical GaN processes are processed in III-V fabs, which allow the use of gold, this project focused on the development of a Au-free, Si-compatible process that can be run in a high productivity CMOS fab. To this extent, the ohmic contacts have been optimized to yield low contact resistances using conventional CMOS-based metal layers. The metal patterning is no longer done by lift-off, but by metal etch, for the same reasons of CMOS compatibility. The device architecture chosen is a metal insulator semiconductor high electron mobility transistor (MISHEMT), which means it has a metal-insulator-semiconductor gate architecture.

Power devices have been fabricated in this technology with effective gate widths up to 100 mm. The specific on-resistance is 2.9 $m\Omega.mm^2$. These devices show the typical low input-, output-, and reverse trans-capacitance of lateral HEMTS, which is more than one order of magnitude lower then the Silicon counterparts, which explains the fast switching behavior. Recently, the feasibility to grown these GaN/AlGaN layers on 8 inch silicon wafers has been demonstrated. Although the tools and processes need still to improve strongly, first results have been obtained with the successful processing of the first pathfinder lots in imec's CMOS 8 inch line. This involved a comprehensive exercise to check if the thicker then usual (1.1 mm) wafers can pass the wafer handling and clamping/chucking systems without wafer breakage, and if the contamination status of all tools was preserved.

The GaN/AlGaN heterostructures spontaneously result in a 2-dimensional electron gas all over the wafer. Therefore, depletion mode transistors are easily obtained. However, these require to be cascoded with a low voltage Silicon enhancement mode device for fail safe reasons. Together with the scaling up to 8 inch, this part of the program focuses on moving from depletion mode to enhancement mode. As there is no mature architecture that has demonstrated to give long-term stable and reliable enhancement mode power transistors, the program develops different enhancement mode architectures for benchmarking. The first enhancement mode transistors have been obtained on 8 inch, but still needs significant improvement. See also our features on GaN-on-Silicon.

www.imec.be

Solutions for Future Energy Supply

electronica 2012
inside tomorrow

"Smart energy solutions" is one of the main themes of electronica 2012, the International Trade Fair for Electronic Components, Systems and Applications from November 13 - 16, 2012 in Munich.

Electronica 2010 ended with 2,597 exhibitors and more than 72,000 visitors. "Can this number be topped in this year?", asked Munich fair manager Norbert Bargmann and gave the answer directly - "yes, it can". The electronica 2012 organizers expect more than 2,600 exhibitors and also a corresponding higher number of visitors. This is due to the fact that the changes in energy supply towards decentralized renewables ask for new structures in the distribution network. "The energy change in Germany away from nuclear and fossile power generation will continue over the coming thirty years", expects Christoph Stoppock, Head of Components within the Central Association of the German Electrical and Electronics Industry (ZVEI). "This will involve a more intelligent grid with bidirectional power flow towards a so-called smart grid." What does this mean for the semiconductor industry? Infineon's CEO Reinhard Ploss has an answer to that question: "A conventional power station with 1,000 to 1,500 megawatts contains around Euro 250,000 worth of semiconductors, whereas a wind farm of the same capacity contains semiconductors worth around Euro 7.5 million."

Thus renewable energies play an increasingly important role in the supply of energy. Given the increased integration of solar and wind energy, energy production is becoming increasingly decentralized and subject to greater fluctuations. To deal with the resulting challenges, grids must not only be expanded, they must also be controlled and monitored more intelligently.

The industry's leading manufacturers will present their solutions and products in the sectors for energy efficiency, energy storage, LEDs and smart grids. Above all, the future of power grids is expected to be the center of attention. Against the backdrop of the global transition to alternative energy sources and the expansion of power grids, electronica 2012 will present technical solutions for the intelligent supply of power in the future. Leading international executives will also discuss this topic at the CEO Roundtable under the motto "Semiconductor Solutions for Smart Grid Challenges" (electronica Forum on Tuesday, November 13, 11 a.m.).

The latest market data also illustrates the extent to which innovations related to smart energy solutions drive the market now and in the future. According to a forecast by the ZVEI, volume on the market for electronic components will increase by 5.7 percent to nearly $503 billion in 2012. Based on the ZVEI forecast, the most important forces that drive growth are the sectors for environmental protection and energy and resource efficiency. According to the industry association, due to increasing energy costs and guidelines to further reduce CO_2 emissions, these sectors will also ensure continued growth in the years to come.

Towards smart grids

Smart Grids upgrade the infrastructure by adding distributed local intelligence, security across the network, enhanced efficiency and advanced control (to accommodate bi-directional power flow), flexible demand management and other new capabilities. Importantly, the chip-level building blocks of these systems must meet the highest quality standards to fulfill industry

From November 13 - 16, 2012, the Munich fairgrounds will serve as the worldwide electronics center

Munich fair manager Norbert Bargmann expects more than 2,600 exhibitors at electronica 2012

ZVEI's Christoph Stoppok predicts the market for electronic components to grow by 5.7 percent to $503 billion in 2012

requirements for reliable, long lifetime use. "Infineon brings expertise to bear in defining and delivering solutions for the Smart Grid," says Dr. Sergio Rossi, Head of Smart Grid and Peripherals at Infineon Technologies. "While power semiconductors represent on average more than one-half of our annual revenue, we also have leading market share positions in chip-based security, deep experience in embedded control, and the ability to meet demanding quality and product lifetime requirements - which we have already proven with our automotive portfolio."

Smart Meters are emerging as a critical element of the grid's interface between providers and end-consumers. They monitor energy consumption, communicate with devices in the household and gather all information required by the grid to efficiently allocate resources. As the market landscape changes from pilot project to mass scale deployment, solutions need to be cost effective yet enriched with features.

Infineon's portfolio for Smart Grids (www.infineon.com/smartgrid) includes power MOSFETs, IGBTs and diodes with power ranges from a few watts to megawatts which are used to enable highly efficient and reliable power conversion (for instance in wind, solar, energy storage applications). Furthermore, the company offers dedicated thyristors for HV DC transmission lines, modules to control industrial drives, sensors, microcontrollers, security ICs and metrology MCUs ideal for implementation of Distribution Automation applications and a wide range of devices dedicated to cost effective implementation of smart meters and energy-efficient, smart home appliances.

STMicroelectronics (www.st.com) will address the challenges of intelligent metering with its large portfolio of smart-meter chips. Its solutions support all

Semiconductor Solutions for Smart Grid Challenges will be discussed in the electronica Forum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phases of operation, from recording and consumption analysis to determining peak loads, diagnosing faults, and comparing consumption with variable electricity rates. Besides having the latest solutions in the Powerline Communications sector, STMicroelectronics is also opening up new application possibilities in data transfer such as the monitoring and control of photovoltaic modules.

The company has recently introduced its cool bypass switches family for photovoltaic modules, enabling an even higher percentage of harvested energy to reach end users and further reducing the cost per watt of renewable energy. ST's bypass devices can be integrated directly in the PV module, combining power switching and intelligent control in a single chip to compensate for the variable effects of hotspots and shadows on the solar panel surface. The new devices can save up to 1 % of the energy produced and normally lost through conventional bypass diodes; in a 1 MWp solar array farm this loss could provide the total annual electricity consumption of two average European households.

LEFT: The automotive conference will cover in some 30 lectures all subjects of electromobility

Next generation of LEDs and displays

Flatter, more compact, higher resolutions and higher contrast - those are the convincing features of the latest displays at electronica 2012. LED technology is also making advances. Implementing the EU's eco-design guidelines is giving the market for innovative light sources positive new impetus.

According to a recent Bitkom study, more than 10 million flat-screen televisions with LCD/LED displays will be sold in Germany in 2012 - a new record. The next generation of displays, which feature OLED and AMOLED technologies for industrial applications and the consumer sector, are already available. When it comes to innovative light sources, LEDs and OLEDs are also on the advance. Implementation of the EU's eco-design guideline 2009/125/EG is accelerating market growth. Since 2009, light bulbs and other inefficient light sources have been gradually phased out. When it comes to these and other topics such as automotive lighting, e-signage and industrial applications, approximately 173 exhibitors will present the latest technical solutions, products and components at electronica.

Light sources for frontlighting in automobiles have to be multitalented. Not only do they have to illuminate the road ahead reliably in rain and fog and at night, they have to perform various functions as low beam, cornering lights and fog lights for example. At the same time, they have to withstand high temperatures in the headlights. For these reasons more and more automobile manufacturers are opting for flexible, efficient and powerful LED technology.

Electromobility of the future

More than 1,000 exhibitors will present technologies and products for the automotive sector. One of the focal points in this sector and a main theme of the fair is electromobility. The electrification of traffic by electric cars, e-bikes, electrical transporters and pedelecs is changing mobility. New electric drive concepts are giving rise to innovations in a number of vehicle components. Besides drive units, storage solutions and battery systems, they include interfaces to the battery-charging infrastructure, power electronics and air-conditioning technology.

New electric automobiles such as the Smart Fortwo Electric Drive, the Renault Twizy or the Opel Ampera illustrate the progress that has been made in electromobility. Electric bicycles and pedelecs are also making advances.

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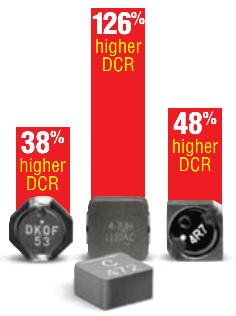

Competitors’ 4.7uH inductors have much higher DCR per mm³ than Coilcraft’s XAL5030.

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The automotive Forum in Hall A6 will give visitors among others an in-depth look at electromobility and power electronics

According to the ACE (Auto Club Europa), a total of 310,000 bicycles with electric motors were sold in 2011. However, there is still a great deal of development potential, especially in the areas of battery-charging infrastructure and vehicle safety.

Besides the exhibition sector, this topic is reflected in the program of events in the automotive Forums and at the automotive conference, starting already on Monday (November 12). In some 30 lectures, international experts will explain the latest technologies and market developments that pertain to "The Car in the Web", "Energy-Efficient Mobility", "Safe Driving" and "Design to Cost".

The first day of the conference mainly addresses leading executives of automobile manufacturers, automotive-supply companies and electronics companies. The program of events includes lectures such as presentations by Dr. Rupert Stützle, Head of Systems Development for Electric Vehicles at Bosch, on the topic of "Powertrain Electrification: Current Challenges and Solutions in Development of Power Electronics" or by Wolfgang Sczygiol, Managing Director of Brose-SEW, on the topic of "Strategies of Suppliers in the Market of Motors and Inductive Charging for Electric Mobility". Other lectures on the first day of the conference deal with increased networking of the automobile and the Internet, the LTE mobile wireless standard and topics such as power electronics, motors and charging units for electric automobiles.

The second day of the conference (November 13) is broken down into two tracks. They both revolve around technologies that address technical management in automotive, auto-supply and electronics companies. The first track focuses on electromobility in the morning and on power electronics in the afternoon. The second track focuses on the topics of safety and the Internet in the automobile. The conference will conclude with a roundtable discussion on "Concepts of Mobility".

The automotive Forum in Hall A6 will also give visitors an in-depth look at this sector. Among other things, the program of events includes lectures on electromobility, power electronics, batteries and drive technologies. For example, in a panel discussion on Wednesday, veterans from AEL, NXP, Osram Opto and other companies will discuss "Lighting concepts and LEDs". The program of events at the automotive Forum in Hall A6 will also deal with the topic of electromobility. Managing fleets of electrical vehicles is a special challenge with existing infrastructures. Thorsten Themme from Phoenix Contact will make a presentation titled "E-Mobility for Fleets - Solutions for Load and Energy Management". On Thursday, November 15, the Automotive Application Group of the ZVEI will present recent developments on the topic of power electronics with an emphasis on electromobility.

Power Electronics at Electronica

Though electronica 2012 covers the broad spectrum of electronics, power devices are on display with some selected exhibitors.

International Rectifier (**www.irf.com,** booth A5-320) will focus on automotive applications within the exhibition and also the automotive conference.

The company will introduce the automotive-qualified AUIRS20302S three-phase gate driver IC for 12V, 24V and 48V vehicle applications including high-voltage air conditioner compressors, pumps, BLDC motor drives up to 600 W and high-voltage motor drives. The AUIRS20302S targets 12V, 24V and 48V boardnet automotive platforms operating at voltages up to 200V maximum. The new device features an external pre-regulator to generate its own supply voltage to ensure that the gate drives do not exceed 17 V even during load dump conditions. The pre-regulator VPR pin can also supply the surrounding system components if the total consumption does not exceed 100 mA. The AUIRS20302S is capable of driving 6 N-channel power MOSFETs or IGBTs using a bootstrap technique to supply the high-side driving circuitry. The device also features embedded deadtime and cross-conduction prevention functions and under-voltage and over-current protection with diagnostics. "With its comprehensive set of protection features and a pre-regulator to sustain load dumps, the AUIRS20302S is a robust 3-phase gate driver tailored specifically for car and truck applications ranging from 12V to 48V," said Davide Giacomini, IR's Product Marketing Director.

The AUIRFR4292 and AUIRFS6535 are automotive-qualified power MOSFETs featuring low on-state resistance of 345/185 m_ for Piezo injection systems for both gasoline and diesel engines extending the range of IR's automotive MOSFET portfolio to breakdown voltage up to 300 V. "These new 250 V and 300 V power MOSFETs are well suited for Piezo injection applications where high-voltage is required to drive the actuators and ensure faster response and more precise control than magnetic solenoid injection systems," said Jifeng Qin, Product Manager, Automotive MOSFETs. Finally, the new AUIR3320S high-side intelligent power switch (IPS) is optimized for automotive auxiliary positive temperature coefficient (PTC) electric heaters. Offering very low on-state resistance of 4 m_ at 25°C, the AUIR3320S delivers higher current with a smaller heat sink to reduce system footprint. The 40 V device also features current sensing to allow precise monitoring of load current in order to provide additional data to the microcontroller for diagnostic applications. "PTC electric heaters are now widely adopted and offer improvements in cabin comfort. However, safety and reliability are critical design factors due to the high current required and the fact that the application resides in the interior of the vehicle," said David Jacquinod, Product Marketing Manager, IR's Automotive Products Business Unit.

At the Automotive Conference, IR's Senior Automotive Manager Power Switch & Modules Benjamin Jackson will introduce a new power switch and package platform designed for next generation (H)EV power trains comprised of IGBT, Diode and dual-sided cooled power package technologies. Solderable Front Metal (SFM) die technology eliminates the need for bond wires and the inherent failure mechanism that limits reliability and shortens operational life times. At the same time, SFM technology enables dual-sided cooling capability to increase thermal performance by 30-40 percent and eliminate bond wire related parasitic impedances which typically increase system level costs and footprint.

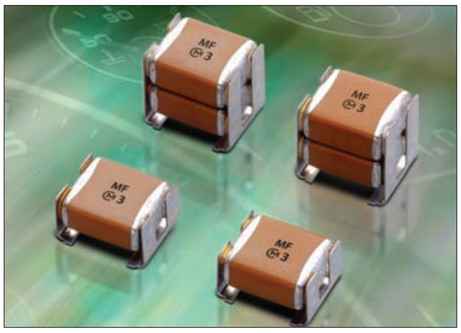
IR's high-side intelligent power switch is optimized for automotive auxiliary PTC electric heaters

Linear Technology (**www.linear.com,** booth A4-538) introduces the LTM4641, a 4.5 V to 38 V input, 0.6 V to 6 V output, 10 A step-down µModule(r) regulator with comprehensive electrical and thermal protection for loads such as processors, ASICs and high-end FPGAs. The LTM4641 µModule regulator monitors input voltage, output voltage and temperature conditions. If any user-adjustable trip thresholds are exceeded, the LTM4641 responds within 500 ns in the case of an output overvoltage fault, ceasing operation, and if necessary, activating external switches. One switch disconnects the input supply rail while the other discharges the output capacitors to protect the load. Additionally, when any trip threshold is exceeded, the LTM4641 will issue a logic level fault signal which may be used to initiate an orderly emergency shutdown sequence in the system. The adjustable trip thresholds are accurate to within ±2.7% over the full operating temperature range. As a µModule regulator, the LTM4641 includes power MOSFETs, DC/DC controller, inductor, compensation and the protection logic circuits in a compact surface mount BGA package. The LTM4641 is designed for point-of-load regulation in robotics and industrial instrumentation, as well as rugged environments such as defense and avionics systems.

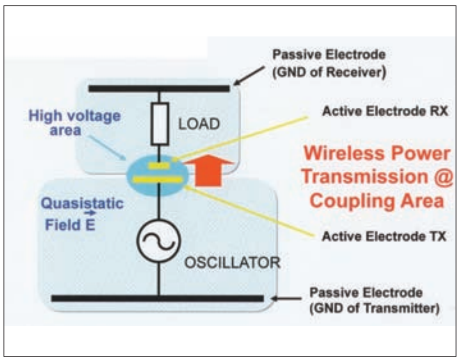
10 A step-down µModule regulator

Murata (**www.murata.eu,** booth B5-107) introdues what is believed to be the world's first SMD safety "Y2" capacitor designed for automotive applications. Approval to the internationally recognized standard for safety capacitors, IEC 60384-14 that stipulates protection from electrical shock and risk of fire is pending. With the growing demand for electric (EV) and hybrid electric vehicles (HEV), the KCA series of capacitors are ideal as part of an AC power line filter in a battery charger or as a DC line filter of a DC/DC converter/inverter unit. The construction of the KCA series also incorporates techniques to improve long-term resilience against vibration and bending stresses. This includes the use of metal terminals as protection against substrate expansion and contraction forces that can cause solder crack failure as a result of the wide temperature changes experienced. Rated at 630 VDC working voltage, the KCA series is available in 2,200, 4,700 or 10,000 pF capacitance values.

The company will also show the concept of wireless capacitive charging for mobile devices. So far methods of wireless power transmission, such as electromagnetic induction, magnetic resonance and radiowave are more popular. Murata's capacitive coupling wireless power transmission modules have two sets of asymmetric dipoles consisting of active and passive electrodes positioned vertically on the power transmitting and receiving sides. Power is transmitted utilizing an electric field generated by coupling the two sets of asymmetric dipoles. This configuration realizes wireless power transmission with high position freedom and efficiency. Voltage is converted during power transmission in capacitive coupling. The wireless power transmission (capacitive coupling) area is high-voltage (up to 2 kV) but small-current; therefore, there is no risk of heat generation.



Safety capacitors for automotive applications



Wireless power transmission via capacitive coupling

Osram Opto Semiconductors (**www.osram-os.com,** booth A5-260) announces the prototype of the Oslon Compact, a compact high-power LED for automotive applications. Thanks to the flexible arrangement of these small LEDs it will be much easier and more cost-effective to create unique, signature headlight designs. The extremely small size - combined with its high light output - enables a single LED type to be used as the default light source for all automotive forward lighting applications. The light points in the headlight can be placed in any arrangement, for example, and customized designs can be developed to give different vehicles a unique appearance. The LEDs can be grouped very close to one another so they can even be used for light guide solutions and adaptive frontlighting systems (AFS).

The latest Oslon Black Flat achieves a typical luminous flux of 200 lm (at 25°C). If operated at

1.2 A it can achieve up to 270 lumen - despite an application temperature of 100°C in the chip.

Thermal management is much simpler with this new LED. This is thanks to the greater thermal stability of the luminous flux even under "hot" application conditions and also to a new temperature-optimized packaging process. This has meant that the typical thermal resistance has been reduced to 4 K/W. The thermal coefficient of expansion of the black QFN package (Quad Flat No Leads) of the Oslon Black Flat LED is matched to the coefficient of expansion of the metal core board. All these properties make the Oslon Black Flat particularly stable and extremely durable

LED for automotive headlights

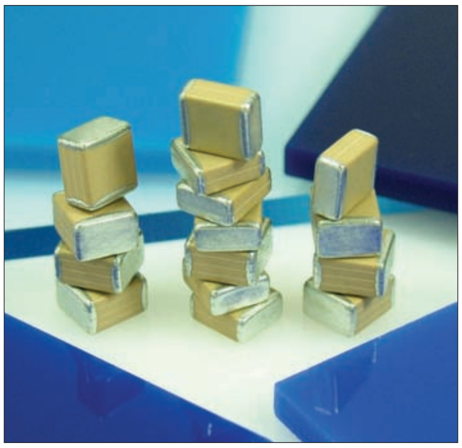
(more than 100,000 hours at 700 mA and a chip temperature of 60°C.

The Oslon Black Flat was developed in Regensburg and has been designed to function without a lens, its light can therefore be injected very close to light guides or lenses. Its luminance, in other words what the human eye perceives as the brightness of a particular surface, is 70 -100 Mcd/m_ (million candelas per square meter). "This is particularly important in automotive frontlighting solutions based on projection systems", said Peter Knittl, Director Automotive LED at Osram Opto Semiconductors. "The greater the luminance of the LED, the smaller the external lens and the smaller the space needed. Headlights can therefore be made much more compact."

ROHM Semiconductor (**www.rohm.com/eu,** booth A5-542) focuses on power management, optoelectronics and wireless low energy technology. In power semiconductors SiC (Silicon Carbide) Schottky barrier diodes (SBD) and MOSFETs are backed by the manufacturing capability of SiCrystal as part of the company. The combination of low loss and high voltage capability as well as fast recovery time makes these devices ideal for many applications, including PFC (power factor correction) circuits, converters and inverters as used in EV/HEV and industrial units. New high-voltage isolated SiC gate drivers facilitate low-power consumption and small designs. Together with SiC devices the new series guarantees a stable, high speed operation even in high power regions. In addition, a full SiC power module - the first in the industry integrating SiC MOSFETs and SBDs enables high frequency operation above 100 kHz - more than 10 times greater - and reduces loss during power conversion by 85% compared with conventional Si IGBT modules.

Additionally new 40V power MOSFETs for DC/DC converters enable ultra-low on-resistance with low gate capacitance.

UK-based Syfer Technology (**www.syfer.com,** booth B6-336) exhibits chip capacitors and EMI filters for the high voltage, high power sectors. Syfer has developed a patented technique to reduce electro-mechanical stresses in the body of the component, allowing for the consistent and reliable volume production of thicker and larger size devices. The first parts to become available in the StackiCap family will be 1812 and 2220 case sizes, with 200 V to 1 kV and 500 to 3 kV operating voltage ranges respectively. Syfer's 2220 500 V device features 1 µF capacitance in a single chip. The 3 kV part also features 33 nF capacitance previously found only in the much larger 5550 case size. Meanwhile, in the 1812 range, the 200 V part also features 1 µF



Syfer StackiCaps can be used up to 3 kV

capacitance, while the 1 kV device features 150 nF capacitance, previously only possible in larger size components. Also on show is Syfer's ProtectiCap process for Multilayer Chip Capacitors (MLCCs) designed to prevent flashover in high voltage applications. While minimising the risk of flashover in high voltage applications, the coating has also enabled an increase in the voltage capability of standard HV devices. Aimed at applications such as power supplies, lighting ballasts, inverters/DC link, and general high voltage circuits, the X7R dielectric ProtectiCap range of MLCCs offers a capacitance range from 220 pF to 33 nF. Alongside, for high current applications, such as IT servers, telecoms base stations, MRI room equipment, power supplies, radar and military vehicles, Syfer is showing its SL range of DC and AC feedthrough capacitors. Rated at 100 A and 200 A, the devices are suited for high power EMI filtering, with selected parts meeting the rigorous demands of EN132400 class Y2 and Y4 safety specifications. The filters are particularly targeted for use on mains supply systems or other voltage lines where safety is critical.

Vishay (**www.vihay.com,** booth A5-143) will introduce new and optimized semiconductor power packages and modules (PowerPAK(r) 8x8L MOSFETs) for improved thermal management, higher efficiency (high-power SMPC package) rectifiers, and increased high-voltage capabilities for 48 V boardnet, hybrid-, and fully electric vehicles. Optical isolators, drivers, controls, and sensors with dielectric strengths above 6 kV are being developed to address increased requirements of galvanic isolation coupled with signal speed enhancements. Increased demand for more accurate high-voltage and high-current sensing is being addressed by new sensor developments with improved accuracy, stability, and digital output. High-voltage and high-power resistive components, such as high-current (up to 1000 A) sense resistors, high-voltage (up to 30 kV) pre-charge and discharge resistors, ultra-precise and stable thin film resistors (0.1 %, 25 ppm) for sensor adaptations, and high-voltage dividers are being developed for electric and hybrid vehicles. DC-link film and electrolytic capacitors assembled to high volumetric efficiency, as well as magnetic components such as low-saturation high-current (up to 200 A) filter and storage inductors and compact planar transformers (up to 25 kW) are on the roadmap to address increased energy storage and conversion demands.

High-Power LED Driver with Multiple Dimming Control Modes

Texas Instruments' LM3463 is a six-channel LED driver with dynamic headroom control for high-power applications, which accurately and efficiently drives up to six strings of LEDs featuring multiple dimming control modes.

The LM3463 is a 12-V to 95-V wide input voltage, six-channel LED current controller. It drives up to 28 LEDs per string with dimming control that is managed by an external microcontroller via the dimming input pins. It works in conjunction with external N-channel MOSFETs and sense resistors to accurately and individually regulate current to each LED string. Dynamic headroom control improves system efficiency by automatically adjusting the LED supply to the lowest level required for LED current conduction. The variation of the output current of every output channel in the temperature range of -40°C to 125°C is well controlled to less than ±1%. The output current of every channel is accurately matched to each other with less than ±1% difference as well.

Individual current regulation

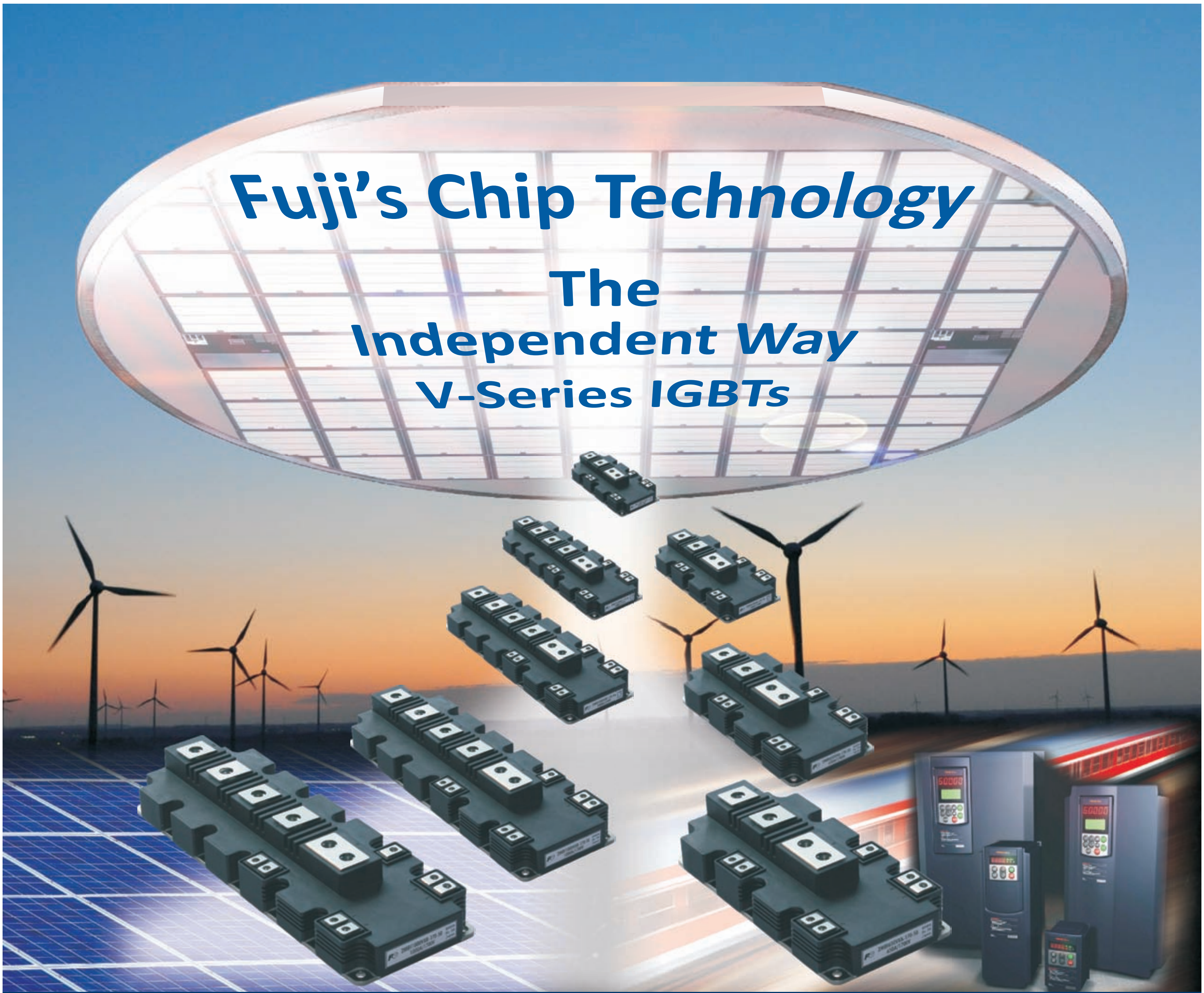
The LM3463 provides six individual linear current regulators to perform LED current regulation. Each current regulator includes an internal MOSFET driver and error amplifier and an external MOSFET and current sensing resistor. The output current of every output channel is defined by the value of an external current sensing resistor individually. The reference voltage of the regulators can be adjusted by changing the bias voltage at the IOUTADJ pin. When analog dimming control applies, the output current of all channels reduces proportional to the voltage being applied to the IOUTADJ pin.

If less than 6 output channels are needed, the unused output channel(s) of the LM3463 can be disabled by not installing the external MOSFET and current sensing resistor. The drain voltage sensing pin (DRn), gate driver output pin (GDn) and current sensing input pin (SEn) of a disabled channel must be left floating to secure proper operation.

RIGHT: LM3463 LED driver chip

The output channel(s) which has no external MOSFET and current sensing resistor installed is disabled and excluded from DHC loop at system startup while the V_{RAIL} reaches V_{DHC_READY}. A total of five output channels of the LM3463 can be disabled. The channel 0 must be in use regardless of the number of disabled channel. This feature also applies in cascade operation.

Since the driving current of a LED string is determined by the



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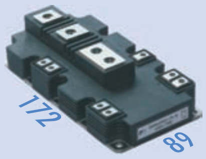
High Power Modules, 2-Pack & Chopper

	I_C	1200 V	1700 V
2-Pack	1000A		E P
	1400A	P	E P
Chopper	1000A		E
	1400A		E
Chopper	1000A		E
	1400A		E



	I_C	1200 V	1700 V
2-Pack	600A	E	
	650A		E
	900A	E P	
Chopper	650A		E
Chopper	650A		E

E : E-type (low switching losses) P : P-type (low $V_{CE,sat}$ & soft turn-off)

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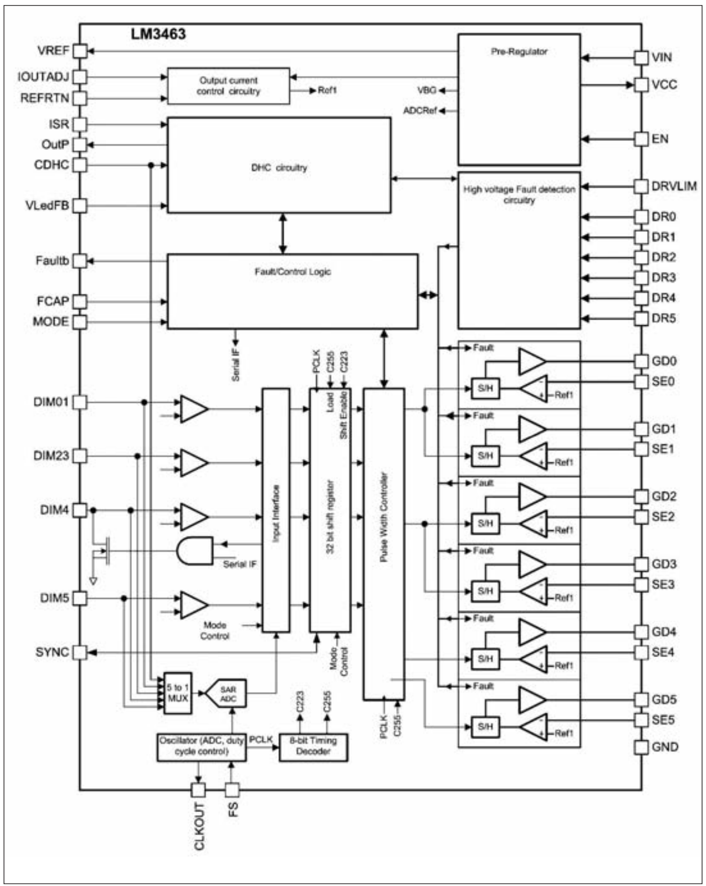


LEFT: LM3463 block diagram

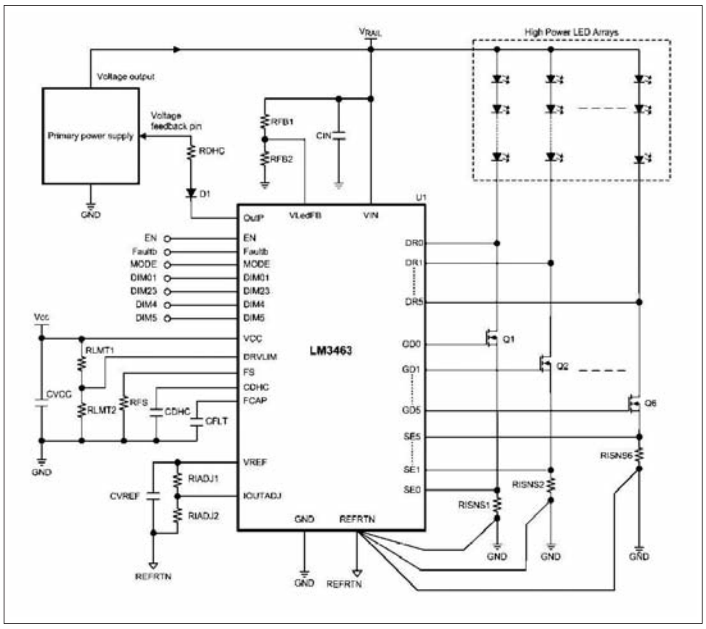
resistance of the current sensing resistor R_{ISNSn} individually, every channel can have different output current by using different value of R_{ISNSn}. Since the analog dimming control interface is designed for slow brightness control only, the rate of change of the voltage at the IOUTADJ pin must not be higher than 1.25 V/s to allow good tracking of the output current and changing of the VIOUTADJ.

Dynamic headroom control

The Dynamic Headroom Control (DHC) is a control method which aimed at minimizing the voltage drops on the linear regulators to optimize system efficiency. The DHC circuit controls the output voltage of the primary power supply (V_{RAIL}) until the voltage at any drain voltage sensing pin (V_{DRn}) equals 1 V. The LM3463 interacts with the primary power supply through the OutP pin in a slow manner which determined by the capacitor, C_{DHC}. Generally, the value of the C_{DHC} defines the frequency response of the LM3463.

The higher the capacitance of the C_{DHC}, the lower the frequency response of the DHC loop, and vice versa. Since the V_{RAIL} is controlled by the LM3463 via the DHC loop, the response of the driver stage must be set one decade lower than the generic response of the primary power supply to secure stable operation.

Practically, the frequency response of the primary power supply might not be easily identified (e.g. off-the-shelf AC/DC power supply). For the situations that the primary power supply has an unknown frequency response, it is suggested to use a 2.2 μF 10V X7R capacitor for C_{DHC} as an initial value and decrease its value to increase the response of the whole system as needed.



LM3463 typical application schematic

If the primary power supply is an off-the-shelf power converter, it is essential to make certain that the power converter is able to withstand the $V_{RAIL(peak)}$. In order to allow DHC, the nominal output voltage of the primary power supply needs to be adjusted to below $V_{LED-MIN-HOT}$ as well.

By interfacing the LM3463 to the output voltage feedback node of a switching power supply via the DHC interface, the system efficiency is optimized automatically. The dynamic headroom control minimizes power dissipation on the external MOSFETs by adjusting the output voltage of the primary switching power supply according to the changing forward voltage of the LEDs.

Comprising the advantages of linear and switching converters, the LM3463 delivers accurately regulated current to LEDs while maximizing the system efficiency. The dimming control interface of the LM3463 accepts both analog and PWM dimming control signals. The analog dimming

control input controls the current of all LEDs while the PWM control inputs control the dimming duty of output channels individually.

Dimming control

Due to the V-I characteristic of the LED, the forward voltage of the LED strings decreases when the forward current is decreased. In order to compensate the rising of the voltage drop on the linear regulators when performing analog dimming control (due to the reduction of LED forward voltages), the DHC circuit reduces the rail voltage (V_{RAIL}) to maintain minimum voltage headroom (i.e. minimum V_{DRn}).

In order to ensure good response of analog dimming control, the VRAIL is maintained at a constant level to provide sufficient voltage headroom when the output currents are adjusted to a very low level. When the voltage at the IOUTADJ pin is decreased from certain level to below 0.63 V, the DHC circuit stops to react to the changing of V_{DRn} and maintains the V_{RAIL} at the level while $V_{IOUTADJ}$ equals 0.63 V. DHC resumes when the $V_{IOUTADJ}$ is increased to above 0.63 V.

The LM3463 provides also three modes of PWM dimming control: Direct PWM dimming mode, Serial interface mode and DC interface mode. Selection of the mode of dimming mode is made by leaving the MODE pin open or connecting the MODE pin to GND or V_{CC}. Regardless of the selection of the mode of PWM dimming control, the output channels 0 and 1 are controlled commonly by the signal at the DIM01 pin and the output channels 2 and 3 are controlled commonly by the PWM signal at the DIM23 pin. The dimming duty of the channel 4 and 5 are controlled by the signals on DIM4 and DIM5 pins respectively.

The DIM01, DIM23, DIM4 and DIM5 pins are pulled down by an internal 2 MΩ weak pull-downs to prevent the pins from floating. Thus the dimming control input pins are default to 'LED OFF' state and need external pulled up resistors when the pins are connected to open collector/drain signal sources.

System startup

When the LM3463 is powered, the internal Operational Transconductance Amplifier (OTA) charges the capacitor CDHC through the CDHC pin. As the voltage at the CDHC pin increases, the voltage at the OutP pin starts to reduce from V_{CC}. When the voltage of the OutP pin falls below V_{FB} +0.7 V, the OutP pin sinks current from the VFB node and eventually pulls up the output voltage of the primary power supply (V_{RAIL}). As the V_{RAIL} reaches V_{DHC_READY}, the LM3463 performs a test to identify the status of the LED strings (short /open circuit of LED strings).

After the test is completed, the LM3463 turns on the LED strings with regulated output currents. At the moment that the LM3463 turns the LEDs on, the OutP pin stops sinking current from the V_{FB} node and in turn V_{RAIL} slews down. Along with the decreasing of V_{RAIL}, the voltage at the VDRn pins falls to approach 1 V. When a V_{DRn} is decreased to 1 V, the DHC loop enters a steady state to maintain the lowest V_{DRn} to 1 V average at a slow manner defined by C_{DHC}.

The system startup time can be shortened by sinking current from the ISR pin to ground through a resistor, R_{ISR}. The lower the resistance, the shorter time the system startup takes. Sinking current from the ISR pin increases the charging current to the capacitor C_{DHC} and eventually increases the rate of the increasing of V_{RAIL} during startup (V_{RAIL} ramps up from V_{RAIL}(nom) to V_{DHC_READY}).

Generally, the system startup time is the longest when the ISR pin is left open. The amount of the decreasing of the startup time is inversely proportional to the current being drawn from the ISR pin, thus determined by the value of the resistor R_{ISR}.

Selection of external MOSFET

The selection of external MOSFET is dependent on the highest current and the highest voltage that could be applied to the drain terminal of the MOSFET. Generally, the Drain-to-Source breakdown voltage (V_{DSS}) and the continuous drain current (I_D) of the external MOSFET must be higher than the defined peak supply rail voltage ($V_{RAIL(peak)}$) and the maximum output LED current (I_{OUTn}) respectively.

In order to protect the MOSFETs from thermal breakdown when a short circuit of the LED sting(s) is encountered, the LM3463 reduces the output current according to the increment of the drain voltage of the MOSFET (V_{DRn}) when the drain voltage exceeds a certain preset threshold voltage to

limit the power dissipation on the MOSFETs. This threshold voltage is defined by the voltage being applied to the D_{RVLIM} pin VDRVLIM and is roughly four times the voltage of the V_{DRVLIM}. For example, if the desired drain threshold voltage to perform output current reduction is 16 V, the DRVLIM pin voltage should be biased to 4 V.

Finally, the LM3463 provides a sophisticated protection mechanism that secures high reliability and stability of the lighting system. The protection features include V_{IN} Under-Voltage-Lock-Out (UVLO), thermal shut-down, LED short / open circuit protection and MOSFET drain voltage limiting. The LED short circuit protection protects both the LED and MOSFETS by limiting the power dissipation on the MOSFETs.

www.ti.com/lm3463-pr-eu, www.ti.com/ww/de/contact.html

LED Driver for Automotive RGB Ambient Lighting

Infineon's LINLED new driver family for automotive applications makes it possible to implement attractive multicolor ambient lighting based on RGB (Red-Green-Blue) blending to produce a broad range of interior colors with predefined color points. The integrated LIN transceiver reduces wiring requirements from 4 to 3 wires, while pre-programmed control of blending and dimming means no additional software development is necessary by the system manufacturer.

Infineon's LINLED new driver family for automotive multicolor ambient lighting

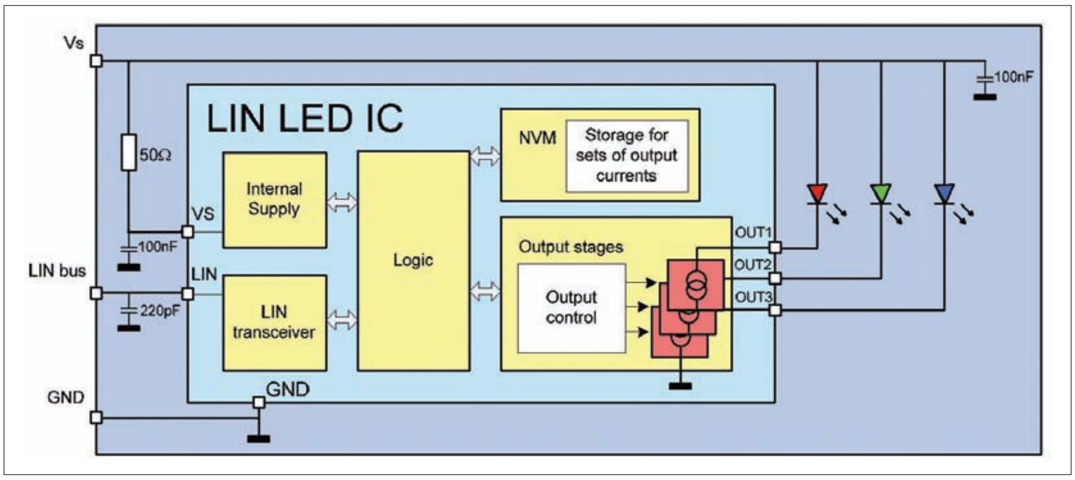
The TLD73xxEK LINLED driver family includes four different members. They vary by output current (up to 48 mA, up to 2 A) and LIN compliance according to the LIN 2.1 and SAE J2602 standards. Each family member combines logic, memory, LIN interface and a three channel linear current source or three external driver stages in one device. To achieve predefined color points for multiple RGB modules, the integrated memory stores calibration points for up to 16 colors. Typically PWM is used to mix the colors, which can cause flickering light output, due to low PWM frequencies. The Infineon TLD73xxEK LINLED driver family uses a proprietary solution for color mixing which allows flicker-free light output as the LEDs are driven with a high frequency signal.

For low current LEDs the devices TLD7305EK and TLD7306EK are used. They offer three integrated low side currents sources driving currents up to 48 mA. For high current LEDs the devices TLD7395EK and TLD7396EK are used. They operate as driver circuit for three external high current bipolar NPN transistors for LED currents up to 2 A. Configuration, diagnosis and programming are done via the LIN-interface.

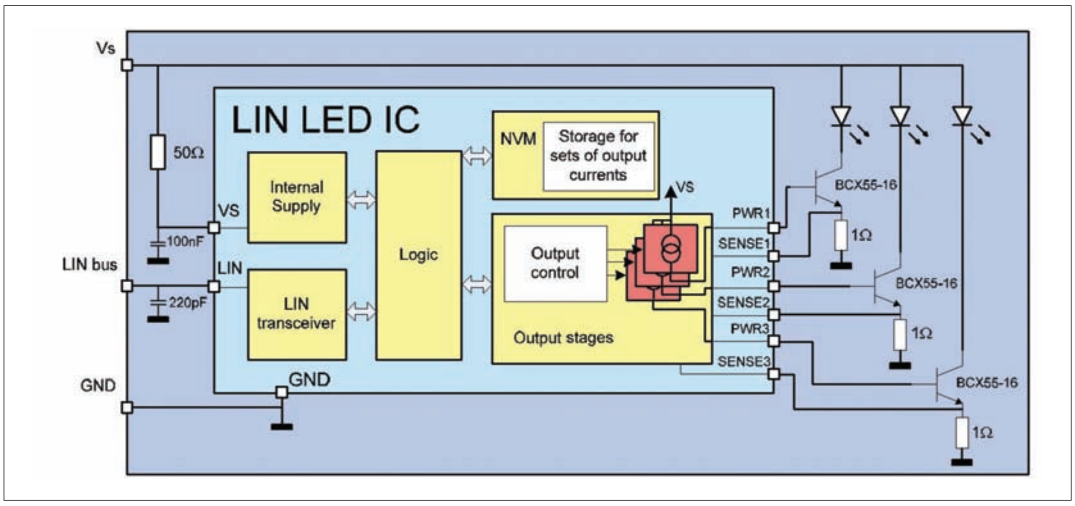
The average output current of each channel can be controlled by an 8-bit intensity setting. Sixteen different sets of intensity settings (i.e. 16 triplets of intensities or average output currents) can be stored in an on-chip non-volatile memory (NVM). This is especially useful, when driving a Red-Green-Blue (RGB) LED, where each triplet of intensities represents one color. In addition to these sets of average output currents, the intensities can be dimmed down in 14 steps. The IC offers an integrated intensity generation unit, which supports theater dimming with dim-times up to multiple seconds. Dimming is done in an exponential way to realize a linear perception by the human eye. Furthermore, the device offers smooth color transitionings. Dimming and color transitions require just a single LIN-frame to activate it. The dimming and color changing is done automatically by the device.

Application with integrated power stages

In the application diagram for the devices with integrated power stages the LED is connected to the supply line. The cathodes are connected to the output pins of



Application with integrated power stages



Application with external bipolar power transistors

the LIN LED IC. The assignment of an LED color (red, green or blue) is not fixed to a particular output. Any output can control any color LED. The effective mixed color is defined by the intensity of each LED color. An intensity register or a register in the NVM sets each output intensity and therefore effective mixed color.

The LIN LED IC has a supply pin (VS), which should be connected to the supply via an RC-filter as shown. Only the IC's operational current flows through the VS-pin. Therefore, the 50 _ resistor can be a low power resistor. The supply pin is connected to the device internal supply, which allows extended operation down to 6 V. A reverse polarity protection diode is required, if there is no central reverse polarity protection circuit.

The LIN-pin is connected to the LIN-bus. A filtering capacitor is recommended. The LIN LED's LIN-transceiver and protocol handler supports LIN2.1 and SAE J2602 standard (depending on the product). The LIN LED IC contains an application specific message decoder. It decodes messages from the LIN-master and provides commands for configuration, control, and diagnosis of the IC via the LIN-interface.

The logic block includes a state machine, which realizes the LIN protocol handler and command decoder, the intensity generation unit, the control of the outputs, diagnosis and fault handling functions. The output stages are implemented as low side constant current sources. The output current can be configured via two bits in the NVM (setting is valid for all three channels). Currents of 12, 24, 36 or 48mA can be selected.

For the devices with external power stages most of the blocks are comparable to TLD7305Ek and TLD7396EK. The main difference is that the LEDs are driven via external NPN-transistors so that higher currents can be driven. This could be useful for higher power LEDs for the dome light or exterior lights controlled via LIN.

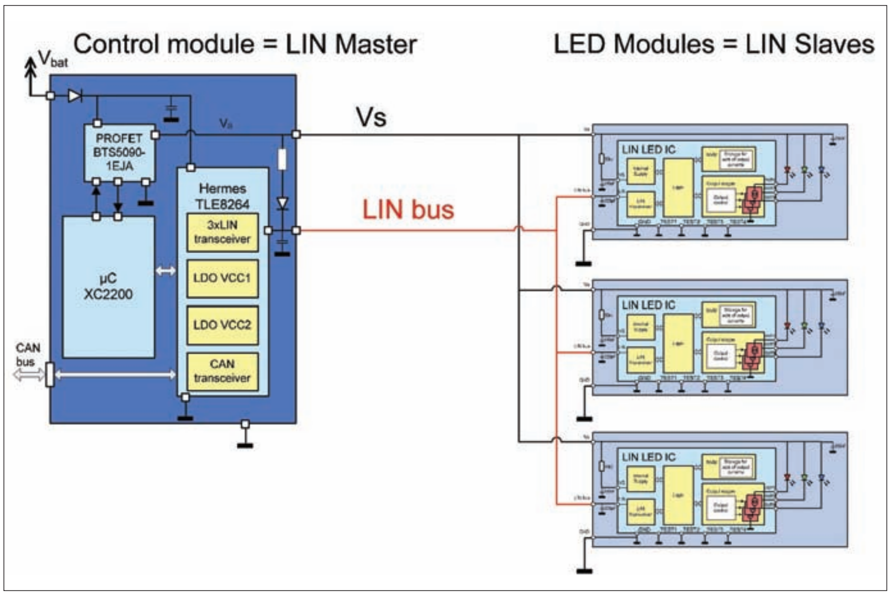
LIN basics

The LIN (Local Interconnect Network) bus is a master-slave network and single wire bus system. The data is transmitted via a single data line between one LIN-master and multiple LIN-slave devices (up to 16). All LIN-slaves are connected in parallel to the LIN-bus, which reduces the wiring effort to a minimum. The LIN-bus uses the supply voltage as reference voltage.

An example is shown for a simple LIN architecture with one master device and three RGB LIN LED modules, which are the slaves. The network can be extended easily by connecting additional modules on with the two wires Vs and LIN. The existing network does not need to be changed. More details can be found under the link below.

www.infineon.com/linled

RIGHT: LIN architecture with one master device and three LINLED slaves



3D-GaN Technology for GaN-on-Silicon

Today, the technical and electrical advantages of the AlGaN/GaN devices are understood and deployed successfully in RF applications. To make these devices commercially successful for high voltage applications, new aspects need to be considered. These aspects of technical, topological and product strategic nature are discussed and solutions are presented in this article. **Dr. Ertugrul Sönmez, Dr. Ulrich Heinle, Dr. Ingo Daumiller, and Dr. Mike Kunze, MicroGaN, Ulm, Germany**

The combination of low static and dynamic losses are provided by the AlGaN/GaN material system, which exhibits high conductivity through its highly mobile 2D-electron gas and makes small devices possible due to its high critical electrical field strength. The resulting lateral normally-on device (HEMT) features for a given R_{DSon} a so low input and output capacitance compared to its Silicon counter parts that the loss mechanisms in the application is dominated by the chosen RDSon. The absence of tail and stored minority charges leads to a switching energy dominated by dielectric charging-discharging losses, which are in the first order neither operation current nor temperature dependent and therefore for today's common switching frequencies negligible. These conditions simply lead to the well known fact that the AlGaN/GaN transistor gives technically a huge freedom in increasing the switching speed and frequency for passive component size and system volume reduction purposes.

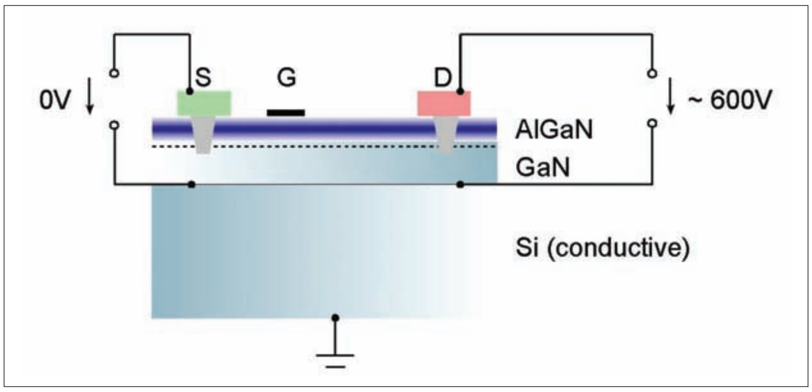


Figure 1: Typical epitaxial structure of GaN-on-Silicon substrates and potential nodes

Commercialization aspects of GaN-on-Silicon

The recent electrical efficiency trend pushes the power electronics market for higher performance at no additional cost. Therefore, to address this market the AlGaN/GaN-devices need to be provided at competitive cost, which leads to the decision to use standard large diameter Si wafers as a substrate.

This decision comes with the constrain that the required GaN epitaxy is mechanically more strained compared to competing substantially more expensive substrates like Sapphire or Silicon Carbide. On the one hand the utilization of large diameter substrates is a prerequisite to keep the process cost low. On the other hand the mechanical strain of large diameter GaN-on-Silicon is the main challenge for the commercialization process. Generally speaking, the lattice mismatch between GaN and Si cause crystallographic defects, which are partly electrically active. On Si wafers the isolating GaN layer thickness is defining the maximum application voltage of the devices processed on such wafers. Figure 1 shows a GaN-on-Silicon HEMT structure and the typical potential distribution schematically. Here, the source electrode potential is provided to the backside of the device substrate.

Compared to the conductivity of the nominally isolating GaN buffer layer, the silicon substrate and its interface to the GaN buffer layer can be assumed to be conductive providing an equipotential plain. Applying the maximum application voltage at the drain electrode leads to the condition that the GaN layer alone will accommodate this voltage vertically. Thus, an increase in the demanded application voltage requires an increase of the buffer layer thickness which in turn contributes to the mechanical stress in the GaN epi-layer deteriorating material quality, homogeneity and device yield. Consequently, it is a demanding engineering task to cope with this mechanical strain for large area wafers.

From MicroGaN's perspective, today 4-inch GaN-on-Silicon wafers with the appropriate epi layer thickness are available, which make 600 V devices feasible. The material quality improvement in 6-inch GaN-on-Silicon is closely monitored and it is a matter of homogeneity progress in the epi quality and thereby a matter of yield improvement to switch to 6-inch utilization. In order to enable commercialization with a smaller wafer diameter, MicroGaN developed a new technological approach, which cuts die size for given performance into half, at least.

3D-GaN technology

The goal was to develop an area efficient device technology with an interconnect technology for surface based lateral devices for high current and high voltage application, minimize parasitics and provide flexibility in device design. The contact electrode areas have been relocated above the active region, keeping the typical low complex technology of GaN-based lateral devices and providing the following advantages at the same time:

- Standard packaging equipment compatible interface,
- minimal die area for given R_{DSon},
- therefore, minimized dynamic parasitics for given R_{DSon},
- improved yield by reduced die size and
- lowest parasitic interconnect for full function block per die by integration.

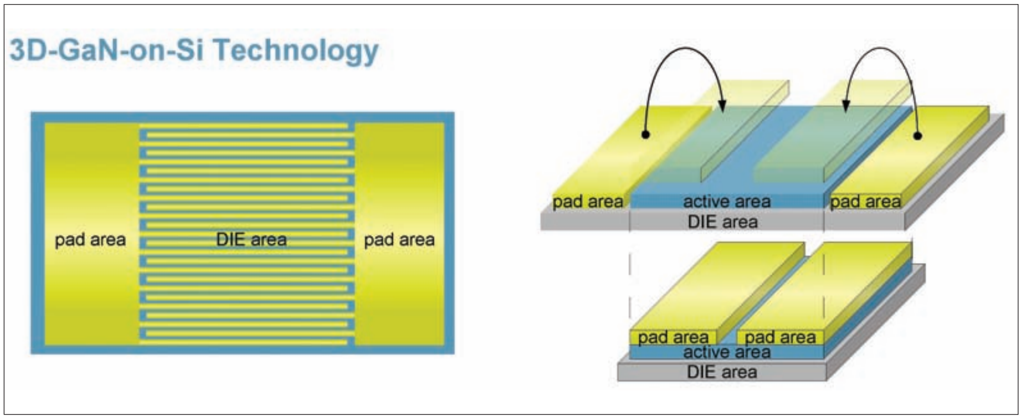


Figure 2: **3D-GaN technology topology**

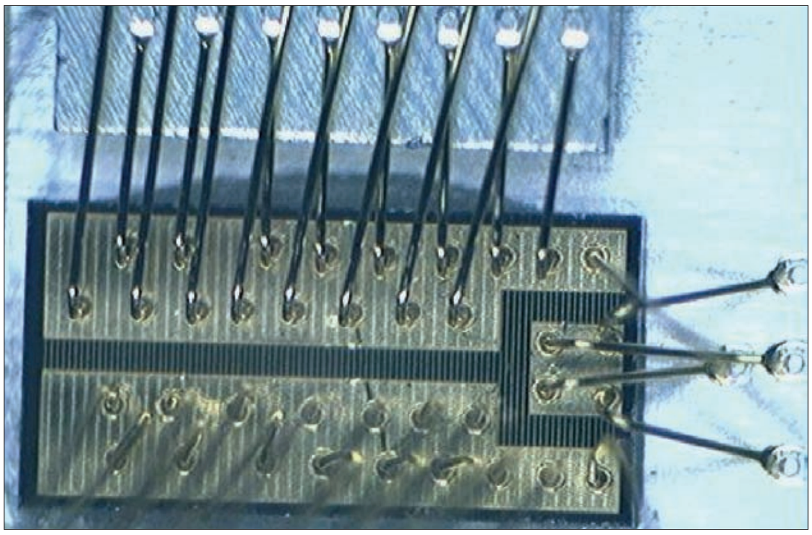


Figure 3: **Standard packaging technology compatible pad areas**

The schematic topology of a single device applying the 3D-GaN technology is shown in Figure 2 and the wire bonding technique compatible switch, on which multiple wire bonds have been applied for low inductive interconnect purposes, is shown in Figure 3, respectively.

To keep this technology flexible, it has been developed and realized modularly. To carry this flexibility to the application and thereby to the customer level, a proprietary simulation tool has been derived to predict and adjust the technology parameters for a required electrical performance. Also from the opposite direction, device topological parameters dictated from processing point of view can be tracked back to the device's electrical performance using the same tool.

Family of function blocks

The static and dynamic operational GaN normally-on switches combined with low voltage Si devices provide all required function blocks to set up an efficient high voltage solution. As a result of such a mini module, i.e cascode or cascade, normally-off switch and high voltage diode operation are available.

The normally-on operation of the devices made on AlGaN/GaN system is the natural one providing the best possible area efficiency and basically promising the fastest improvement in maturity level. All deviations from the normally-on operation at device level requires additional technology development action, which has not been prioritized at MicroGaN at the first step. The fully operable normally-on switch is depicted in Figure 4.

The 170 mΩ normally-on switch with C_{iss} = 38pF, C_{rss} = 8pF and C_{oss} = 90pF is combined with low voltage Si-MOSFET to a normally-off switch in terms of cascode configuration. This new normally-off switch has now again a very low C_{oss} of 42pF (@100V) with a resulting R_{DSon} of 250 mΩ. Using a low voltage Si diode in reverse polarization instead of the Si-MOSFET in same circuit configuration is ending up in diode operation with a voltage barrier defined by the Si diode and a differential resistance dominated by the high voltage GaN switch. The resulting diode capacitance is again defined by the GaN switch resulting in 43pF (@100V).

Attention should be payed that the low voltage Si devices are only operated at the GaN switch gate control voltage level and therefore transferring a very low amount of charge, representing the lost energy per cycle. The GaN normally-on switch is providing the high voltage isolation capability and is properly connected to its controlling Si low voltage device.

This article is derived from a paper given at PEE's Special PCIM 2012 Session [1].

Literature

[1] "Efficient Power Electronics for the price of Silicon - 3D-GaN Technology for GaN-on-Silicon", PEE Special Session "High Frequency Switching Devices and Technologies for Green Applications", PCIM 2012, Nuremberg.

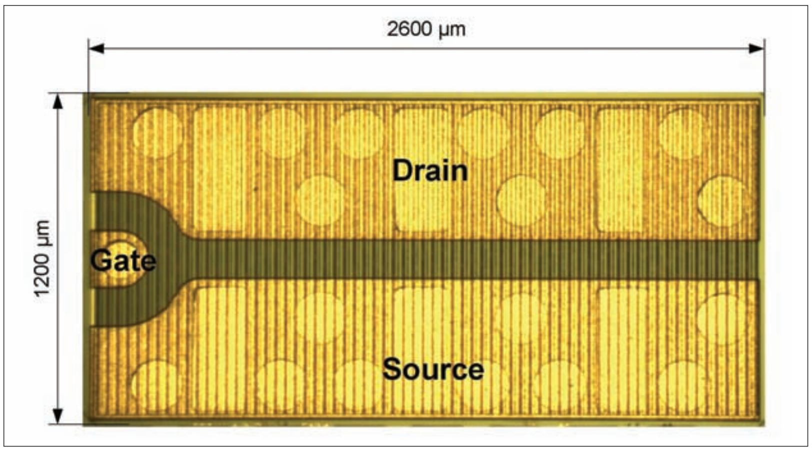


Figure 4: **600 V / 170 mΩ normally-on switch (full device area ~570 mΩmm²)**

Current Handling Capability of 600 V GaN High Electron Mobility Transistors

The development of thick, crack-free Gallium Nitride (GaN) epitaxy on standard thickness Silicon (Si) substrates, together with device fabrication in high volume silicon CMOS factories, has opened the potential for highly cost competitive, high voltage GaN devices. The simultaneous combination of advantages in efficiency, power density and cost over silicon based devices presents a compelling competitive advantage, which should help to drive rapid and widespread adoption of GaN devices throughout the power electronics industry including automotive and industrial applications. **Michael A Briere, Tim McDonald, International Rectifier; Han S. Lee, Delphi Automotive Systems; and Laura Marlino, Oak Ridge National Laboratory, USA**

The revolutionary performance capabilities of Gallium-Nitride (GaN) based power devices compared to the incumbent Silicon based alternatives has been frequently demonstrated in a variety of power electronic applications where such GaN based High Electron Mobility Transistors (HEMTs) provide remarkably improved performance for essentially any power conversion circuit in terms of power density and efficiency.

There have, however, been several members of the power electronics community who have suggested that, due to the lateral near surface nature of the GaN based power HEMTs (Figure 1), there is an inherent current handling limitation to less than 10 A for these devices. Whereas it has been previously shown that low voltage GaN-on-Si based HEMTs can process more than 150 A, even with a drain-source potential drop of 40 V [1], such current handling capability has not yet been shown for more recently developed 600 V rated devices. In this article, we present the measured current handling capability of such 600 V rated GaN-on-Si based HEMTs. Further, these results are for normally-off switches using the well established and robust cascode configuration [2], with a low voltage Si device in series with the GaN based HEMT, and with the Si device source tied to the GaN device gate. These output characteristics represent the expected initial configuration that will be used in several power electronic applications in the near future.

Research on high current capability

One impetus for higher current and voltage (power) handling power semiconductor devices is the requirements for electrification of transportation vehicles, which involves the main traction drive motor inverter, as well as auxiliary power conversion for steering, air conditioning and other passenger comfort functions.

As in other industrial motor drive applications, the main traction inverter for hybrid and electric vehicles requires significant power density, while processing as much as 200 kW of power, or even greater. For the present power bus voltage of about 450 V, this can require up to 500 A of current. Inverters for this task currently utilize IGBTs, which have a rated current density of 150 A/cm^2 with maximum current handling capabilities of some 300 A/cm^2. It is expected that any alternative power semiconductor technology, suggested for use in these applications, should provide at least the same current handling capability as the incumbent silicon based devices.

In an effort to investigate the potential for GaN based devices for such higher-powered motor drive applications, a program was sponsored by the U.S. Department of Energy under the Advanced Research Projects Agency for Energy (ARPA-E) with Delphi Automotive Systems,

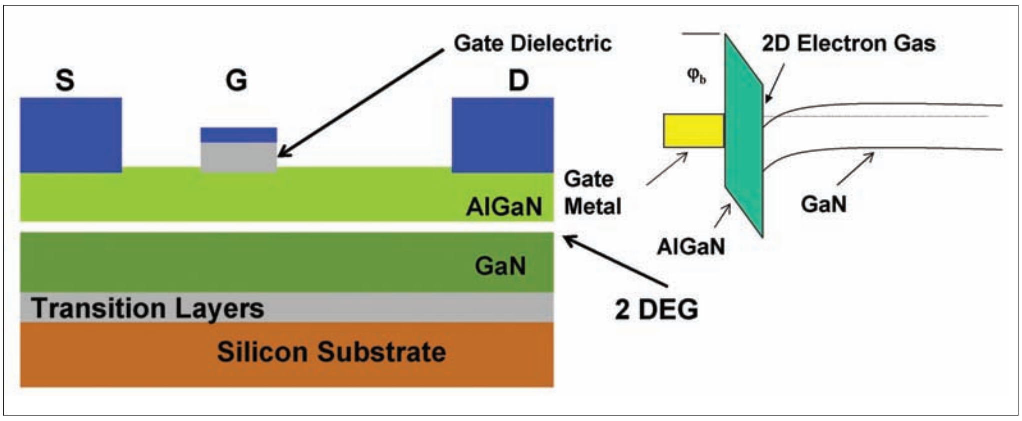


Figure 1: Schematic of a depletion mode (normally on) GaN-on-Silicon FET. 2D Electron gas spontaneously forms between AlGaN and GaN

International Rectifier (IR) and Oak Ridge National Laboratory participating. In addition to the use of IR's GaNpowIR® 600 V rated devices, the program investigated the use of a scalable two-sided cooled, sintered (wire-bondless), surface mount dual-side cooled power device package from Delphi [3]. In as much as both the package and the device layout are scalable, the early results of this study are also expected to scale to device sizes at least 5 to 10 times larger.

Figure 2 shows the 600 V GaN-on-Si based HEMT cascoded with a low-voltage

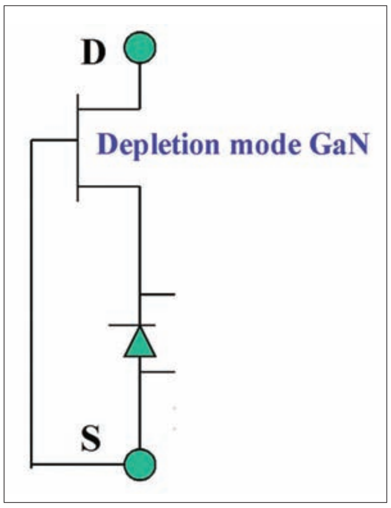


Figure 2: HV GaN switch cascoded with a Silicon FET

Silicon FET and Figure 3 the measured output characteristics of this device in a Delphi dual-side cooled power device package at room temperature. As can be seen, this device, with an active area of 8 mm_ and a gate width of 300 mm, shows well behaved current handling capability to nearly 80 A. The resulting current handling density of nearly 1000 A/cm² is well in excess of that achieved by state-of-the-art 600 V rated trench IGBTs. It can also be seen in the figure that a gate drive of at least +15 V is supported by the cascode switch design, demonstrating the advantage of the cascode switch design over an enhancement-mode GaN gate structure.

However, as can be seen in Figure 4, the current handling capability is severely degraded at 150°C, as expected for a FET and unlike the behavior for IGBTs where the saturated current capability are not adversely effected by increasing device temperature. The resulting current density per active area of the GaN based HEMT at 150°C is still a respectable 625 A/cm². The unipolar device also has the advantage that it does not exhibit the large forward knee voltage associated with the bipolar IGBT, which is very deleterious in

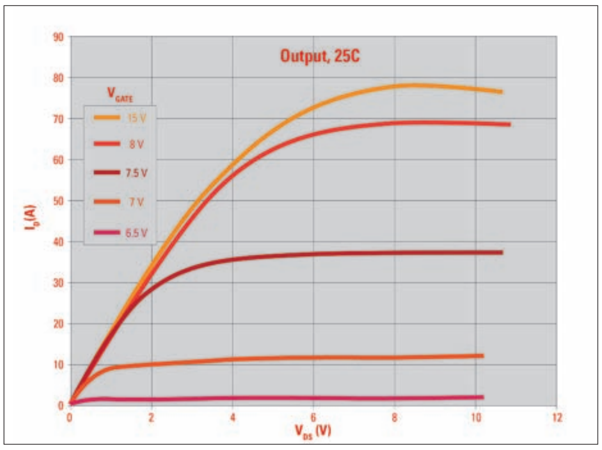


Figure 3: Measured output characteristics of a cascoded 600 V rated GaN-on-Si based HEMT with an active area of 8 mm² and a gate width of 300 mm in a dual sided cooled package at room temperature

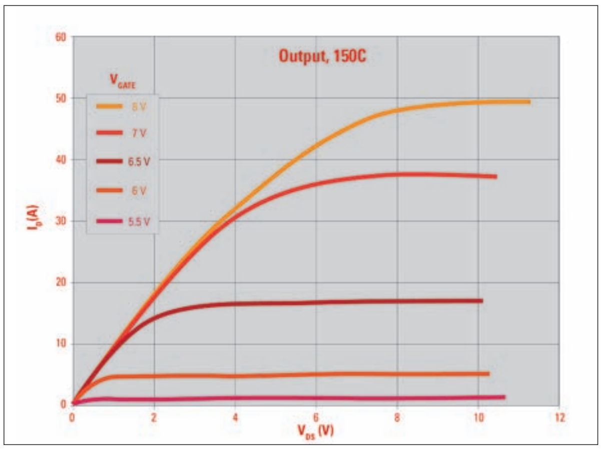


Figure 4: Measured output characteristics of the 600 V rated GaN-on-Si based HEMT in a dual sided cooled package at 150°C

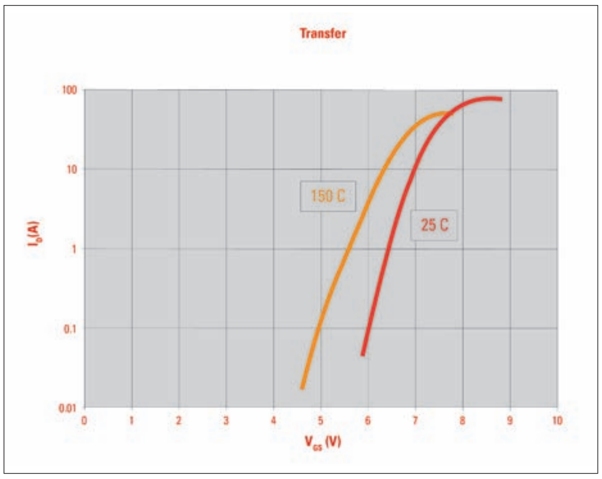


Figure 5: Measured transfer characteristics of the 600 V rated GaN-on-Si based HEMT in a dual sided cooled package at room temperature and 150°C

applications at light load conditions. As such, the improved working current density of approximately 200 A/cm_ can be achieved for the GaNpowIR HEMTs with enhanced application performance, allowing the simultaneous achievement of greater power density and efficiency.

Figure 5 shows well behaved normally-off transfer characteristics at both room temperature and 150°C, with near full channel enhancement at a gate voltage of +9 V. The stable threshold voltage of more than +4 V at 150°C provides for a high level of noise immunity, further demonstrating the advantage of the cascode switch design over a discrete enhancement mode GaN gate structure.

The consistency of the measured on-state resistance as a function of drain-to-source current is shown in Figure 6, for both room temperature and 150°C operation. As expected, there is approximately a factor of 2 in the measured on-resistance over this temperature range, due primarily to the decrease in the mobility of the electrons in the two-dimensional electron gas of the GaN based HEMT.

Cooling down

It is important to note that the ability to practically extract the current carrying capability of lateral GaN based HEMTs depends on the proper application of modern packaging technology. While a

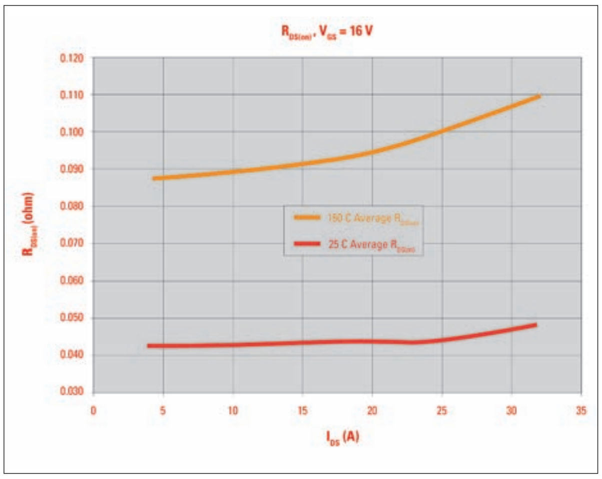


Figure 6: Measured on-state resistance as a function of drain to source current for the 600 V rated GaN-on-Si based HEMT in a dual sided cooled package at room temperature and 150°C

flipped GaN device, as described previously [4], using solderable front metal to attach the device to the external circuit elements without wirebonds, allows for the scaling of the semiconductor, it must be properly paired with a packaging technology that can effectively transfer this current to the application circuit, if chip scale packaging is undesirable. Another advantage of the flipped, direct-mount device construction is that much of the heat generated in the conduction region of the GaN device is removed very effectively through the top surface of the device, negating the often touted deficiency of Silicon substrates for poor heat conduction compared to, for instance, Silicon Carbide (SiC).

In this way, highly efficient higher power devices can be constructed using the combination of GaN-on-Si semiconductors with flip chip, direct surface mount packaging technologies. It is expected that considerable efforts will be expended over the coming several years to further demonstrate and leverage the inherently high current handling capability of efficient, unipolar GaN-on-Si based power HEMTs in many power electronic applications where higher power density and higher efficiency are needed at a commercially viable cost.

This material is based upon work supported by the Department of Energy ARPA-E under Award Number DE-AR0000016, resulting from the collaborative development efforts of Delphi Automotive Systems, LLC; International Rectifier; and Oak Ridge National Laboratory.

Literature

[1] Electronics in Motion and Conversion, November 2010 pp. 20-24

[2] Power Electronics Technology, July 2012 pp. 19-21

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High-Efficiency Multiphase DC/DC Converters

The electricity consumption of data centers worldwide has become an important issue in recent years as demands for Internet services grow significantly. The need to reduce the power dissipation will be a major focus for the next several years. Designers of POL DC/DC converters for almost any kind of system face many challenges due to the multiple constraints of limited space and cooling within a given enclosure, as well as the need for high efficiency throughout the entire load range. Despite having to navigate through this myriad of constraints, many of the recently introduced multiphase regulators provide a simple, compact and efficient solution. By moving toward the diverse multiphase topologies, designers can effectively save space, simplify layout, lower capacitor ripple current, improve reliability and reduce the amount of power wasted as heat. **Bruce Haug, Senior Product Marketing Engineer, Power Products, Linear Technology Corp., USA**

Data centers fill rooms, floors or even entire buildings that house computer, storage and networking equipment. The aggregate electricity used for data centers doubled worldwide from 70 billion kWh/yr in 2000 to 140 billion kWh/yr in 2005, and continues to grow at an average of 16.7 % per year, with the Asia Pacific region (without Japan) being the only major world region with growth significantly exceeding that average [1].

The computers used in data centers, commonly called servers, are similar to PC architectures, with a CPU, ASICs, FPGAs and memory. However, unlike PCs, servers in data centers are packed together as densely as possible and use substantial amounts of electricity, producing heat, which must then be dissipated. Power is delivered to these servers via uninterruptible power systems (UPS), typically followed by a distributed power system and then step-down DC/DC converters for point-of-load (POL) powering. These power delivery methods are not 100 % efficient and produce copious amounts of heat as well. This heat must be carefully and continuously managed to keep the systems running within their specified operating temperature ranges. Regardless of the type and efficiency of the cooling system, heat must be removed from the data center in some way. To do so requires additional energy to operate the cooling infrastructure.

Efficient power conversion required

The data centers' incremental overhead power consumption, due to inefficiencies and cooling systems is estimated to be equal to the amount of power that is consumed by servers, storage and networking. The user of a single PC, workstation, or laptop doesn't see system heat generation as a concern, but for data centers, managing this thermal overhead is as important as the servers themselves. If system power is reduced, then the available overhead can handle a greater IT load and perform more useful work in the same power envelope.

As the data center power demand continues to increase, higher efficiency power conversion is required to reduce the amount of power wasted as heat. Smart multiphase controller technology is an excellent solution for high current POL applications. This architecture allows a high current regulator to achieve well over 90 percent efficiency at full load. However, most designs do not address the need for higher efficiency at light to medium loads. Wasted power at a light to medium load is just as important to save as wasted power at heavy loads.

Most embedded systems are powered via a 48 V backplane. This voltage is normally stepped down to a lower intermediate bus voltage of 24 V, 12 V or 5 V to power the racks of boards within the system. However, most of the sub-circuits or ICs on these boards are required to operate at voltages ranging from sub-1 V to 3.3 V at currents ranging from tens of milliamps to hundreds of amps. As a result, point-of-load DC/DC converters are necessary to step down from either of the 24 V, 12 V or 5 V voltage rails to the desired voltage and current level required by the sub-circuits or ICs.

It is clear that the growing demand for increased current at ever decreasing voltages is driving power-supply development. Much of the progress in this area can be traced to gains made in power conversion technology, particularly improvements in power ICs and power semiconductors. In general, these components contribute to enhancing power supply performance by permitting increased switching frequencies with minimal impact on power-conversion efficiency. This is made possible by reducing switching and on-state losses thereby increasing efficiency while allowing for the efficient removal of heat. However, the migration to lower output voltages places more pressure on these factors, which in turn, creates significant design challenges.

Multiphase topology

Multiphase operation is a general term for conversion topologies where a single input is processed by two or more converters, where the converters are run synchronously with each other but in different, locked phases. This approach reduces the input ripple current, the output ripple voltage and the overall RFI (radio frequency interference) signature, while allowing high current single outputs, or multiple lower current outputs with fully regulated output voltages. It also allows smaller external components to be used, producing a higher efficiency converter and also providing the added benefit of improved thermal management with less cooling.

Multiphase topologies can be configured as step-down (buck), step-up (boost) and even as a forward converter, although

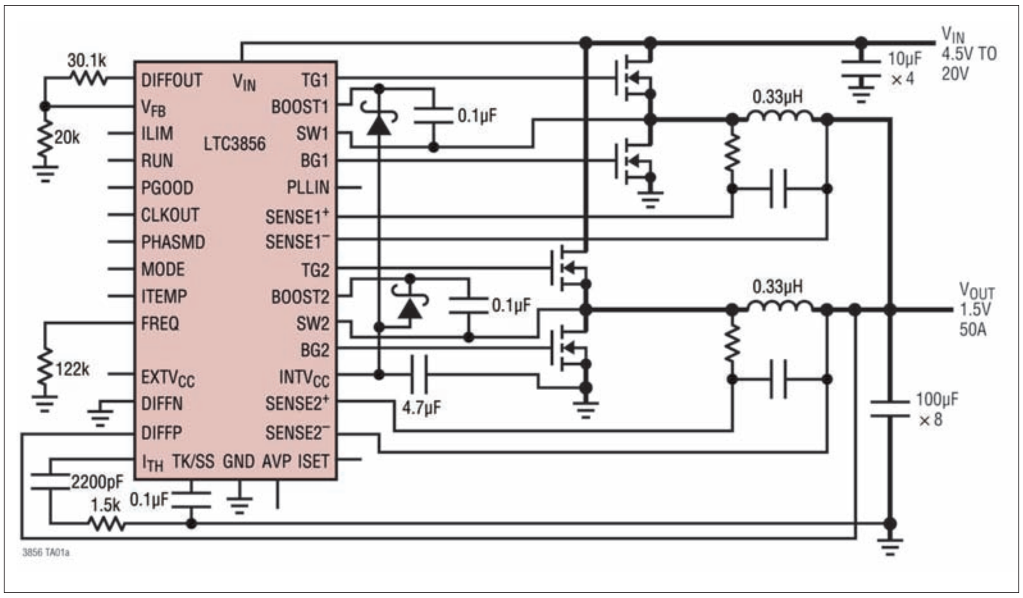


Figure 1: High output current 1.5 V/50 A application schematic

generally the buck regulator is the more prevalent application. Conversion efficiencies of up to 95 % from 12 V in to 1.xV out are commonplace today.

At higher power levels, scalable multiphase controllers reduce the size and cost of capacitors and inductors using input and output ripple current cancellation caused by interleaving the clock signals of several paralleled power stages. Multiphase converters help minimize the external component count and simplify the complete power supply design by integrating PWM (pulse width modulation) current mode controllers, true remote sensing, selectable phasing control, inherent current sharing capability, high current MOSFET drivers plus over-voltage and over-current protection features. The resulting manufacturing simplicity not only helps improve power supply reliability, but it is also scalable. Such systems can be expanded up to 12 phases for high current outputs as high as 300 A.

Linear Technology has several multiphase DC/DC controllers, including the LTC3856 and LTC3829 single output synchronous step-down controllers for high current POL conversion. Not only can these parts increase full load efficiency, but they also have an optional Stage Shedding(tm) feature that decreases light to medium load power loss as well. The circuit in Figure 1 shows a typical LTC3856 application schematic for developing a 1.5 V/50 A output from a 4.5 V to 14 V input voltage using two phases.

The circuit in Figure 2 shows a typical LTC3829 application schematic for developing a 1.2 V/75 A output from a 6 V to 28 V input voltage with three phases.

The LTC3856 has two channels and up to 12 phases possible with multiple ICs. The LTC3829 has three channels and can operate at up to 6 phases when used with two ICs. The onboard differential amplifier provides true remote output voltage sensing of both the positive and negative terminals, enabling high accuracy regulation independent of IR losses in trace runs, vias and interconnects.

These controllers operate with all N-channel MOSFETs from input voltages ranging from 4.5 V to 38 V, and can produce ± 0.75 % accurate output voltages from 0.6 V to 5 V. The output current is sensed, monitoring the voltage drop across the output inductor (DCR) for highest efficiency or by using a sense resistor. Programmable DCR temperature compensation maintains an accurate over-current limit set point over a broad temperature range. The onboard gate drivers minimize MOSFET switching losses and allow the use of multiple MOSFETs connected in parallel. A fixed operating frequency can be programmed from 250 kHz to 770 kHz or synchronized to an external clock with its internal PLL. A minimum on time of 90 ns makes the LTC3729 and LTC3856 suited for high step-down ratio/high frequency applications.

Stage shedding operation

At light loads, switching-related power losses normally dominate the total loss of a switching regulator. Eliminating the gate charge and switching losses of one or more of the output stages during a light load will significantly increase efficiency.

Stage Shedding allows one or more phases to be shut down to reduce switching related losses during a light load condition and is typically used when the load current is reduced to less than 15 A. The overall efficiency can be increased by

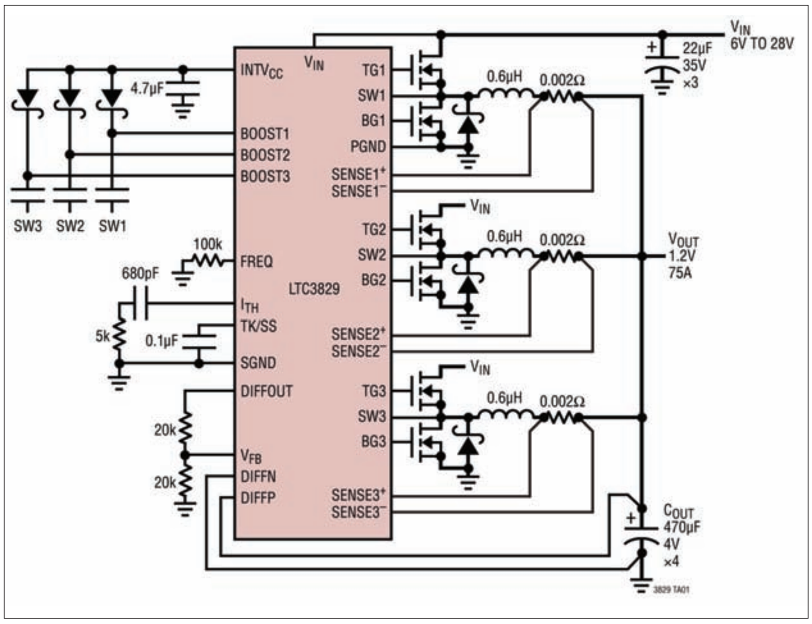


Figure 2: High output current 1.2 V/75 A application schematic

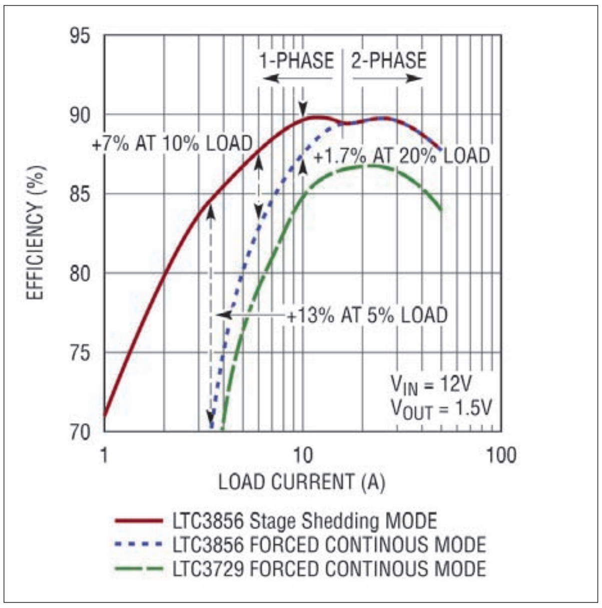


Figure 3: LTC3856 efficiency curve with Stage Shedding phase vs. an older controller

up to 13 %, as shown in Figure 3. This figure also shows the efficiency of an older comparable LTC3729 2-phase controller. Due to the stronger gate drive and shorter dead time, the LTC3856 can achieve 3-4 % greater efficiency than the LTC3729 over the whole load range.

Stage Shedding operation is triggered when the onboard feedback error amplifier output voltage reaches a user-programmable voltage. At this programmed voltage, the controller shuts down one or more of its phases and stops the power MOSFETs from switching on and off. This ability to program when Stage Shedding takes place provides the flexibility to determine when to enter this mode of operation. The diagrams in Figure 4 show the SW waveform and how the LTC3829 goes into and out of Stage Shedding operation.

The LTC3856 and LTC3829 can operate in any of three modes: Burst Mode(r) operation, forced continuous or Stage Shedding mode, all of which are user selectable. At heavy loads of greater than 15 A, these devices operate in constant frequency PWM mode. At very light loads, Burst Mode operation can be selected and produces the highest efficiency at load currents of less than 0.5 A. Burst Mode operation switches in pulse trains of one to several cycles, with the output capacitors supplying energy during internal sleep periods.

Active voltage positioning

The LTC3856 and LTC3829 also have Active Voltage Positioning (AVP), which reduces the maximum voltage deviation during a step load and reduces the power dissipation at heavier loads further increasing its efficiency. Figure 5 shows the difference in behavior between the circuit in Figure 1 with and without AVP. Without AVP, the maximum voltage deviation for a 25 A step load is 108 mV. With AVP, the maximum voltage deviation is 54 mV for the same 25 A step load. In addition, the output voltage drops by 54 mV with AVP when the output current goes from 25 A to 50 A, resulting in a lower 2.7 W dissipation by the load.

Literature

[1] "Worldwide electricity used in data centers," by Jonathan Koomey, Lawrence Berkeley National Laboratory, 2008

Figure 4: LTC3829 Stage Shedding phase waveforms - going into Stage Shedding (left) and coming out of Stage Shedding (right)

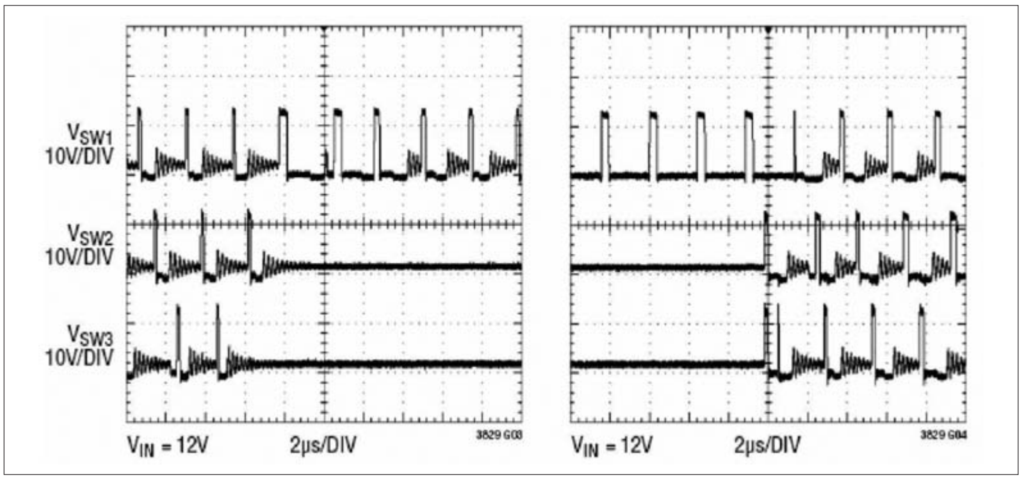
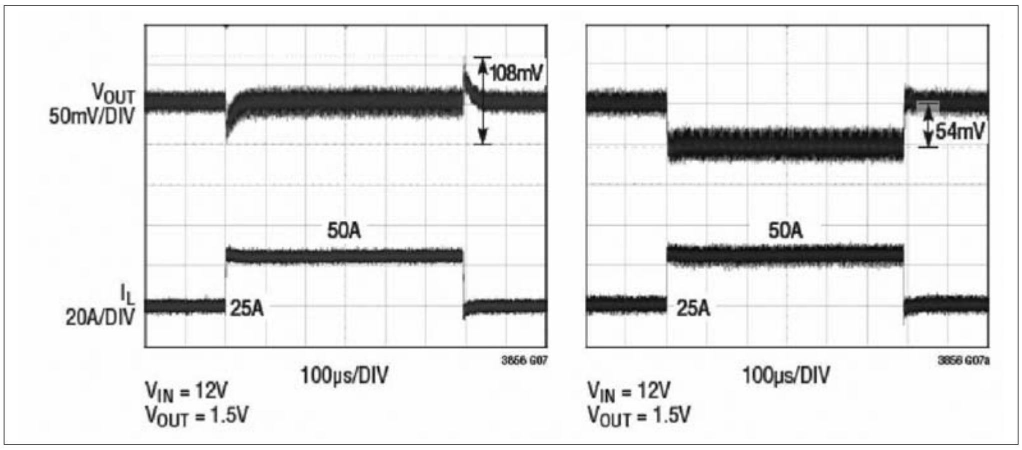


Figure 5: Load step characteristics without Active Voltage Positioning (left) and with Active Voltage Positioning (right)



Sugar-Coated Power Cycling Lifetime

Power cycling is an important method to characterize the lifetime of power semiconductor modules. Application engineers use lifetime curves published by manufacturers to verify that their system design meets the required reliability. An important condition for the lifetime of a module under repeated temperature swings is the control strategy applied during the test. Power cycling tests with identical start condition but different control strategies have been performed, which have been conducted on specially assembled test equipment with ultimate control of all test parameters. The results show, that different control strategies deliver lifetime results that vary by a factor of 3. **Stefan Schuler, Development Engineer and Dr. Uwe Scheuermann, Department Manager Product Reliability, SEMIKRON, Nuremberg, Germany**

In the early days of power cycling testing the temperature swing was considered as the only parameter relevant for the test result. The very comprehensive investigation conducted during the LESIT project [1] in the middle of the 1990s revealed that also the medium temperature of the temperature swing has a significant impact on the number of cycles to failure.

A recent publication [2] confirmed this result and extends the list of parameters with an impact on the test result by four additional factors: the on-state time of the load impulse, the bond wire diameter, the current density in a bond contact and even the chip blocking rating, which reflects the variation in chip thickness with the blocking voltage in state-of-the-art IGBT designs.

The discussion so far only addressed the set of start parameters, which are relevant for a power cycling test; the numbers of cycles to failure are conventionally related to this set of initial parameters. In an experimental power cycling test, however, these initial parameters are not constant throughout the test. Degradation effects can cause a change of these parameters and an important feature of the power cycling test is the control strategy, i.e. the strategy how to react on parameter changes during the test.

Control strategy in PC tests

Since a power cycling test simulates the stress incorporated in a power module under highly accelerated test conditions, wear-out and degradation effects must be expected.

Solder fatigue phenomena increase the thermal resistance of the device and thus increase the junction temperature under constant test conditions. The positive temperature coefficient of modern IGBT devices will consequently lead to increased losses, which again will increase the device temperature. This positive feedback loop can significantly accelerate the failure process.

The mechanical and thermal stress implied on wire bond interconnections can result in an increasing resistance of the contact and can alter the current distribution in the devices (Figure 1). This degradation process, which can lead to a total breakdown of individual wire bonds, can be detected in the monitored forward voltage drop by instantaneous stepwise increase. Therefore, the control strategy is a very important feature of the power cycling test. Four different control strategies will be compared in the experimental investigation:

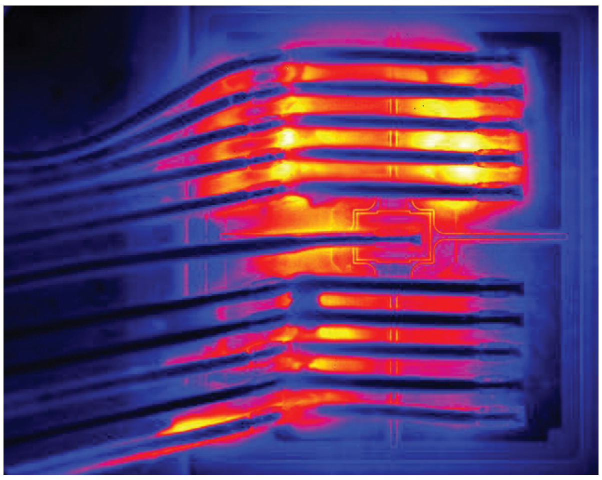


Figure 1: Infrared image of an aged IGBT with inhomogeneous surface temperature

1) t_{on} and t_{off}=const.

The strategy of constant timing switches the load current on and off in fixed time intervals. A degradation of the module will have an immediate impact on the resulting temperature swing with no compensation by a control strategy. This is the most severe test strategy.

2) ΔT_c=const.

This control method uses a reference thermocouple to turn on and off the load current according to fixed case temperatures. The on-time and off-time is not fixed, but is determined by the time constants for heating and cooling the device. This is the preferred test method, since a change of the cooling liquid temperature would be compensated by adjusting the heating and cooling times. However, also a potential degradation of the thermal interface between the case of the module and the heat sink surface would be compensated by this control strategy. It is therefore less severe than the constant timing strategy.

3) P_V=const.

The third control method is based on constant t_{on} and t_{off} times with the additional requirement, that the power losses are kept constant. This requirement is achieved by controlling the gate voltage. At test start, the gate voltage is reduced, so that an increase of the forward voltage drop due to degradation can be compensated by enhancing the gate voltage. This control strategy is much less severe for a power module, because it significantly reduces the acceleration effects by positive feedback loop described above.

4) ΔT_j=const.

As a pendant to the most severe test with no compensation at all, the junction temperature swing control totally compensates for any degradation. This can be accounted for by adjusting the load current, by controlling the timing or by regulating the gate voltage.

Experimental PC test equipment

Experimental test equipment has been constructed for power cycling a single chip in an open housing without silicone gel. The chip temperature can be directly monitored by a pyrometer (2.5 mm spot size).

The module is mounted on a 18°C liquid cooled copper heat sink with an attached thermocouple to measure the base plate temperature. The test equipment is controlled by a Linux PC. It records the gate voltage V_G, the collector emitter voltage V_{CE}, the collector current I_C, the pyrometer temperature T_j and the case temperature T_c with a sample rate of 66.7 ms.

The gate voltage can be adjusted via a digital analog controller 15 times a second by software and thus allows a control of the gate voltage during the power cycles. The desired value is calculated as a feed forward control with a low pass filter to eliminate gate voltage overshoot.

An adjustable fast switching constant current source (250 A/12 V) is used to supply the load current. It is controlled by the software as well, so that the equipment is not limited to square shaped current pulses, but can run freely defined current waveforms and even customer specific temperature profiles.

All test parameters must be carefully adjusted to ensure identical start conditions. Since the individual test sample each have a slightly different thermal resistance $R_{th(j\text{-}c)}$ and V_{CE} values, the gate voltage V_{GE} control was applied to adjust them as close as possible (Figure 2).

After a stabilization sequence, an automated procedure starts with the measurement of the thermal resistance $R_{th(j\text{-}c)}$. Then all other parameters were evaluated on a statistical basis during the next 100 power cycles. Based on these results, the initial parameters were adjusted to generate a temperature swing ΔT_j=125°C at a medium temperature T_m=87.5°C. The constant DC current was fixed at I_C=85 A for all tests with the 9.1 x 7.7 mm² generation 4 IGBT from Infineon.

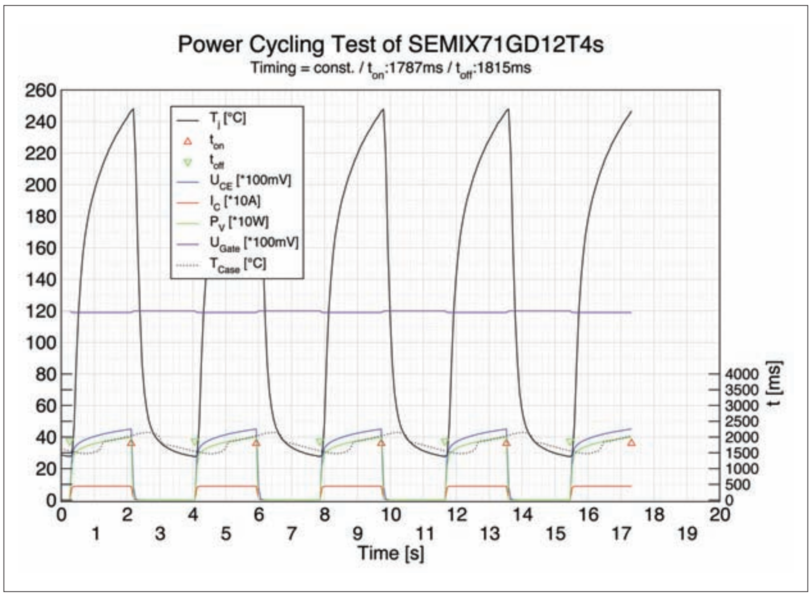


Figure 3: PC parameters for t_{on}/t_{off}=const.

Experimental results

After the initial adjustment procedure, the four previously described control strategies were applied to four different test samples. The differences in evolution of parameters are presented here for the situation after 31,000 power cycles, when degradation effects have already caused a change of the initial conditions.

1) t_{on}=const. and t_{off}=const.

The control strategy of constant timing leads to an increase of the temperature swing during the test. After 31,000 cycles, the end-of-life is almost reached and the maximum junction temperature has well exceeded 240°C. The dissipated power has increased by 23 % from the initial value (Figure 3).

2) ΔT_c=const.

This control strategy maintains constant maximum and minimum case temperature limits and adjusts the ton and toff times accordingly. These limits were selected to 27.10°C and 33.77°C in the initial adjustment procedure. The power dissipation has increased by 8.9 % due to degradation. The total cycle time (t_{on}+t_{off}) has decreased by 6.9 % and the maximum junction temperature has just exceeded 175°C after 31,000 cycles (Figure 4).

3) P_V=const.

The third control method of constant timing with the additional requirement of

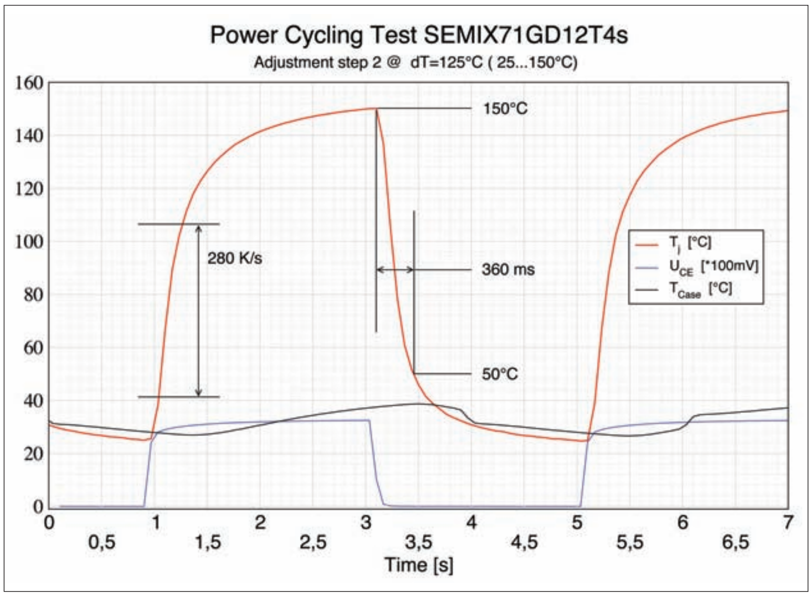


Figure 2: Initial adjustment of parameters for the PC test

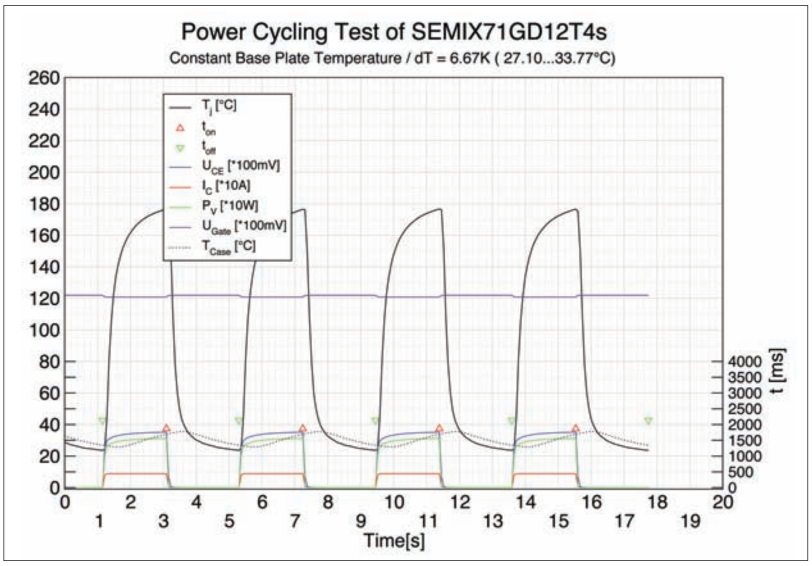


Figure 4: **PC parameters for Δt_c=const.**

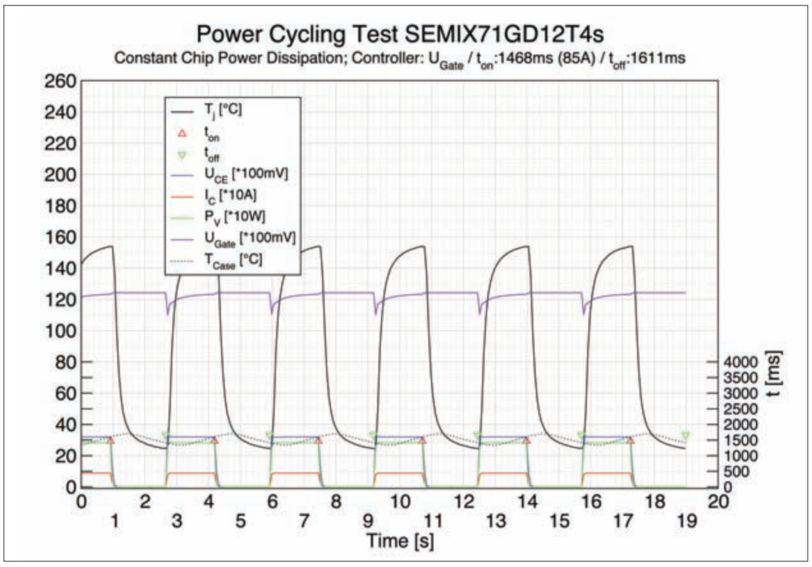


Figure 5: **PC parameters for P_V=const.**

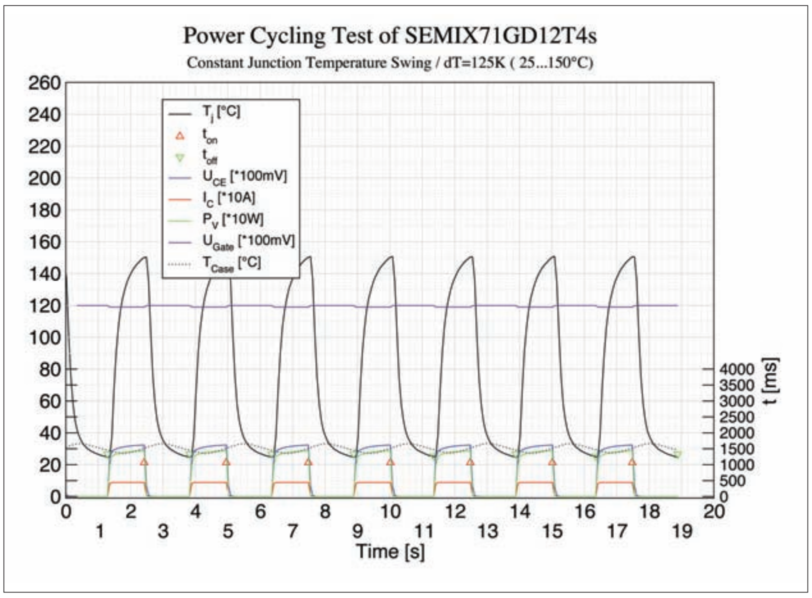


Figure 6: **PC parameters for ΔT_j=const.**

constant power losses shows only little deviation from the initial starting conditions. The maximum junction temperature reaches only 155°C after 31,000 cycles, which is equivalent of a 3 % increase in temperature swing. The control of the gate voltage can be seen clearly in Figure 5, starting with a low value right after turn on and is then increased as the temperature rises in each cycle. The control of the gate voltage leads to almost square shaped power loss profiles during the cycles. The maximum gate voltage at the end of each cycle was adjusted to 12.06 V in the initial phase and has increased to 12.5 V after 31,000 cycles. The increase continued and reached 14.53 V at the end-of-life.

4) ΔT_j=const.

Finally, the control strategy that maintains a constant junction temperature swing, indicates no change in temperature swing after 31,000 cycles (Figure 6). The reduction of on-time, however, is significant to a value of 42 % of the initial adjustment value, showing that severe degeneration effects are to be compensated. Due to this ongoing compensation, the lifetime can be dramatically increased. In the final phase of this test, ton will be reduced to even 11.8 % of the initial value.

End-of-life results

Figure 7 shows the evolution of the maximum junction temperature versus the number of cycles during the power cycling test in comparison for all four control strategies. The curves also show the numbers of cycles to failure.

For the constant timing, the end-of-life was reached after 32,073 cycles, when the junction temperature approached 360°C and the emitter metallization melted and failed.

In case of constant base temperature swing, the final failure was observed after 47,485 cycles, when the maximum junction temperature exceeded 340°C. Again, the metallization of the emitter failed.

With the third one, the constant power losses, a lifetime of 69,423 cycles was determined. In this case, the maximum junction temperature never exceeded 178°C and the failure was caused by the lift-off of all wire bonds, while the emitter metallization remained intact.

Last, the constant junction temperature swing recorded a lifetime of 97,171 cycles. Obviously, the control loop limits the maximum junction temperature effectively to values below 160°C until the end-of-life is almost reached. Then, the temperature control procedure fails to function when

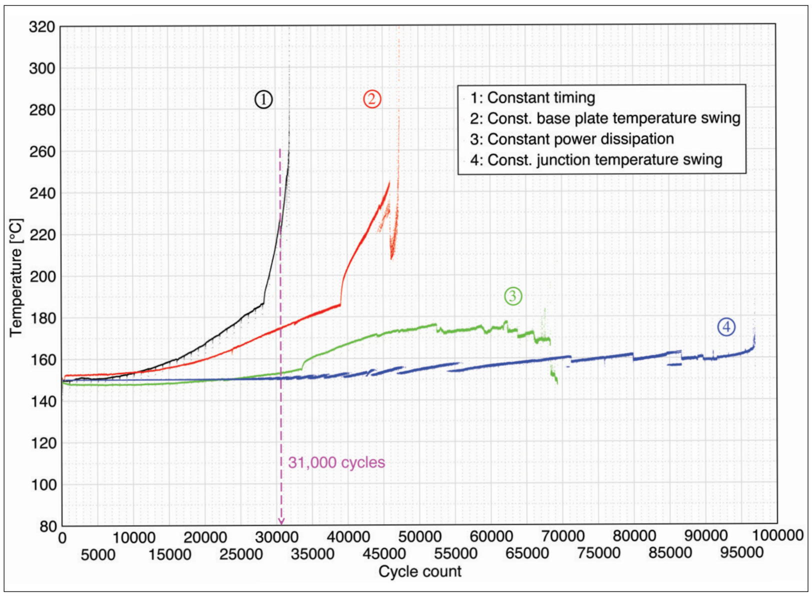


Figure 7: Comparison of maximum junction temperature evolution for all four different control strategies

the on-time is approaching the control interval. The minimum value for the on-time just before the final failure was t_{on}=0.42 s.

Reliability estimation

As seen, lifetime is determined strongly by the chosen control strategy [3]. Therefore, the answer for the right strategy also needs to consider the practical usage. From this application point of view, only the first two control strategies are relevant to estimate the reliability in real applications. Here, the constant base plate temperature swing control (ΔT_c=const.) is the preferred method. It is immune to changes in the cooling condition and also eliminates degradation effects in the thermal grease interface to the heat sink. The last two strategies are not suited for field life estimation, because they reduce the stress during the lifetime to compensate for ageing effects.

Application engineers, who are using power cycling curves to estimate the lifetime of a module in their application, should consult the manufacturer. Why? For information on the applied control strategy, to generate non-sugar-coated lifetime curves.

Literature

[1] M.Held, P.Jacob, G.Nicoletti, P.Scacco, M.H.Poech, Fast Power Cycling Test for IGBT Modules in Traction Application, Proc. Power Electronics and Drive Systems 1997, 425-430.

[2] R.Bayerer, T.Herrmann, T.Licht, J.Lutz, M.Feller: Model for Power Cycling Lifetime of IGBT Modules - various factors influencing lifetime, Proc. CIPS 2008, pp. 37-42.

[3] S.Schuler, U.Scheuermann: Impact of Test Control Strategy on Power Cycling Lifetime, Proc. PCIM 2010

MOSFETs and Schottky Diodes for Wireless Power Transfer

Among Toshiba's new devices is a MOSFET suited to load switching in a wireless charging transmitter circuit. The 30V SSM6N55NU is a dual -channel MOSFET in a UDFN6 package measuring 2.0 mm x 2.0 mm x 0.75 mm. A drain current of just 4 A and a maximum on-resistance of 46 mΩ ensure high-efficiency operation. Toshiba's single and dual Schottky Barrier Diodes (SBDs) are rated for reverse voltages of 30 V and feature very low forward voltage ratings down to 0.45 V. Packaging options range from USC (SOD-323) with dimensions of 2.5 mm x 1.25 mm x 0.9 mm to CST2B options that measure 1.2 mm x 0.8 mm x 0.6 mm. Applications for the new MOSFETs and diodes include load switching, low-voltage rectification, bridge circuits and reverse current protection.

www.toshiba-components.com

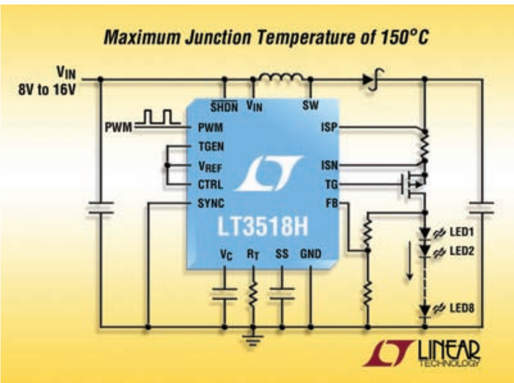
1200 V NPT IGBTs

Microsemi announced three more devices in its new generation of 1200 V non-punch through (NPT) IGBTs: the APT85GR120B2, APT85GR120L and APT85GR120J transistors. The devices can be packaged with Microsemi's FREDs or Silicon Carbide Schottky diodes and are designed for high power, high performance switch mode products such as arc welders, solar inverters, and uninterruptible and switch mode power supplies. The APT85GR120B2 transistor is offered in a TO-247 MAX package, the APT85GR120L is packaged in a TO-264 and the APT85GR120J is packaged in a SOT-227. Microsemi's new NPT IGBTs are fully characterized and in production now. The company will soon offer an APT85GR120JD60 device that is packaged in a SOT-227 and includes a 60A anti-parallel, ultrafast recovery diode built with proprietary "DQ" generation of low switching loss, avalanche energy rated diode technology.

sales.support@microsemi.com, www.microsemi.com

Buck-Boost LED Driver

Linear Technology announces the H-grade version of the LT3518 a 45V, high-side current sense DC/DC converter designed to drive high current LEDs at constant current. Its 3 V to 30 V input voltage range with transient protection to 40 V makes the LT3518 suited for a wide variety of applications, including automotive, industrial and architectural lighting. The H-grade version operates with a junction temperature up to 150°C. They are intended for automotive and industrial applications, which are subjected to high ambient temperatures. The LT3518 can drive up to eight 300 mA white LEDs from a nominal 12 V input, making it well suited for applications such as automotive display backlighting. The LT3518 senses output current at the high side of the LED, enabling buck, buck-boost or boost configurations. It can deliver efficiencies up to 90% in boost mode from a 4mm x 4mm QFN package.



www.linear.com/product/LT3518

25 W LED Driver ICs

iWatt has launched its iW3616 (12 W) and iW3617 (25 W) LED driver ICs based on the third-generation digital AC/DC SSL (solid state lighting) LED driver platform. The drivers are designed for 120 V/230 VAC offline LED lighting bulbs and fixtures. So-called Flickerless technology features an intelligent dimmer interface with digital dimming algorithms to automatically detect and then adapt to the dimmer type, resulting in smooth, flicker-free dimming. Achieving power factor >0.95, low total harmonic distortion (THD) < 15%, and efficiency of > 85%, the new drivers exceed global energy and LED lighting standard requirements, including the European Union IEC61000-3-2, NEMA SSL 6 dimming and Zhaga hot-plug interchangeability standards.

www.iwatt.com/PR082812.php

High Lumen Power LEDs

Lumileds has launched with the Luxeon Z the smallest high-power LED package. The un-encapsulated LEDs can be used to create specialized 2x2, 3x2, 6x1 and other mono- or multi-color arrays. Available in a full color spectrum from 440-670 nanometers including white, virtually limitless configurations are possible, and with the ability to mount as many as 250 LEDs in one square inch, new levels in lumen densities can be reached. The new Luxeon Z LEDs are available from Future Lighting Solutions.

www.futurelightingsolutions.com

Alpha and Omega Semiconductor Enters the IGBT Market

AOS's patent pending AlphaIGBT technology combines a unique cell and vertical device structure to offer saturation voltage of 1.6 V versus switching loss of 0.11 mJ at 15 A trade-off and longer short-circuit capability. As a result, AlphaIGBT enables a wide operation frequency range to address a variety of applications such as white goods (air conditioners, refrigerators, washing machines), industrial equipment (general inverters, servo motors, sewing machines, welding machines, uninterruptible power supplies), as well as commercial type heating and solar inverters. Combined with the 5.6 V VGE(TH), a feature that can be used as an advantage to extend the use of unipolar (0-15 V) gate drives saving the expense and complexity of bipolar (-15/15 V) gate drives. The positive temperature coefficient of VCE(SAT) and low overall gate charge characteristics of AlphaIGBT technology allow designers to easily parallel more devices and, or larger devices with existing drive circuits. The 600 V 5 A, 10 A and 15 A parts are available in production quantities with a lead-time of 12 weeks.

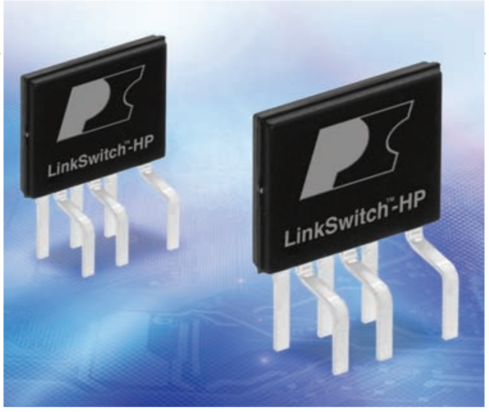
www.aosmd.com

60V Battery Charging Controller & Power Manager

Linear Technology Corporation introduces the LTC4000-1, a controller and power manager with input maximum power point control (MPPC) that converts virtually any externally compensated DC/DC power supply into a full-featured battery charger. The LTC4000-1 is capable of driving typical DC/DC converter topologies, including buck, boost, buck-boost, SEPIC, flyback and forward. The device offers precision input current monitoring and charge current monitoring and regulation. It operates across a wide 3 V to 60 V input and output voltage range, compatible with a variety of different input voltage sources, battery stacks and chemistries. The LTC4000-1's MPPC circuit features an input voltage regulation loop that controls charge current to maintain the input voltage at a programmed level, ideal for solar panels or other high impedance sources. Applications include: high power battery charger systems, high performance portable instruments, battery backup systems, and industrial or military battery-equipped devices. The LTC4000-1 features an intelligent PowerPath™ topology that preferentially provides power to the system load when input power is limited. It controls external PFETs to provide low loss reverse current protection, efficient charging and discharging of the battery, and instant-on operation to ensure that system power is available at plug-in, even with a deeply discharged battery. External sense resistors and precision sensing ensure accurate currents at high efficiency, allowing operation with converters that span the power range from milliwatts to kilowatts.

www.linear.com/product/LTC4000-1

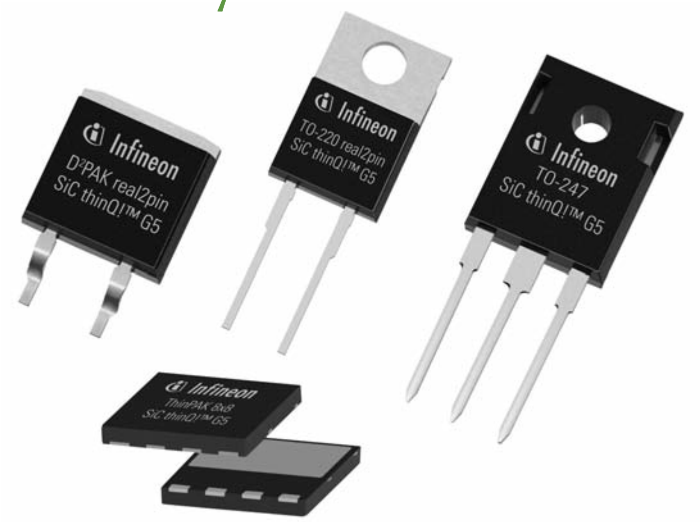
Off-Line Switcher ICs Deliver 90 W



Power Integrations' new LinkSwitch-HP ICs utilize innovative control algorithms and the properties of the main power transformer and output diode - instead of optocouplers and related feedback circuitry - to determine the amount of power to deliver from the primary to the isolated secondary side. The devices automatically select their control mode according to prevailing line and load conditions to optimize conversion efficiency and response to transient load demands, while minimizing output ripple and audible noise. Continuous-conduction-mode (CCM) operation results in reduced RMS currents, leading to higher efficiency and less heat dissipation, while 132 kHz, full-load operating frequency enables the use of smaller magnetics and LC post-filter components. LinkSwitch-HP ICs are capable of no-load power consumption of less than 30 mW at 230 VAC and are more than 50 percent efficient at 0.1 W input power, easily meeting all global energy efficiency regulations. The ICs meet Chinese safety standard GB 4943.1-2011, which mandates the use of warning labels on power supplies that do not meet strict creepage and clearance rules. Similar to UL 60950-2007 and set to become mandatory on December 1st, 2012, the new rule requires designers to increase the primary-to-secondary clearance by a factor of 1.48 for power supplies used in equipment above 2000 m, or else add a warning label to the product.

www.powerint.com

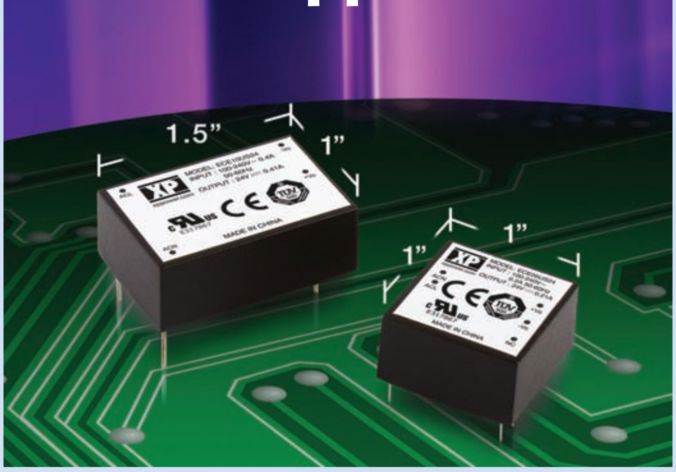
5th Generation SiC Schottky Barrier Diodes



Infineon announces the expansion of its SiC (Silicon Carbide) portfolio with the introduction of the 650V thinQ!(tm) SiC Schottky Barrier Diodes Generation 5. The new family has a higher breakdown voltage level of 650 V instead of the 600 V of Generation 2 and 3, matching the latest releases in CoolMOS(tm) devices. This feature provides higher safety margins in applications like Solar Inverters and in SMPS environments. Generation 5 offers moreover a high robustness against surge currents and a broader portfolio including products with both higher current ratings and new packages, such as TO-247 and ThinPAK.

www.infineon.com/sic-gen5

Smallest AC/DC Power Supplies



XP Power launches of what are believed to be the world's smallest 5 & 10 W single output AC/DC power supplies. Measuring just 25.4 x 25.4 x 15.24 mm (1 x 1 x 0.6 inches) the miniature 5 Watt ECE05 series of encapsulated board mount power supplies are ideal for end-product designs where the available board space is at a premium and a low power high power density supply is required. Complementing the ECE05 series, the ECE10 series provides 10 Watt output from an equally compact encapsulated package measuring just 38.1 x 25.4 x 15.24 mm (1.5 x 1 x 0.6 inches).

www.xppower.com

200 V Schottky Barrier Rectifiers

Taiwan Semiconductor extends its series of high-voltage rectifiers with two new parts (20/30 A) with 200 V reverse voltage, using Schottky Barrier Technology with a platinum barrier metal. These new Schottky Diodes fit into power supply applications (DC output 24 V - 48 V) using secondary side output rectification, by offering improved Schottky performance at frequencies from 250 kHz to 5.0 MHz. These devices are also designed to be used in high-frequency inverters, freewheeling and polarity protection applications.

As additional advantage they can replace ultrafast diodes with better dynamic characteristics.

www.taiwansemi.com

Low Voltage LDO Linear Regulators

Intersil's new ISL80111, ISL80112 and ISL80113 are specified for 1 A, 2 A and 3 A output currents, and are optimized for precision low voltage regulation. Each includes a very low resistance NMOS pass transistor, and the ISL80113 can deliver an ultra-low 75 mV dropout voltage at 3A. The devices' 1.6 % output voltage accuracy, 80dB power supply rejection ratio (PSRR) and 100 µVrms noise result in exceptional output voltage regulation. The LDOs are available now in compact 10-lead, 3 mm x 3 mm DFN packages, with prices starting at $0.99 each for the 1A, ISL80111, $1.32 each for the 2A ISL80112, and $1.65 for the 3A ISL80113 product in 1,000-unit quantities.

www.intersil.com/en/products/power-management/linear-regulation.html

Automotive-Qualified 600V Trench IGBT

International Rectifier introduced a family of automotive-qualified 600 V IGBTs for electric and hybrid vehicle applications including air conditioner inverters, pumps and Positive Temperature Coefficient (PTC) heaters. Co-packaged with a diode and available in a D2Pak package for compact surface mount systems, the new 600 V trench IGBT features a nominal current of 24 A and a minimum short circuit rating of 5 µs. The new devices also offer low voltage drop to reduce power dissipation and achieve higher power density, and positive temperature coefficient making the device well suited for paralleling. The family of IGBTs also features an optimized square reverse bias safe operating area (RBSOA), and up to 175°C maximum operating temperature. The new IGBT is also available in TO-262 and TO-220 packages for standard through-hole assembly. IR's automotive IGBTs are subject to dynamic and static part average testing combined with 100 percent automated wafer level visual inspection. The new devices are all environmentally friendly and assembled with IR's automotive grade bill of materials which are lead-free and RoHS compliant.

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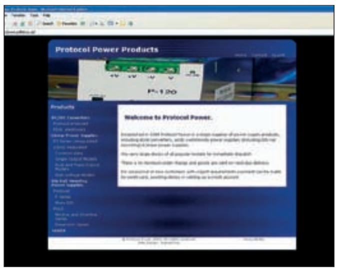

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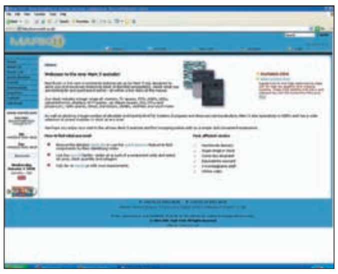

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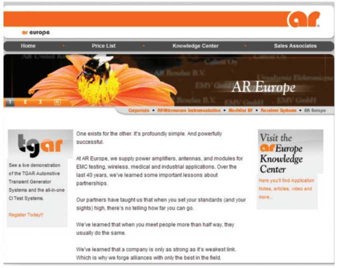

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