POWER ELECTRONICS EUROPE

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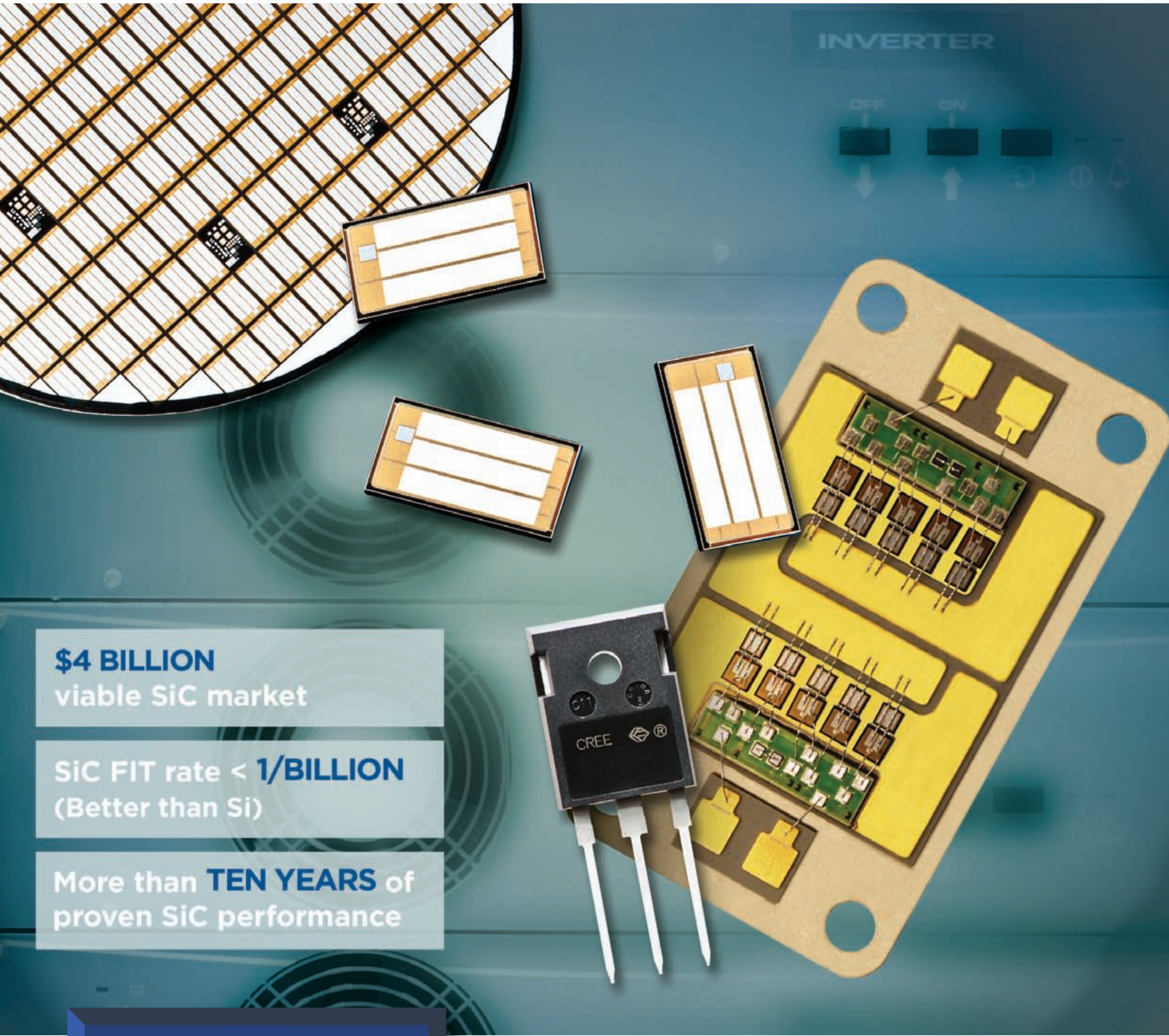
POWER SEMICONDUCTORS

SiC Power Devices and Modules Maturing Rapidly



THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

Also inside this issue

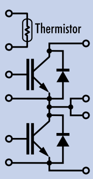
• Trench-FS IGBT • High thermal cycling capability • Low spike voltage & oscillation free • Excellent turn-on dI_C/dt control by R_G

Dual Pack IGBTs

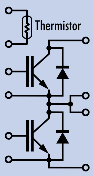
	Ic	1200V	1700V
Spring Contacts	225A	●	
	300A	●	
	450A	●	
	550A		●
	600A	●	
Solder Pins	225A	●	
	300A	●	●
	450A	●	●
	550A		●
	600A	●	

Red= With Si_3N_4-substrate

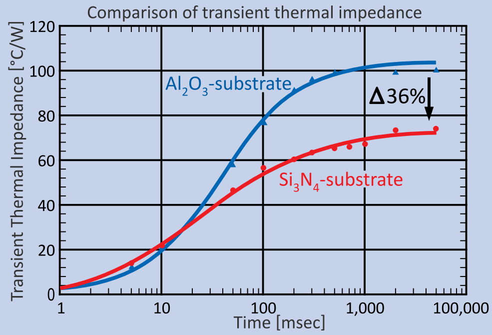
Spring Contacts



Solder Pins



- $T_{j(max)}$ = 175°C
- $T_{j(op)}$ = 150°C continuous operation
- New solder material for higher reliability
- Low switching losses & low over voltage spike



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Innovating Energy Technology

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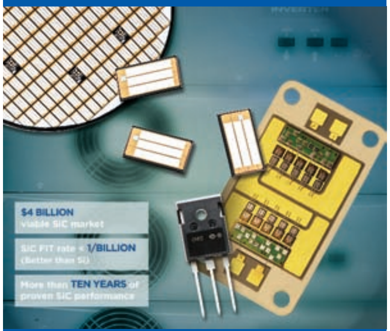
COVER STORY



SiC Power Devices and Modules Maturing Rapidly

The SiC power semiconductor industry has matured to a point which is surprising even industry analysts, and leading to significant (> $100 M in 2010, and expected to eclipse $200 M in 2013, $400 M in 2015) market penetration according to industry analysts from IMS or Yole. The underpinning of the SiC industry, just as for any other semiconductor industry, is the maturity of the SiC wafers. First offered commercially in 1991, over 20 years of industry growth has led to increased volume, increased wafer diameter expansion to 100 mm in 2005, 150 mm in 2012, and dramatically reduced defect densities allowing the larger die necessary to penetrate up to the MW level markets. The 150 mm wafers will allow the SiC power semiconductor industry to scale up volume at a much reduced cost structure as device vendors switch over their fabs. SiC has reached cost parity from the system perspective in volume, and now modules are being developed and released to take advantage. Depending on topologies used, a 1700 V SiC MOSFET module can be much more efficient than a 1700 V Si module. Both SMA (2011) and REFUsol (2012) released commercial PV inverters with All-SiC modules using both FETs and diodes. Both inverters were conventional frequency, 20-23 kW, and were ranked #1 and #2, respectively by Photon International in terms of peak and broad input power range efficiencies. Full article on page 16.

Cover supplied by Cree Inc.

Growth Opportunities for Power Electronics in 2013

According to IMS Research the digital power market is currently one of the fastest growing segments of the power management industry for power supply and power IC manufacturers. The total global market for digital power components is forecast to quadruple to $15 billion from 2012 to 2017. The market for digital power supplies is projected to grow to almost $12.5 billion in 2017 and the digital power IC market is forecast to be worth over $2.5 billion. The digital power IC market is projected to grow at a faster rate as they are used in the end-equipment at board level and also in digital power supplies. Early adopters of digital power components include applications such as servers and telecommunications/data-communications, however, manufacturers in other sectors are now beginning to adopt digital power solutions, creating more opportunities. Applications outside of the server and telecommunication sectors are beginning to adopt digital control and digital management solutions as manufacturers become more aware of the benefits they can offer compared with some analog products. These include reducing the overall bill of materials cost by reducing the number of discrete components, reducing the overall footprint, increasing power density, providing the ability to monitor and optimize power levels and system requirements whilst in operation and speeding up product time to market. Over two-thirds of manufacturers and designers surveyed by IMS predicted that more than 10 percent of their products will have digital control or digital management in 2015. There are still barriers to adoption with 27 percent of manufacturers and designers surveyed stating that cost was still the largest barrier. This highlights lack of knowledge from some potential implementers regarding the overall cost savings that digital solutions can provide and shows that there is still some way to go in educating designers at OEMs/ODMs. Perhaps a mixture of analog/digital functionalities can overcome this cost and knowledge issues, as outlined in our feature on digital power.

Having a digital controller on the same die as the analog switching regulator makes it possible to dovetail analog functions and digital control very tightly enabling direct manipulation of the compensation circuit, switching frequency, dead-time control, system level thresholds and many other features during runtime. Furthermore, as the MCU itself is encapsulated in the analog switching regulator architecture, the need for additional auxiliary power supplies or external MOSFET drivers has been eliminated.

In recent years, the global motion controls market grew strongly with revenues increasing over 20 percent in both 2010 and 2011 to reach an estimated value of $13.1 billion. 2012 presented a very different situation, with the Eurozone recession and softening of the Chinese economy causing motion control sales to fall well below expectations. In 2013, the global motion control market is projected to rebound with revenue growth of nearly 5 percent spurred by recovery of the Chinese market but limited by the continued Eurozone recession.

Also the photovoltaic industry is in the midst of wrenching change—buffeted by government incentive cuts and nose-diving prices that has hurt solar suppliers worldwide, rocked by trade disputes among its major players, and hamstrung by a sputtering global economy. However, there are some bright spots ahead: Solar installations are on the rise, technology is becoming more efficient, and a weak EU market roiled by financial turmoil will be offset by an ascendant China and the United States. The global PV market will achieve double-digit installation growth in 2013, but market revenue will fall to $75 billion. Industry revenues—measured as system prices multiplied by total gigawatts installed—peaked at $94 billion in 2011, but fell sharply to $77 billion in 2012. Revenue is projected to decline once again in 2013 to $75 billion, on the back of lower volume growth and continued system price declines, given that PV component prices continue to fall. But double-digit returns remain possible for European PV projects in 2013. With the subsidy schemes that are currently in place, all EU countries continue to offer attractive conditions for both private and institutional investors. Meanwhile, an evaluation of no-incentive scenarios shows that the most mature market segments are on the cusp of grid parity, allowing healthy returns on investment. Solar will surpass wind in the United States. The year 2013 marks an important milestone, representing the first time that new U.S. solar PV capacity additions will be greater than those made by wind.

As most of the PV inverter market is now designing for not only high-efficiency (~99%), but high-frequency (30-100 kHz), to achieve reliable, efficient, and higher-frequency for lower cost/kW, variations of this topology are receiving extreme interest. Highly efficient Silicon Carbide modules first appeared on the PV inverter market in 2011 (SMA) and 2012 (REFUsol). Both of these inverters, the first PV inverters to use entirely SiC FETs and SiC diodes, received the top two efficiency rankings in their class according to Photon International, with efficiencies in the 98.2-98.6 % range. The next phase of PV (and UPS) inverter design promises to be even more interesting, as designers take further advantage of rapidly improving SiC transistors and diodes to move the inverter frequency up, while maintaining very high efficiency, using fairly simple, rugged topologies with low part counts.

All of these subjects will be covered in this issue. Enjoy reading and have a successful year 2013.

Achim Scharf
PEE Editor

Top-10 Solar Market Predictions for 2013

"The photovoltaic industry is in the midst of wrenching change—buffeted by government incentive cuts and nose-diving prices that has hurt solar suppliers worldwide, rocked by trade disputes among its major players, and hamstrung by a sputtering global economy," said Ash Sharma, director, solar research at IHS. "However, there are some bright spots ahead: Solar installations are on the rise, technology is becoming more efficient, and a weak EU market roiled by financial turmoil will be offset by an ascendant China and the United States."

The IHS market researchers (www.ihs.com) thus have provided 10 predictons for the solar power industry in 2013:

1. The global PV market will achieve double-digit installation growth in 2013, but market revenue will fall to $75 billion. Industry revenues—measured as system prices multiplied by total gigawatts installed—peaked at $94 billion in 2011, but fell sharply to $77 billion in 2012. Revenue is projected to decline once again in 2013 to $75 billion, on the back of lower volume growth and continued system price declines, given that PV component prices continue to fall.
2. The solar module industry will consolidate further in 2013. As 2012 comes to a close, fewer than 150 companies will remain in the photovoltaic upstream value chain, down from more than 750 companies in 2010. Most of the consolidation will involve companies going out of business entirely. Many integrated players, particularly those based in China, will fold up shop in 2013. The large expense of building and then operating integrated facilities that are underutilized will be more than many can handle financially.
3. PV module prices will stabilize in 2H 2013 as oversupply eases. Despite a drastic decline in prices along the Silicon supply chain since March 2011, solar prices will stabilize by mid-2013. Changes in market dynamics will help restore the global supply-demand balance.
4. Solar trade wars will rage on in 2013, yielding few winners. As of November 2012, there were six different solar trade cases proceeding involving China, Europe, the United States and India. This cycle of sanction and retaliation will not help solve the fundamental challenge of overcapacity plaguing the global PV industry.
5. South Africa and Romania will emerge as PV markets to watch in 2013. The two countries next year will expand from virtually no solar installations to capacity of several hundred megawatts. The PV uptake in both markets is driven by distinct factors. In South Africa, PV additions will mainly stem from the tenders awarded in 2012; in Romania, the growth driver will be a green certificate (GC) scheme that will stay in place until 2014.
6. Double-digit returns remain possible for European PV projects in 2013. With the subsidy schemes that are currently in place, all EU countries continue to offer attractive conditions for both private and institutional investors. Meanwhile, an evaluation of no-incentive scenarios shows that the most mature market segments are on the cusp of grid parity, allowing healthy returns on investment.
7. Solar will surpass wind in the United States. The year 2013 marks an important milestone, representing the first time that new U.S. solar PV capacity additions will be greater than those made by wind. This is partly a result of the near-term uncertainty over the federal production tax credit for wind. However, it is also a reflection of solar PV's increasing competitiveness as a form of renewable power generation in some key U.S. Markets.
8. China will become the world's largest PV market. Total PV installations are predicted to surpass 6 gigawatts, allowing the country to surpass Germany as the No. 1 solar market on the planet.
9. Energy storage will transform the solar industry. Batteries increasingly are being seen as an attractive way of retaining PV electricity, letting people use the power later in the day to avoid paying high prices for electricity from the grid. Next year IHS forecasts a big jump in the number of residential PV systems installed with batteries attached.
10. New technology will revive equipment vendors' prospects. Improved technologies will help PV manufacturers cut costs, increase margins and ultimately distinguish themselves from the competition. Such a focus creates an opportunity for both manufacturers and equipment suppliers to obtain larger revenue streams.

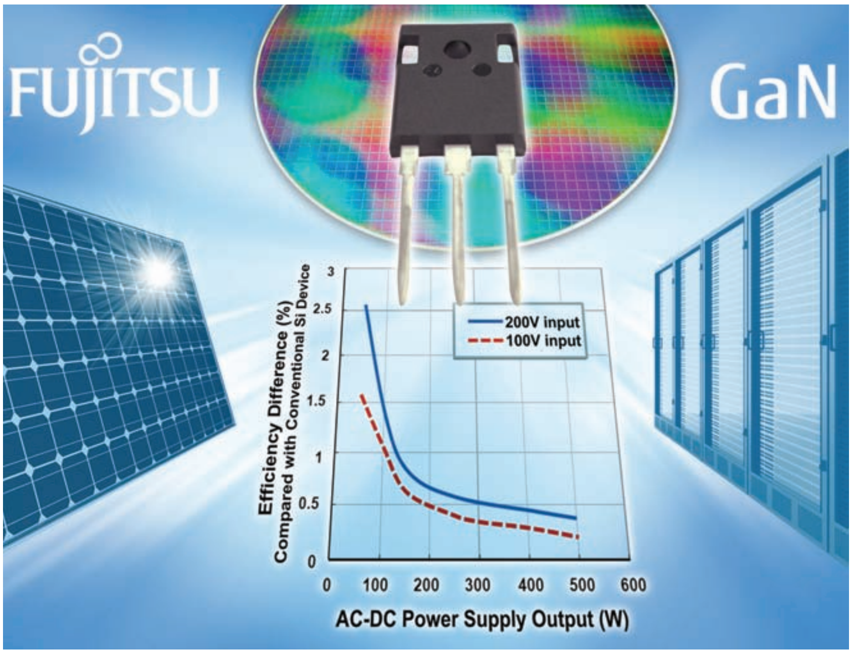
Fujitsu to Start Production of GaN Power Devices

Fujitsu Semiconductor Europe (**http://emea.fujitsu.com/semiconductor**) has achieved high output power of 2.5 kW in server power-supply units equipped with gallium-nitride (GaN) power devices built on a silicon substrate. Using GaN technology in power supply applications enhances power efficiency and helps reduce the carbon footprint.

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

Fujitsu Semiconductor plans to commercialise GaN power devices on a silicon substrate, increasing the diameters of the silicon wafers and enabling low-cost production. The company began work on GaN technology in 2009 and began providing specific power-supply-related partners with sample GaN power devices in 2011. Since then, Fujitsu has worked on optimizing the devices for use in power supply units. A mass-production line for 6-inch wafers has been established at Aizu-Wakamatsu plant, full-scale production of GaN power devices will begin in the second half of 2013.

Fujitsu Semiconductor collaborated closely with Fujitsu Laboratories on several key technical initiatives to achieve this technological progress, including the development of the process technology for growing high-quality GaN crystals on a silicon substrate. The collaboration also delivered device technologies, such as optimizing the design of electrodes to control the rise of on-resistance during switching, and devising a circuit layout for power supply units that can support high-speed switching of GaN-based devices. A prototype server power-supply unit incorporating a GaN PFC achieved output power of 2.5kW. This impressive performance makes GaN power devices suitable for use in high-voltage, large-current applications.

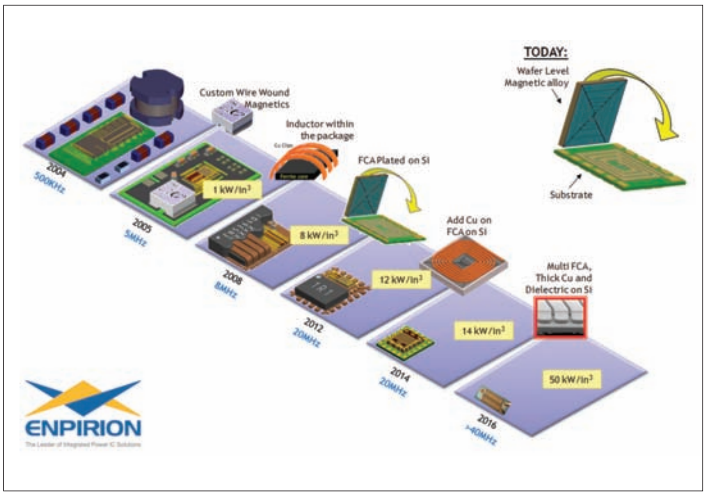


Fujitsu Semiconductor will start production of GaN power devices for high-efficiency power supply units for servers, which achieve high output power of 2.5 kW

2-Dimensional Wafer Level Magnetic Cores

Enpirion (**www.enpirion.com**) has developed a new magnetic alloy, which enables the miniaturization of passive magnetic components and their assimilation with integrated circuits at wafer level.

So-called wafer level magnetics (WLM) present a leap in traditional technology, which will take magnetic components from their 3-dimensional discrete shape to a planar 2-dimensional thin-film form that can be deposited with standard wafer processes on top of CMOS wafers. WLM is fully qualified for full-scale mass production in a high volume foundry and enables Power System-on-Chips based on electroplated wafer level magnetics. Developed with a view to achieving monolithic Power System-on-Chips, the WLM technology can be easily transferred to other micro-magnetic applications. "Increasing the switching frequency allows the use of smaller inductors utilizing electroplated WLM materials that can be post-CMOS processed. We developed an amorphous Fe-Co based alloy called FCA, which is capable of operating at frequencies higher than 20 MHz with minimal attenuation of magnetic properties," explains Dr. Trifon Liakopoulos, Director of MEMS technology and Enpirion's co-founder. "With wafer electroplating methods, it is possible to cost-effectively deposit photolithographically defined FCA magnetic cores on silicon wafers." FCA has high resistivity, low coercivity and maintains high effective permeability at frequencies higher than 20MHz. FCA's high magnetic saturation makes it suitable for use as single or multiple layers in power circuits, where it is compatible with flip-chip, wire-bonding and solder re-flow packaging methods. Enpirion developed a turnkey process module, which features low cost of ownership plating equipment to deposit FCA on 6 inch or 8 inch wafers. The 1 A EL711 and the 1,5 A EL712 are the industry's first Power System-on-Chips based on electroplated wafer level magnetics.



Enpirion's technological roadmap from 2004 – 2016 envisioning a Power System-on-a-Chip

LED-Driver ICs for Commercial Lighting

Power Integrations introduced at Electronica its latest family of LED-driver ICs delivering tight regulation and high efficiency for tube replacements and high-bay lighting, while providing TRIAC-dimmable bulb applications.

LYTSwitch ICs (**www.powerint.com**) combine PFC and CC into a single switching stage, increasing driver efficiency to more than 90 % in typical applications, delivering a power factor greater than 0.95 and easily meeting EN61000-3-2C requirements for total harmonic distortion (THD). Optimized designs deliver less than 10 % THD. The combined single-stage converter topology also eliminates high-voltage electrolytic bulk capacitors, leading to extended driver lifetimes even in high ambient temperatures. Accurate primary-side control yields true tight CC performance with better than +/- 5 % regulation across load, a wide temperature range and production variation enabling tighter design margins and reduced system cost. High switching frequency of 132 kHz means that small, low-cost magnetics can be used in space-constrained bulb applications, while frequency jittering ensures reduced EMI filter requirements. "LYTSwitch ICs enable small, longer-lasting lamps for a wide range of applications including consumer bulbs, commercial lighting and T8 tubes, industrial, high-bay and exterior lighting. Tight CC performance across a wide range of operating conditions simplifies design while ensuring that lamps deliver uniform light output," commented senior product marketing manager Andrew Smith. A detailled application example can be found in our Industry News.

PI's Andrew Smith demonstrates new LED driver ICs on the example of a PAR-38 lamp design

30 Years in Drive Technology

Munich-based MACCON (MAChine CONtrol) celebrates its 30th anniversary this year. The company has grown over the years from a distributer of drives to a solution provider in industry, science and space applications with now 40 employees.

MACCON (**www.maccon.de**) provides several families of servo and stepper motors, which can be used in a variety - in most cases demanding - machine and process applications up to 180 kW. Torque motors are rotary direct drive motors for high torque at low speed; in most cases supplied as kit motor. Linear direct drive motor in 3-phase version (ironless or ironcore), also as ready to use integrated linear tables; voice coil actuators. Servo motors as dynamic 3-phase brushless DC-motors, for low voltage to 3x 480V AC supply, many feedback options (resolver, halls, incremental encoder (digital and sine/cosine), absolut encoders (EnDat, Hiperface, BiSS), brakes, gearboxes, housed or kit versions. Stepper motors: cost-effective positioning motors, industrial and low cost versions, optional encoders, brakes or gearboxes available.

MACCON's Managing Director Edward Hopper expects healthy growth for the years to come

"And we do not only adapt our motors to your application, we design your own motor if needed along with the associated power electronics under the slogan drive electronics to match", Managing Director Edward Hopper underlined.

Today's demanding projects are the so-called 'more electric aircraft', in astronomy 'Sofia - Stratospheric Observatory for Infrared Astronomy' or in electric vehicles 'ELMAR'. ELMAR's power train is based on wheel rim motors, four 7.5 kW synchronous motors as outer rotor versions providing an optimal degree of efficiency and incomparable starting torque operating extremely efficiently at the same time. "Our wheel rim motors combine a number of advantages such as no transmission as torque is generated exactly where it is needed, the natural airflow is sufficient to cool the motor and the wheel's design without the traditional hub help reducing the vehicle's weight, and the integration of the motor windings into the rims combined with the independent suspension of our wheels epitomizes elegance and functionality", Hopper explained.

European Manager to head Fuji Electric Europe

In October 2012, Peter Hermann Maier took over management of Fuji Electric Europe GmbH in Offenbach (Germany), succeeding Hiroshi Miki. After 25 years of Japanese management the CEO in Tokyo has decided to implement European management. This suggests that products and services are going to be more targeted for European customers.

Fuji Electric (**www.fujielectric.com**) was founded in 1923 by Furukawa and Siemens in Tokyo and employs 25.000 people worldwide. Maier was the founder and managing partner of curamik electronics until 2005, a world-leading manufacturer of substrates for power semiconductor modules. The last 7 years he mainly focussed on utility scale photovoltaic projects. He brings vast experience in power semiconductors and renewable energies to the company. In his new position he will promote and accelerate the development of Fuji Electric to a customer driven, globally competitive provider of energy related products and systems. Maier is the first non-Japanese President and speaker of the management board of Fuji Electric Europe. The subsidiary of the Japanese high-tech-company with the slogan 'Innovating Energy Technology', is responsible for the sale and marketing of electric drives and power semiconductors as well as for the introduction of new products into Europe, Russia, the Middle East and Africa.

Peter Hermann Maier is heading Fuji Electric Europe

New Head of Development at Isabellenhütte

Over the past three decades, Isabellenhütte Heusler has gone through a fundamental change. The company based in Dillenburg, Germany, has evolved from a supplier of semi-finished products into a globally active company whose thermoelectric and resistance alloys, low-ohmic precision and power resistors, and current, voltage and temperature measurement systems are in demand worldwide.

Ullrich Hetzler, head of R&D for many years, retired from his position in July, and is followed by physicist Jan Marien who joined Isabellenhütte (**www.isabellenhuette.de**) in October 2010 as head of development for measuring technology. In his new role, Marien will be making use of his experience as head of development and head of technological development at Sensitec, a manufacturer of sensor solutions, for which he worked from 2003 to 2010. Prior to these positions, he spent five years as a team leader for physical materials analysis and as a project manager for sensor systems at IBM Deutschland Speichersysteme GmbH and five years as a researcher at the Max Planck Institute for Intelligent Systems in Stuttgart. The company aims to become a tier 1 supplier specifically in industrial drives, energy distribution networks and renewable energies.

Physicist Jan Marien is new head of development at Isabellenhütte

New Microcontroller Family for Drives and Digital Power

The total microcontroller market is around $18 billion with 32 bit architectures growing fastest. Infineon now introduces a low-cost ARM-based 32-bit controller for drives and power supply applications.

Particularly for low-end industrial applications the XMC1000 family will come in three series XMC1100 (Entry series), XMC1200 (Feature series) and XMC1300 (Control series). The three series differ essentially in terms of their memory capacity and peripheral set. On-chip flash size ranges between 8 KB and 200 KB, which is a far broader memory range than is usual today for 8-bit microcontrollers.

The XMC1000 family addresses industrial applications which, to date, were reserved for 8-bit MCUs. In addition to as much as 200 KB flash memory, the MCUs feature high-performance PWM timers, 12-bit A/D converters and programmable serial communication interfaces. Additional features include a module for touch control and LED displays, a peripheral unit for the dimming and color control of LEDs – otherwise known as the Brightness and Colour Control Unit (BCCU) – and a mathematical co-processor specifically for motor drive controls. The microcontrollers satisfy the requirements defined by the standard IEC60730 Class B, which is prescribed for the safety of household appliances sold in Europe, and offer, for example, hardware error correction (ECC) and corresponding memory tests. A further feature is a flash loader with a 128-bit AES accelerator, which allows a design engineer's valuable software IP to be better protected, important especially in cost-sensitive applications.

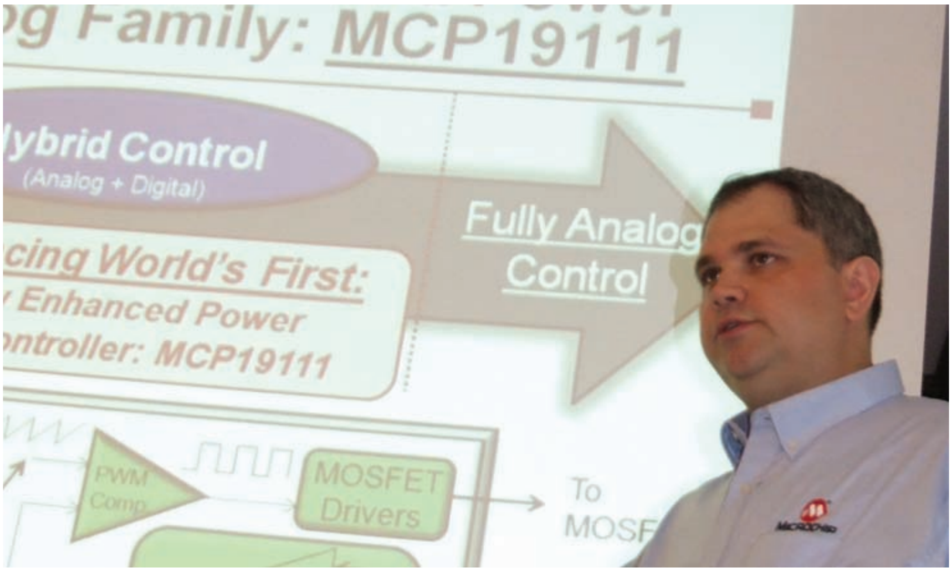
The XMC1100 Entry series have six 12-bit A/D converter channels, which operate up to 1.88 mega samples/second, and four 16-bit timers in a capture/compare unit 4 (CCU4) and a broad voltage tolerance, between 1.8V and 5.5V. The XMC1200 Feature series incorporates additional application-specific features, including a unit for capacitive touch sensing and LED display controls and the BCCU. The BCCU permits flicker-free dimming and colour control of LEDs with virtually no burden on the processor. Variants in this series are available for the extended temperature range of -40°C up to 105°C. The XMC1300 Control series is specifically optimized for motor control and digital power conversion applications. It features a very efficient capture/compare unit 8 (CCU8) with two compare channels and asymmetric PWM functionality plus a position interface (POSIF) for the detection of the motor position. XMC1300 devices also offer a mathematical coprocessor, which permits efficient sensorless FOC (field oriented control) for electric motors. This is unique for Cortex-M0-based products. The XMC1300 series also offers variants for the temperature range up to 105°C.

Samples of all three XMC1000 series and the DAVE software development environment for XMC1000 will be available from March 2013. Volume production is planned for Q4 2013. Depending on the particular XMC1000 series and peripheral set, prices for order quantities of several million units can range between Euro 0.25 and Euro 1.25.

www.infineon.com/xmc

To be cost competitive the new microcontrollers are manufactured on 300-mm wafers by TSMC, as shown by Infineon's General Manager Peter Schäfer Photo: AS

Microchip Expands Power Management Solutions



Arizona-based Microchip Technology Inc., one of the leading microcontroller vendors with a turnover of roughly $ 380 million in the final reported quarter is now investing heavily in devices for industrial applications such as motor control and power management, A new hybrid controller family has been designed for power supply applications.

"Power management is becoming a core technology for Microchip. In Europe alone and particularly in Romania we employ around hundred engineers involved in analog design and application support", underlined Stephen Stella, Product Marketing Manager Analog & Interface Products at a press tour in Munich. He announced the MCP19111, a digitally enhanced power analogue controller, and the expansion of its MOSFET family with the new MCP87018, MCP87030, MCP87090 and MCP87130 devices. Rated at 25 V, these 1.8 m?, 3 m?, 9 m? and 13 m? logic-level MOSFETs (no wire bonds) are optimized for Switched-Mode-Power-Supply applications. The combination of the MCP19111 controller and MOSFETs supports configurable, DC/DC power-conversion designs for a broad array of consumer and industrial applications up to 1.6 MHz switching frequency. The BCDMOS 8-bit controller can be used as a sequencing device in multiple rail configurations. The planar MOSFETs are capable of supplying up to 40 A or 150 W.

The MCP19111 Evaluation Board (ADM00397), priced at $49.99, includes the MOSFETs and is offered with standard firmware, which is user-configurable through an Graphical User Interface plug-in. The combined evaluation board, GUI and firmware allow power-supply designers to configure and evaluate the performance of the MCP19111 for their target applications. The Power MOSFETs are available now for sampling and volume production. The MCP19111 controller is offered in a 5 x 5 mm, 28-pin QFN package. The MCP87030 and MCP87018 MOSFETs are housed in a 5 x 6 mm, 8-pin PDFN package. The MCP87090 and MCP87130 MOSFETs are offered in both a 5 x 6 mm, 8-pin PDFN package, as well as a 3.3 x 3.3 mm, 8-pin PDFN package. More details in our feature "Digitally Enhanced Power Analog Controllers for Point-Of-Load Applications". AS

www.microchip.com/MCP19111

Applied Power in Long Beach

The "Applied Power Electronics Conference and Exposition" to be held from March 17 – 21 in Long Beach/California is the first major event on power electronics focusing on the practical and applied aspects of the power electronics business. APEC 2012 closed with more than thousand delegates and 170 exhibitors, more are expected for this year's event.

Professional Education Seminars will b held on the first day covering two sessions on Understanding MOSFET Parameters, Digital Control For Power Supplies, Converters for Renewable Energy and Transportation, Small-Signal Methods for AC Power Electronics Systems, High Frequency Magnetic Circuit Design for Power Conversion, Wireless Power Technologies, GaN Transistors for Efficient Power Conversion, Gate Drive Circuits and Techniques, AC-DC

Converters in Industrial and Automotive Products, Electric Machines for Automotive Applications, High-Frequency Magnetics Design and Measurement, and Nanotechnology for Power Electronics. The second day will start also with seminars on 600V-Class GaN Power Devices: the Technology, Performance and Application Case Studies; Galvanic Isolation for Power Supply Applications; Solid-State Transformer Concepts in Traction and Smart Grid Applications; Small-Signal

Modeling and Analytical Analysis of Power Converters; Building Switching Power Transformers; and Operation and Exploitation of Electrochemical Capacitor Technology.

Opening Plenary

The plenary session on the Monday afternoon will highlight the more general aspects of power electronics presented by internationally recognized experts.

Western industrialized societies rely on the use of electrical energy for providing a high quality of life for their citizens. The comforts of refrigeration, air-conditioning, and lighting are taken for granted by people. Convenient transportation and communication capabilities are no longer considered a luxury. These benefits are derived by ever increasing demands on our electrical power delivery systems which produces a detrimental environmental impact. In his talk "The Role of Power Semiconductor Devices in Creating a Sustainable Society", Dr. B. Jayant Baliga from North Carolina State University describes the impact of power semiconductor devices on reducing electricity usage through enhanced efficiency of power delivery.

What will be the next driver for the power industry, GaN or SiC or some combination of both? That's the question raised by Transphorm's CEO Dr. Umesh Mishra in his presentation entitled "Compound Semiconductors: GaN and SiC, Separating Fact from Fiction in both Research & Business". Engineers are barraged with press releases touting the latest break through result from both companies and universities which is often confusing, misleading or contradicting. With his extensive background in the technology, Umesh Mishra PhD. will educate the APEC attendees about the fundamental differences between the two alternate technologies as well as provide some humorous insight into how to read not what is in the press releases but rather what is not stated in them. This will help the decision makers to ask the right questions in order separate fact from fiction so they can make profitable business decisions for their projects or engineering investments.

The Tyndall National Institute will present an update on progress in the area of power supply on chip, based on the presentations made at the 3rd International Workshop on Power Supply on Chip (PowerSoC2012) with the paper "PwrSoC Update 2012: Technology, Challenges, and Opportunities for Power Supply on Chip". Speaker Cian Ó Mathúna, National University of Ireland, will discuss the challanges and opportunities, from both the technology and commercial perspectives, in this emerging space.

Every two years The Power Sources Manufacturers Association (PSMA) forms a team of industry experts to compile the latest trends shaping the power conversion technologies. From AC adapters to DC/DC converters, and from micro inverters to high-power embedded power supplies, the findings for key power conversion segments and the application ramifications are then compiled in the Power Technology Roadmap report which is published by the PSMA. The talk "PSMA Power Technology Roadmap 2013 Summary" by Eric Persson, Executive Director of Field Applications Engineering at International Rectifier, highlights some of the technology trends identified in the report that will shape power conversion products for the next two to five years.

Innovations in power distribution architectures, conversion topologies and packaging have enabled Vicor to advance its power component methodology and deliver a compounded power density growth rate of 15% per year over three decades. Vicor's CEO Dr. Patrizio Vinciarelli will highlight in his talk "Power Components Come of Age" major steps along the way and reveal recent advances enabling breakthrough power system applications.

The emergence of nanotechnologies into commercial markets is already exceeding the original US National Science Foundation projection of $1.5 trillion of nanotechnology products by 2015. Current forecasts estimate $1.6 trillion of nanotechnology incorporated in goods manufactured in the USA in 2013 alone. For the power supply industry, advances in nanostructured materials, synthesis of nanoscale interfaces, nanoengineered semiconductor and insulator structures, and nanoscale assembly of hydrid materials and devices will enable new technologies in next generation systems for power generation, control, storage, and transmission. Dr. Terry C. Lowe, New Mexico Tech, Los Alamos National Laboratory, Metallicum Inc., will in his talk "Advances in Nanotechnologies for the Power Supply Industry" systematically review developments in nanotechnology that can transform the design, performance, reliability, longevity, and manufacturability of electrical power supply systems.

Though in existence for over 100 years, wireless power transfer has failed to meet the needs to power any mass market consumer electronics devices. In recent years, different technologies have been introduced to meet this need, though a single technology has yet to gain mainstream acceptance. Wireless power technology that delivers spatial freedom, capable of simultaneously satisfying different power levels (from a Bluetooth headset to a Tablet device and more), is finally emerging, after considerable effort to ensure interoperability, coexistence and the ability to be embedded in multiple environments, like furniture and automobiles. With a focus on the technical constraints as they relate to users expectations, this presentation "Wireless Power Transfer – Overcoming the Technological Hurdles" by Francesco Carobolante, Vice President of Engineering at Qualcomm Incorporated, discusses the different types of wireless power transfer along with the related regulatory and technology issues, and provides the background to understand the specification being developed by the newly formed Alliance for Wireless Power.

After the plenary session the exhibition with some 190 exhibitors will be opened. More in our next issue.

PCIM
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International Exhibition and Conference
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Nuremberg, 14 – 16 May 2013

PCIM 2013 Focuses on Renewable Energy

With the number of companies registered at PCIM Europe 2013 well above last year's event, PCIM Europe is expected to record growth once again. Many companies are taking part for the first time at PCIM Europe 2013. The number of exhibitors has risen in areas such as energy storage, renewable energy and e-mobility, especially. And these topics are also strongly represented at the PCIM Europe 2013 conference. "Renewable Energy" in particular is a focus of this year's main topic "Wind and Solar - Integration, Challenges and Solutions".

For the conference 276 abstracts in total have been submitted at this years' Call for Papers, which represents an increase of 10 % in comparison to last year. 141 authors have applied for the Young Engineer Award, of which all three winners receive a prize money of 1,000 Euros each. Again Power Electronics Europe (PEE) will sponsor the Best Paper Award prized for visiting PCIM Asia 2014 including flight and accommodation.

Special Session on GaN Power

And again PEE has organized a Special Conference Session, this year under the headline "GaN Power for Highly Efficient Converters".

"The high importance of GaN-on-Si technology for power conversion applications is by now evident," says Boris Petrov, managing director of the Petrov Group, a US-based market research firm. "It is driven by cost and performance superiority, established manufacturing infrastructure, and global market drivers for efficient energy generation, distribution and consumption. There are major commercialization efforts worldwide driven by the need for higher energy efficiency – GaN-on Si for power conversion (GaN Power) is one of the most promising "green" technologies.

Because the GaN Power technology is of national significance, the speed of adoption in power conversion applications will likely be much faster than it was for legacy silicon technologies. At present there are more than 40 semiconductor vendors and more than 20 academic and R&D institutions in the race to commercialize the GaN-on-Si technology for power conversion applications."

While accelerated adoption in power conversion applications is evident, what remains elusive is use of Silicon wafers and high voltage (600 V to 1200V) devices. So - which vendors are likely to win the race to GaN Power commercialization?

Thus PEE has invited four companies already commercializing GaN Power to present their technologies in converter applications, illustrating what can be achieved in terms of reduced power losses and overall size of a highly efficient converter.

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Bond Wireless Power Packaging for Hybrid and Electric Vehicles

Traditional industrial motor drive modules are generally based on 600 V or 1200 V IGBTs and diodes in a wire bonded package. However there are several limitations with wire bonding: multiple wires are needed to carry higher currents, therefore more complex and costly assembly processes are needed. When an issue occurs in the assembly it is very hard to rework the module resulting in a particularly expensive yield fall out. Reliability is also the week point of the wire bonds – after thousands of active power cycles the wire bond and its interface to the Silicon is all too often the cause of a failure. A new approach to overcome these issues will be introduced in this article. **Benjamin Jackson, Senior Manager, Automotive Power Switch & Power Module Product Management & Business Development, International Rectifier, El Segundo, USA**

Visit any motor show in the last few months and it will very quickly become apparent what the latest trend is – electrification! The mass production of hybrid and electric vehicles represents a seismic shift in the motor industry, but it is conceptually nothing new. The origins of the electric car can be traced back to the 1830s, by around the turn of the century in 1900 about 38 % of all cars on American roads were electric powered, second only to steam power, and furthermore, the world's first hybrid car was the Löhner-Porsche Mixte Hybrid which was released in 1901!

Given this background it is reasonable to be skeptical about what could be seen as the latest phase of enthusiasm for electric cars. But given the dramatic increase in fuel costs over the last 20 years and ever more stringent taxes on emissions, the drivetrain of an automobile is being squeezed from both ends – simply put the efficiency must improve and the electrification of the car is an effective means to do this. The challenge for Engineers is daunting – the internal combustion engine has been a cost effective, reliable and high performing solution for over 100 years – and it still has life left in it! So for the power electronic solution to succeed it must achieve outstanding reliability, high performance and efficiency at a low price point.

Getting rid of wire bonds

In most (H)EV platforms on the road today there are three main emerging applications for power electronics: Battery management, DC-DC conversion and the main inverter motor drive. The main inverter drive is one application which so far has relied on power semiconductor and module technologies which have been adapted from the industrial market where similar power levels and voltages are often seen. However in an effort to reduce cost, size, and weight, improve efficiency and not sacrifice one bit on reliability a new set of silicon and power packaging technologies are needed which are to be developed specifically for automobiles.

Traditional industrial motor drive modules are generally based on 600 or 1200V IGBTs and diodes in a wire bonded package. On the left hand side of Figure 1 an example of wire bonding can be seen, as the name suggest this method relies on the use of small wire bonds, perhaps 20 mm in diameter that are attached directly on top of the silicon and then to a lead frame assembly which makes the final connection to the wider system. Such technology is highly established and considered cost effective. However there are several limitations with wire bonding: multiple wires are needed to carry higher currents, therefore more complex and costly assembly processes are needed. When an issue occurs in the assembly it is very hard to rework the module resulting in a particularly expensive yield fall out. Reliability is also the week point of the wire bonds – after thousands of active power cycles the wire bond and its interface to the silicon is all too often the cause of a failure. Finally the wire bonds take up space on top of the semiconductor die and around its edge; this reduces the power density of a given solution and inhibits the ability to cool from the top as well as the bottom side of the device.

To this end Solderable Front Metal (SFM) technology was developed several years ago, which enables direct soldering from the substrate to the top side of the semiconductor. SFM has been successfully used in billions of devices over the last decade and the improvements in reliability over wire bonds are well charted in literature. SFM allows the wire bond to be eliminated and in addition to the improved reliability the manufacturing process of modules can be dramatically simplified with the elimination of the wire bond process step in its entirety and its associated yield loss.

With the need to provide a new power module building block specially tailored to the needs of (H)EV systems the Engineers at International Rectifier applied SFM along with concepts similar to those used on the DirectFET® package to produce a new device, CooliR^{2}DIE™ capable of holding die up to 225 mm^2 and targeting power levels above 50 kW. The right hand side of Figure 1 shows the CooliR^{2}DIE assembly; a 680 V, 175°C $T_{j\,max}$ ultra-thin IGBT and DIODE along with an SFM finish are mounted on a ceramic carrier. Solder bumps complete the package, the resulting product eliminates the wire bonds but also eliminates the needs for module manufacturers to handle the sawing and placement of die that can be 70 µm thin, or even less! Rather than having to buy thin wafers, the manufacturer is supplied with CooliR^{2}DIE parts on Tape and Reel, these parts go through a standard pick and place process and are then reflowed to the substrate – more like populating a PCB with D^{2}Pak devices than building a module with 70 µm thin die and wirebonding.

There is then a second step which

enables further system simplification; two variations of the CooliR²DIE give the designer the opportunity to construct a very optimum circuit layout using only a single layer substrate material. Figure 2 shows the two variations – 'Die Up' and 'Flipped Die'. Both are identical in terms of dimensions and electrical performance, the only difference is the orientation of the IGBTs and DIODEs; in the 'Die Up' configuration the collector of the IGBT and the cathode of the DIODE is connected to the ceramic carrier. This is reversed in the 'Flipped Die' configuration. By using the Die Up for the high side switch and the Flipped Die for the low side switch a very compact, low inductance half bridge can be constructed. It has been shown possible to build a module with a loop inductance of less than 12 nH using such a configuration – well below that of standard wire bonded modules on the market today.

Furthermore the construction of the CooliR²DIE means that the solder bumps on either end of the carrier are in fact connected to each other (see Figure 2, terminals C/C' and E/E'). This means when constructing a full three phase inverter (as shown in Figure 3) the CooliR²DIE carrier itself can act as part of the DC bus bar – thereby eliminating the need for multiple layer boards or complex interconnects. If a scalable design is needed to address a wide variety of platforms devices can be placed in parallel.

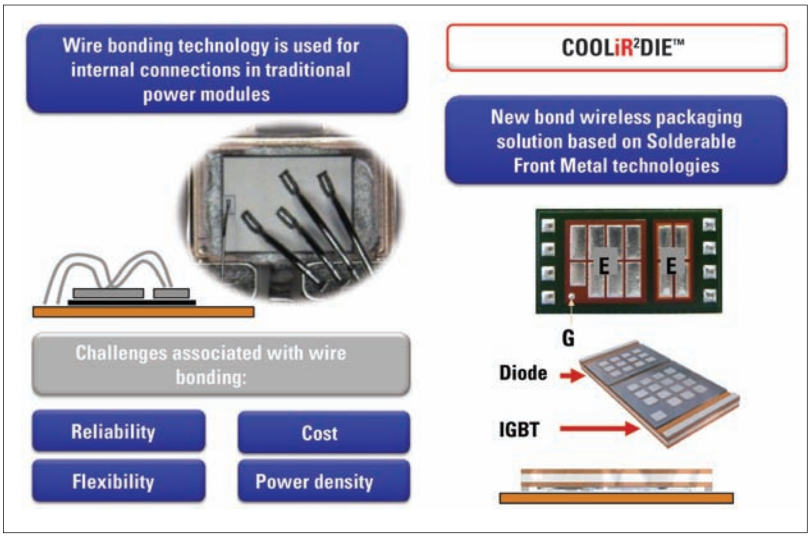

Figure 1: Comparison of traditional wire bonding and the new CooliR²DIE™

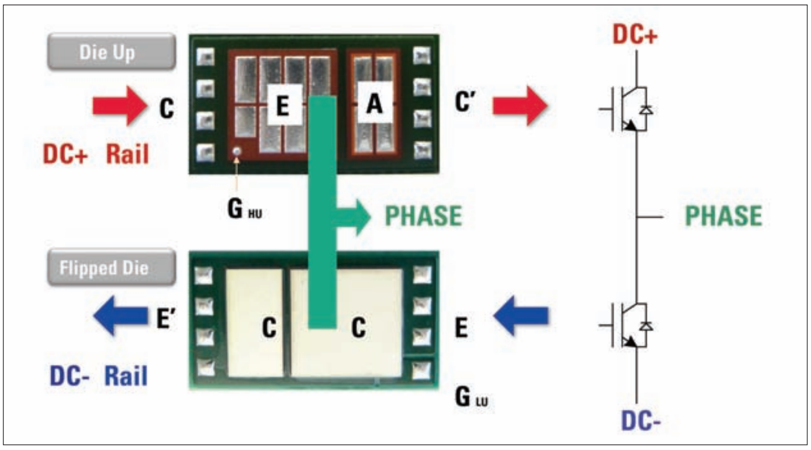

Figure 2: Two different versions of the CooliR²DIE™ forming a half bridge

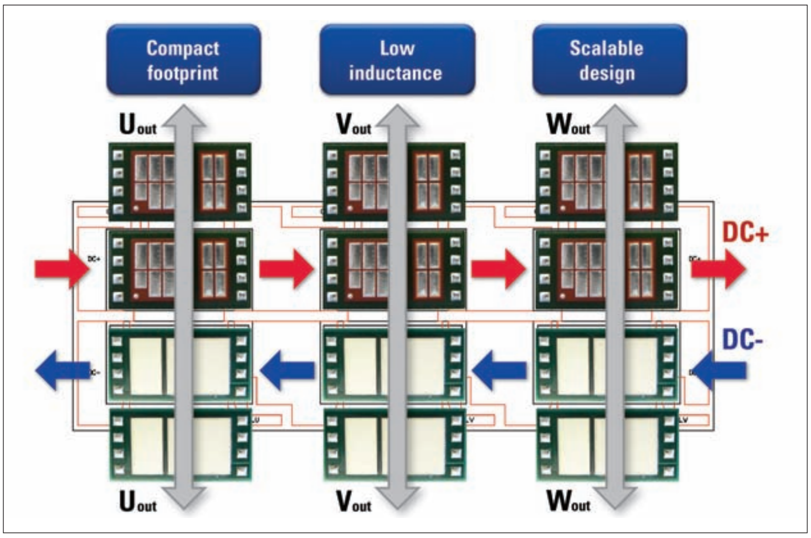

Figure 3: Using the CooliR²DIE™ to form part of the DC bus bar connections in a three phase inverter

More reliable electrified cars

By moving from a wire bonded module construction to one using direct solder connections to the die much more compact and electrically efficient systems can be constructed, furthermore the manufacturing simplification and cost reduction is clear – the cumbersome wire bonding step can be removed altogether. But more over the impact on reliability is dramatic. The number of active power cycles creating a temperature delta on the junction of the semiconductor is one such metric of measuring the reliability of power modules. Figures for the reliability of a wire bonded modules vary, but it is not uncommon for a traditional module to achieve up to 100 k cycles with a T_j of 85°C. In prototype testing the CooliR²DIE has achieved over 950 k cycles!

For the electrification of the automobile to be a success will require political will, which the world now has. Financial motivation is also a key driver and increasingly such vehicles are coming more affordable through tax incentives, lower capital cost as volumes ramp and a growing charging structure. But ultimately the performance of the car must not be compromised, the internal combustion engine has set a very high benchmark and electric and hybrid vehicles must rise above this to succeed, optimized power electronics meeting the specific needs of the automotive industry will be a vital driver for electrification of the car to be a success.

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SiC Power Devices and Modules Maturing Rapidly

The SiC power semiconductor industry has matured to a point which is surprising even industry analysts, and leading to significant (> $100 M in 2010, and expected to eclipse $200 M in 2013, $400 M in 2015) market penetration according to industry analysts from IMS or Yole. The announced 150 mm wafers will allow the SiC power semiconductor industry to scale up volume at a much reduced cost structure as device vendors switch over their fabs. **Jeffrey B. Casady, Product Portfolio Planning Manager, Cree Power & RF, Durham, NC, USA**

The underpinning of the SiC industry, just as for any other semiconductor industry, is the maturity of the SiC wafers. First offered commercially in 1991, over 20 years of industry growth has led to increased volume, increased wafer diameter expansion to 100 mm in 2005, 150 mm in 2012 [1], and dramatically reduced defect densities allowing the larger die necessary to penetrate up to the MW level markets.

People often mistakenly attempt to compare SiC wafer diameter and costs with Si, without considering that the inherent material advantages of SiC allow for up to 10 times more die product per comparable Si wafers. The decrease in cost of SiC wafers due to increased production volume actually allows SiC device manufacturers to reach cost parity at a system level today [2] which explains the rapid market growth SiC power devices are experiencing. For example, the SiC wafer maturity has allowed cost-competitive solutions in Light Emitting Diodes (LED) to be offered to the market, as Cree now manufacturers and ships millions of LED die per day on SiC wafers [3], and now the SiC power device market is also experiencing market gains. The 150 mm diameter wafers are now readily available to further allow much improved volume and cost structure (example wafers shown in Figure 1).

SiC diodes

The first released SiC power semiconductor devices released were SiC diodes in 2001. There has been substantial diode revenue for more than ten years, and the $100+ million market (Yole) in 2010 was primarily for SiC diodes.

Quietly, the SiC diode industry is continuing to mature rapidly, with over 100 different SiC diode part numbers on the market from Infineon, Cree, Rohm and others (over 60 at Cree alone), breakdown voltages available ranging from 600 V to 1700 V, current ratings available from 1 A to 50 A, and a wide assortment of package options – through-hole, ceramic, bare die for modules and surface mount.

With over a decade of product experience, and over 100 different products, the SiC diode product family is delivering not only dramatic efficiency improvements, but also field data reliability which is astounding. Currently, after over ten years in the market, the Failure-In-Time (FIT) rate of SiC diodes is better than Si, and is less than one fail per billion hours of operation. Indeed, SiC's reliability is attracting customers who want not only energy-efficient, cost-effective solutions, but also ultra-high reliability in their components.

The SiC diode market is continuing its expansion. Outside of the mature high end server / telecom power supplies for data centers and growing PV inverter business, it is penetrating new markets such as

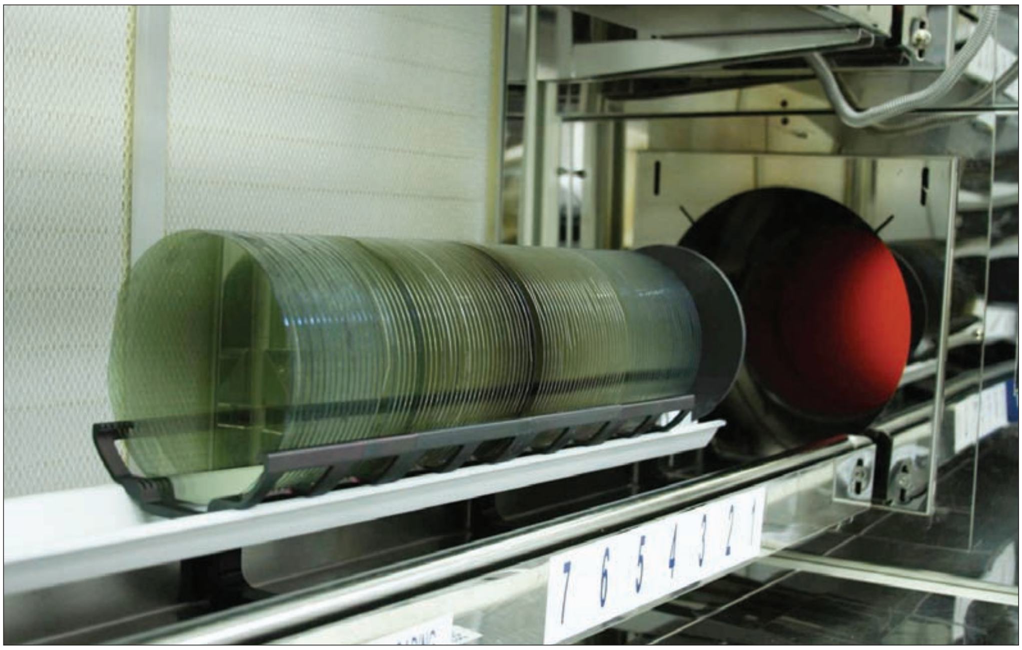
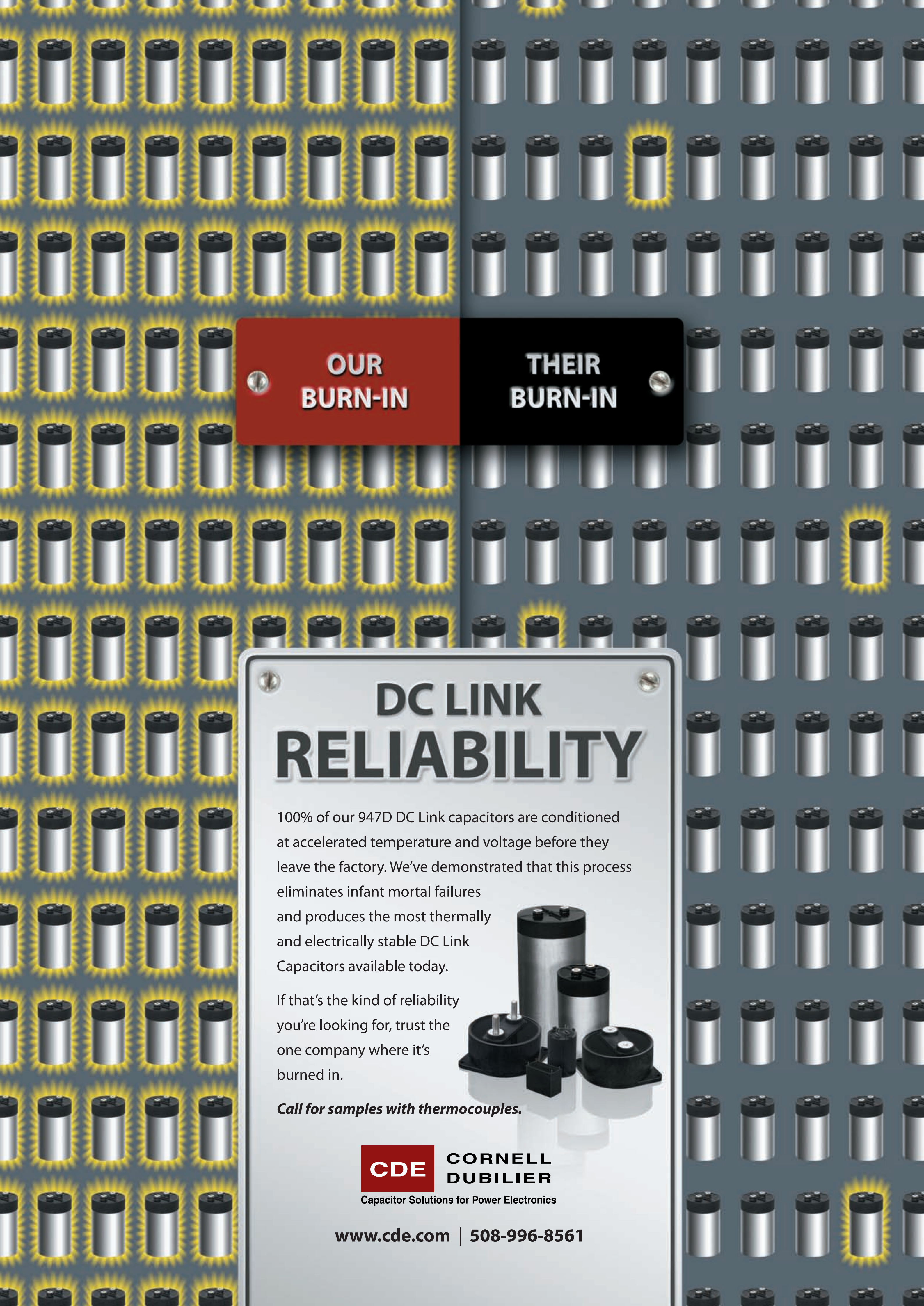


Figure 1: Example lot of 150 mm diameter SiC wafers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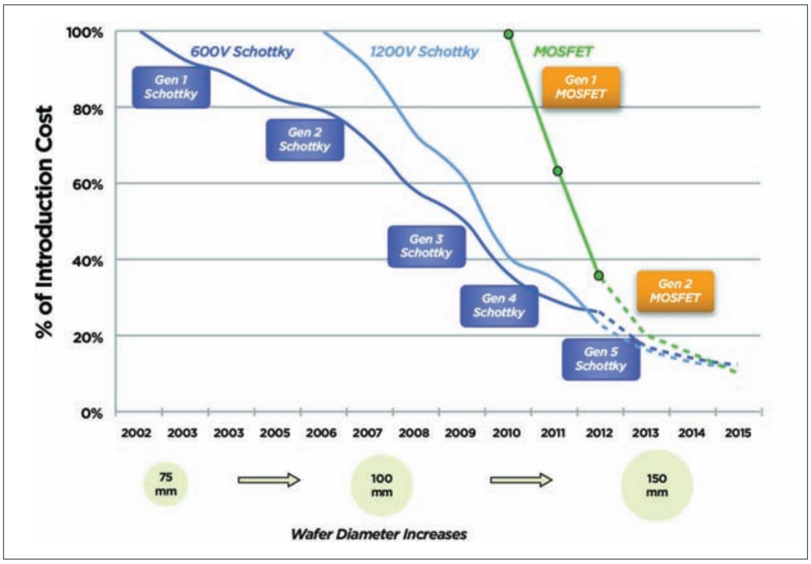

Figure 2: Cost reduction curves on a normalized basis for one manufacturer (Cree) which is illustrative of the SiC power device industry

Intelligent Power Modules (IPMs) for motors/fans, hybrid modules for drives, UPS inverters, LED light bulbs and fixture drivers. Customers are reducing overall system cost with SiC in ways not available with traditional Si. And with 150 mm substrates available within most design windows, very high-volume users can now work with SiC diode vendors to achieve costs and volumes significantly different than what has been possible to date, as illustrated in Figure 2.

SiC MOSFETs

In 2011, the SiC industry achieved a major milestone as the first commercial SiC MOSFETs were released [4]. Cree and Rohm both released 1200 V, 80 to 160 mΩ MOSFETs, in plastic through-hole packages, and bare die for modules. Rohm also produced 600 V MOSFET's in 2011 [5], and Infineon [5] announced selective sampling of a SiC JFET in 2012. Nearly two years since initial release, many customers are now using SiC MOSFETs in applications ranging from industrial power supplies to commercial inverters and converters. Example application notes have been published for 100 kHz, 10 kW boost converters [6] as well as auxiliary power supplies.

According to the latest Cree sales data, for SiC MOSFET's to date, there has not been a single field failure when operated within their datasheet limits. This fact leads to a FIT rate of less than 20 fails per billion device hours, and field accelerated lifetime data predicts a MTTF of one million years at 75 % of continuous rated voltage. Additionally, measurements of the avalanche energy capability show that the 1200 V SiC MOSFET has the highest rated avalanche energy of any 1200 V power switch (1200 V, 80 mΩ SiC MOSFET from Cree measured EAS of 2.2 J, EAR of 1.5 J, compared to Si IGBT EAS of 10-100 mJ).

What's next? Many new commercial releases of SiC MOSFET's are expected in 2013. Just as SiC diodes experienced after their release over a decade ago, the MOSFET's are maturing rapidly, and new generation / broader product families are already being sampled and are targeted for full release in 2013 at major power electronics exhibits. Last year [7] it was publicly announced at PCIM that large (50 A) MOSFETs would be available with 1700 and 1200 V ratings. These new ratings will allow higher power applications in motor drive, UPS, PV inverters, and traction drive markets among others to utilize SiC technology.

Additionally, newer generations of MOSFET technology are being released, which enable better efficiency, cost, and gate driver control through improvements in the on-resistance per unit area (from 8-9 mΩ cm^2 to 5 mΩ cm^2) and transconductance [8,9]. These improvements will also allow even more efficient switching at higher frequencies, driving the cost reduction that so many customers are seeking for their inverter boxes which contain a substantial amount of inductors and magnetic due to the efficiency and frequency limitations of silicon. As an example of switching energy, a SiC MOSFET will typically have five to seven times lower switching energy than comparably rated Si IGBTs (for example see Figure 3).

SiC Modules

Silicon carbide modules (using both the MOSFET and the diode) are now becoming available as well. From 2011-12, companies such as Vincotech, POWERSEM, Danfoss, Microsemi, and others began releasing SiC modules with both SiC power transistors and diodes. In late 2012 and into 2013, the SiC device vendors themselves are now starting to release SiC modules [10], and it is widely expected the larger module vendors such as Fuji, Semikron, Mitsubishi and Infineon will also begin releasing modules based on technical articles and trade presentations. The modules being released have gone through full, standard JEDEC qualification, along with more stringent power cycling out to 20 M cycles with no failures.

For less than 50 kW, one of the more popular "All SiC" example modules is the 1200 V MNPC topology used by many vendors, including Vincotech [11, 12]. The switching is very fast, with no tail current in the SiC FETs, unlike the Si IGBTs. The MPNC topology allows for not only fast switching, but also low-inductance and fewer voltage overshoots for greater EMI compatibility.

As most of the PV inverter market is now designing for not only high-efficiency (~99%), but high-frequency (30-100

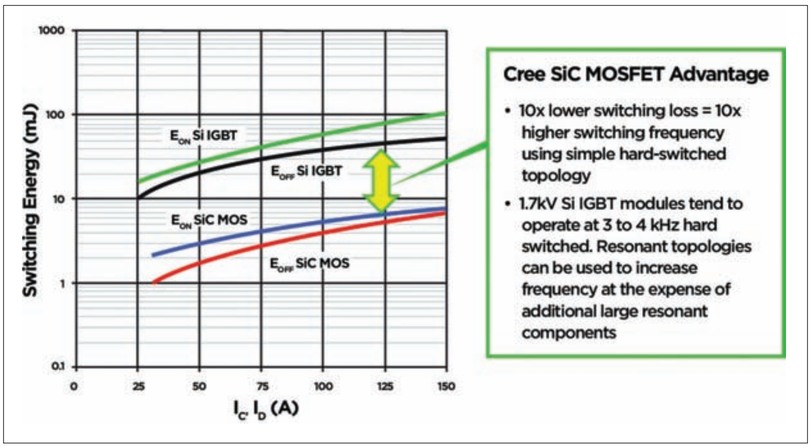

Figure 3: Illustrative advantage of SiC MOSFET's comparing a 1.7 kV dual 100 A Si IGBT module compared to a 1.7 kV, 100 A dual module using Cree SiC MOSFETs

Figure 4: **Both SMA (2011) and REFUsol (2012) released commercial PV inverters with all-SiC modules using both FETs and diodes. The REFUsol inverter (note "Silicon Carbide Inside") is shown here. Image courtesy of REFUsol**

kHz), to achieve reliable, efficient, and higher-frequency for lower cost/kW, variations of this topology are receiving extreme interest. These modules first appeared on the PV inverter market in 2011 (SMA) and 2012 (REFUsol). The SMA Solar Technology AG's Sunny Tripower 20000TLHE-10 was the first to be certified by Photon International in December 2011, using SiC FETs and SiC diodes, in an all-SiC module. The rating it received from Photon was the highest for its power rating (22 kW) that had ever been achieved. Then, shortly after, in July 2012, Photon gave another A+ rating to REFUsol's GmbH's 020K-SCI, which is a 20.2 kW three-phase inverter (shown in Figure 4).

Both of these inverters, the first PV inverters to use entirely SiC FETs and SiC diodes, received the top two efficiency rankings in their class according to Photon International, with efficiencies in the 98.2-98.6 % range. Even more striking, not only were peak efficiencies higher, but the range of input power where the efficiencies were above 98 % was much larger than with Si power switches [12] in three level topologies. The next phase of PV (and UPS) inverter design promises to be even more interesting, as designers take further advantage of rapidly improving SiC transistors and diodes to move the inverter frequency up, while maintaining very high efficiency, using fairly simple, rugged topologies with low part counts.

The larger, more economical power die in SiC, coupled with 150 mm wafer diameter availability, are also now driving design activity in new markets such as UPS, motor drive, traction-drive, and utility-scale solar inverters at power levels above 50 kW to as high as MW level. Designers new to SiC are sometimes surprised as the features of SiC allow for higher-frequency, lower-loss (and therefore lower current) operation. For example, a typical 1,000 A IGBT single-switch module used in a 250 kW inverter, half-bridge design, is often operated at a much lower (300 to 600 A) current level due to the losses in the module generating thermal issues. So, when designing with a SiC replacement module, a 1,000 A module using Si IGBTs can be replaced with a more efficient SiC module, that allows a much higher fraction of its rated current to be used. When matching losses, anticipating using matching two-level half bridge topologies, it is possible to lower the SiC rating by 1/3 to 2/3 relative to the Si module rating based on the efficiency gains (see Figure 5). SiC FETs allow for synchronous rectification possibilities as well, furthering that advantage.

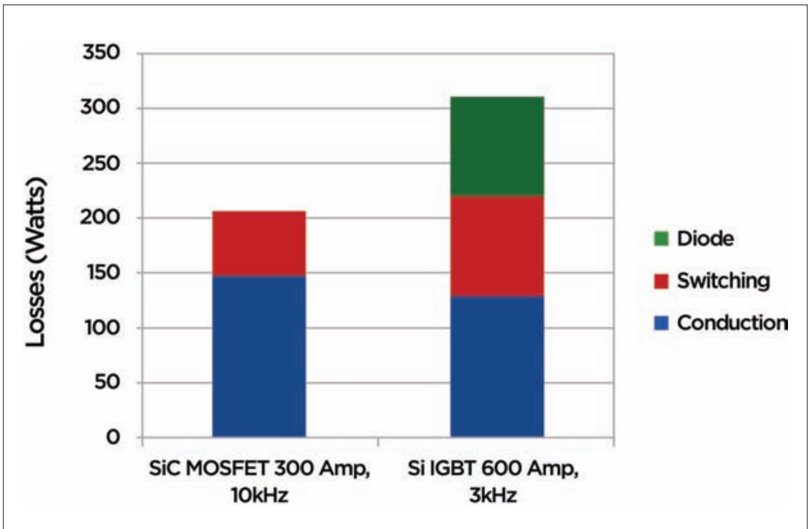

Figure 5: **SiC has reached cost parity from the system perspective in volume, and now modules are being developed and released to take advantage. Depending on topologies used, a 1700 V SiC MOSFET module can be much more efficient than a 1700 V Si module which contains twice the current rating, operating at three times lower switching frequency**

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Digitally Enhanced Power Analog DC/DC Controllers for Point-Of-Load Applications

In many systems microcontrollers are used to control multiple Point-of-Load (POL) DC/DC converters forming a hybrid control system to manage system start-up behavior, monitor electrical parameters and manage the power consumption of peripheral sub-systems. The most sophisticated solutions, however, can be found on motherboards of computers, graphic cards or on CPU blades of servers, where Voltage Regulator Modules (VRM) directly communicate with their load to adjust supply voltages and/or even adapt their control characteristic to temporary operation conditions. This kind of "intelligent" power conversion management and control offers significant advantages in terms of total system efficiency, performance and reliability – preferences which are dominant in industrial, medical, automotive and consumer market segments as well. **Andreas Reiter, Technical Business Development Manager for Power Electronics, Europe, Microchip Technology**

Since almost one decade Microchip Technology focuses on so-called intelligent respective smart power conversion (IPC/SPC) applications to bring more features and enhanced capabilities to power conversion applications. One main focus has been, and still is, the fully digital control of power converters/inverters using DSP-based microcontrollers with highly dedicated high-speed, high resolution peripherals as well as dedicated controller families for hybrid control systems combining microcontrollers with fully analog based control loops. Looking into the particular solutions more closely, it becomes obvious, that neither the analog-based hybrids nor the fully digital solutions are 100 % analog or 100 % digital. Both urgently need their analog and digital counterpart to overcome certain limitations and therefore offer specific strength for their specific target applications. The latest product family of smart power conversion controllers MCP191xx marks a new technological step in making power converters more intelligent and focuses on dedicated power converter topologies and applications.

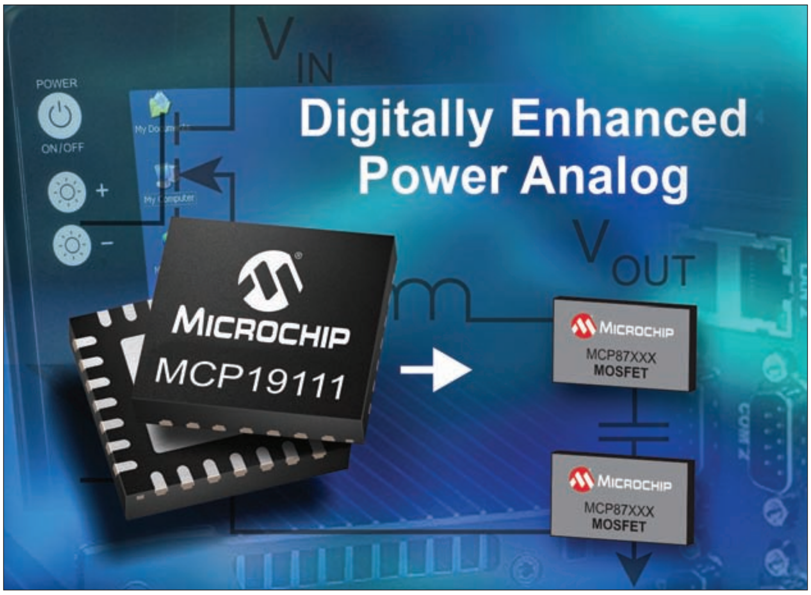


Figure 1: **The MCP19111 merges an analog synchronous buck converter controller and an 8-bit MCU into one monolithic IC**

The first members of this family of products MCP19111 are merging an analog synchronous buck converter controller and an 8-bit MCU into one monolithic IC, offering enhanced, flexible configuration, control and monitoring capabilities as well as they allow the integration of standardized or proprietary communication to align multiple converters within a higher power management structure. The MCP19111 are fully programmable in C-language, offering full flexibility to adjust the device to many different application requirements, to adapt to certain operating conditions, to implement generic monitoring tasks and customized features. The wide input voltage range of 4.5 V to 32 V DC and output voltages as low as 0.5V together with drivers supporting up to 2 A source/4 A sink opens a wide variety of applications to be supported.

Digital enhancements

Having a digital controller on the same die as the analog switching regulator makes it possible to dovetail analog functions and digital control very tightly enabling direct manipulation of the compensation circuit, switching frequency, dead-time control, system level thresholds and many other features during runtime. Furthermore, as the MCU itself is encapsulated in the

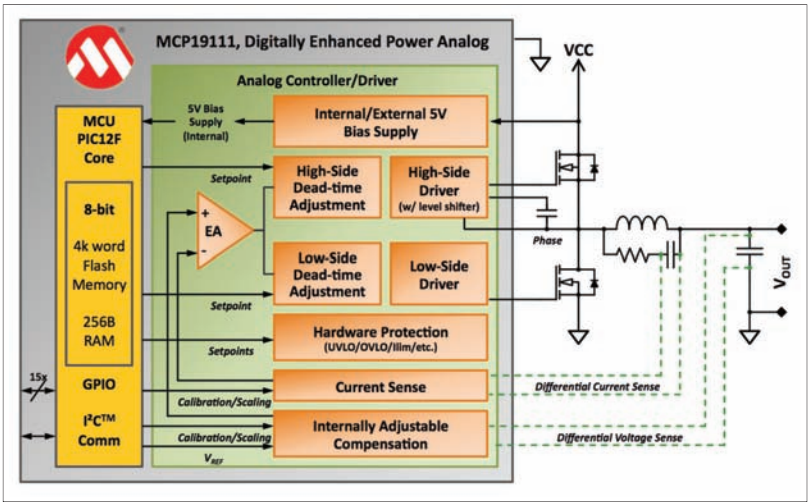


Figure 2: MCP19111 high-level application block diagram

analog switching regulator architecture, the need for additional auxiliary power supplies or external MOSFET drivers has been eliminated. Figure 1 shows a high-level block diagram of the MCP19111 Digitally Enhanced Power Analog Controller together with a typical application circuit. The analog switching regulator section covers all components of the analog control loop including the MOSFET drivers and also contains the auxiliary supply for the MCU. The digital section consists of an 8-bit PIC12F mid-range MCU core with 8 kB of Flash and 256 byte of RAM. It further offers up to 15 GPIOs, of which eight are additional analog inputs, an I²C/SMbus based serial communication interface, external interrupts and three free timers. Many internal signals like the input voltage, output voltage or the inductor current can be monitored directly on-chip without need for external sensing. The digital implementation even allows reading the current duty ratio, a very useful feature which was, up to now and for many technical reasons, reserved to fully digital controllers only.

Besides the enhanced monitoring capabilities the monolithic integration of a digital core also gives direct access to many parameters, which are typically fixed in hardware or inaccessible in Silicon. The most remarkable ones are the adjustable dead-time, the programmable compensators, internal feedback calibration, programmable protection thresholds and even the capability to switch over between current and voltage mode control during runtime.

Adjustable dead-bands

In synchronous buck converters the dead-time setting between high- and low-side switch has significant influence on the total efficiency of the system. If analog controllers offer any adjustable dead-time settings at all, the designer has to refer to some sort of worst case scenario considering the highest temperatures and load conditions, where the dead-time typically needs to be at maximum, and "program" this value in hardware e.g. by placing capacitors and/or resistors. This inevitably results in increased core and diode losses as the converter will most probably be never exposed to these assumed worst case conditions.

One proper solution would be to automatically adapt the dead-time to certain load and temperature conditions. Unfortunately using an on-board zero-crossing detector to always drive the switches with an optimum dead-time has certain serious limitations for two reasons. First, all kinds of analog zero crossing detectors are based on comparators. The fastest (affordable) analog comparators have typical propagation delays of 15-20 ns, which is, given the results shown in Figure 3, too slow to reach the optimum level. Second, this zero-crossing detector would have to operate in the switching node of the half-bridge where the high frequency switching noise would require filters, which would slow down the trigger even more, eventually making this feature effectless.

However, where the analog domain fails, the digital domain offers a solution. The most common technique used to accomplish this optimization is to monitor and analyze the converter's outer conditions until they become stable. As soon as a steady state operation is detected, the dead-time is modified and the duty ratio of the high-side switch is monitored. The theory of this technique for constant voltage converters is that under steady state conditions, the shortest relative on-time of the high-side switch determines the point of highest efficiency, as in this point the least amount of power has to be drawn from the bus to provide a certain, constant output power (see Figure 2).

Figure 3 shows results of one single sweep over a defined range of dead-time settings during steady state operation, measured on a test bench. The green line shows the dead-time applied to the rising edge of the high-side switch (DTR). The red curve gives the development of the on-time of the high-side switch over the different dead-time settings, the dotted black line shows its 3rd order approximation.

The given range for the dead-time sweep was determined by characterizing the system and defining a best-case scenario (shortest dead-time) and a worst-case scenario (longest dead-time). The sweep was performed with the maximum resolution of 4 ns at 90 % load (Vin = 12 V, Vout = 3.3 V, Iout = 9 A). On the left side of the chart, the duty-cycle starts with values of around 1.394 µs and rapidly drops as soon as the dead-time is increased. In this area the high- and low-side switch already show some overlap and some of the power drawn from the input is directly shorted to ground.

At dead-times around 25 ns the on-time

For I_{OUT}, V_{OUT} and V_{IN} = const.

(I) $$\frac{P_{out}}{P_{in}} = \eta \Rightarrow \frac{V_{out} \cdot I_{out}}{V_{in} \cdot I_{in}} = \eta$$

constant if control loop is working properly

Input current inversely proportional to efficiency

(II) $$\frac{V_{out}}{V_{in}} \cdot \frac{1}{\eta} = \frac{t_{on}}{T} \Rightarrow \underbrace{\frac{V_{out}}{V_{in}} \cdot T}_{= \text{const.}} \cdot \frac{1}{\eta} = t_{on}$$

On-time inversely proportional to efficiency

(III) $$\Rightarrow t_{on} = c \cdot \frac{1}{\eta} \quad \text{with} \quad \frac{V_{out}}{V_{in}} T = \text{const.}$$

Figure 3: Basic equations of the Automated Dead-Time Adjustment (ADTA) technique

reaches its minimum of 1.384 μs and starts to rise again when the dead-time is further increased. In a non-adjustable design, the dead-time would have been adjusted to at least 70 ns for the switches used, so the typical on-time for this operating condition would have been 1.395 μs. In accordance with equation III of Figure 2, the difference between the original and optimized high-side on-time is 11 ns wide. On the first glimpse this doesn't sound much, but in this high frequency converter it stands for ~0.9 % increase in efficiency respective an increase in total efficiency from ~92 % to 93 %.

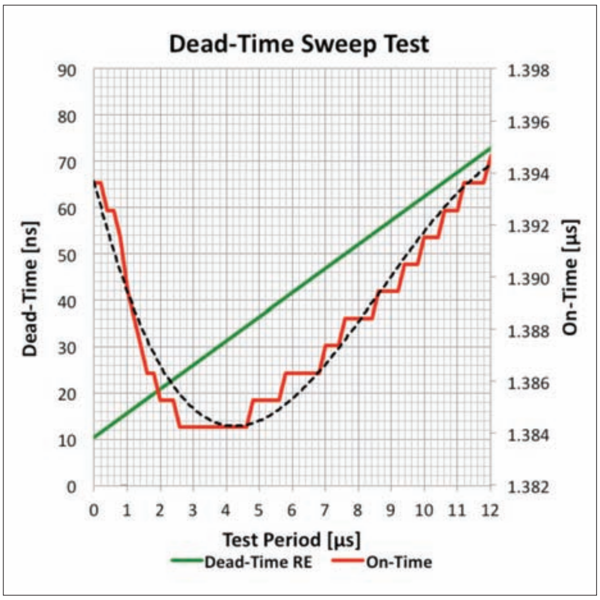


Figure 4: Measurement results of one sweep over different dead-time settings during steady state operation

Adjustable switching frequency and compensation network

One additional very nice feature is the capability to adjust the compensation network and switching frequency by software. This not only eases the basic adjustment during setup configuration, it also allows to make adjustments during runtime. This, so far, has been the unbreakable core domain of fully digital controllers. In hard-switching topologies like synchronous buck converters, the switching losses are dominantly responsible for the majority of power losses. To improve the efficiency especially at light loads, reduction of the switching frequency can significantly help to improve the total efficiency of the converter.

However, when the switching frequency is being reduced while the compensation network is fixed in hardware, commonly the gains start to drop and might result in a loss of phase and gain margin. To compensate this effect, an adjustment of the system's gains is required. The MCP19111 offers registers to adjust the ramp voltage of the PWM generator, the zero frequency (resonance frequency at the origin, defining the first pole), the total gain and slope gain as well as the slope itself. Further there are register sets to adjust the amplifier offset and current sense gain. Although this technique might require a process of extensive system characterization, it bares the chance for significant improvements in terms of efficiency and stability.

Very light load efficiency optimization

In asynchronous buck converters the power losses in the freewheeling diode are determined by the forward voltage drop times the current. As the significant forward voltage drop across the diode is present permanently and cannot be minimized, an additional switch with significantly lower forward voltage drops is commonly used to bypass/replace the diode eventually forming a synchronous rectifier. This technique is commonly used when load currents above 1A are required. However, during light load conditions, when there is very little current flowing through the low-side switch, the power required to drive its gate exceeds the savings gained by bypassing the freewheeling diode with a switch. To support further efficiency enhancements under this particular conditions, the MCP19111 offers the so-called diode-emulation mode, where, when enabled, the low-side driver is turned off. With a disabled driver, the gate is not biased anymore and the MOSFET's body diode will become the rectifier, minimizing the power losses.

This kind of measure to minimize partial power losses and increase the total overall efficiency can additionally be backed-up by using Microchip's new family of power MOSFETs MCP870xx. This family of low RDS(on), well balanced Figure-Of-Merit (FOM) fast Power-MOSFETs offer a range of different On-Resistance vs. Total Gate Charge (QT) combinations to optimize the total FOM of the half-bridge. The higher QT of the low side switch, the more effective becomes the diode emulation mode of the MCP19111.

Optimizing no-load operation

The MCP19111 are current mode controllers to offer best performance during normal operation. However, a current mode controller needs to have at least some current flowing to function properly. When load switch into low-power standby operation, the output of the converter still has to provide the nominal output voltage, but the output power might almost be zero. Commonly current mode controllers switch into some sort of hick-up or Pulse-Frequency-Mode (PFM) operation with higher output ripples, violating line regulation tolerances and often also

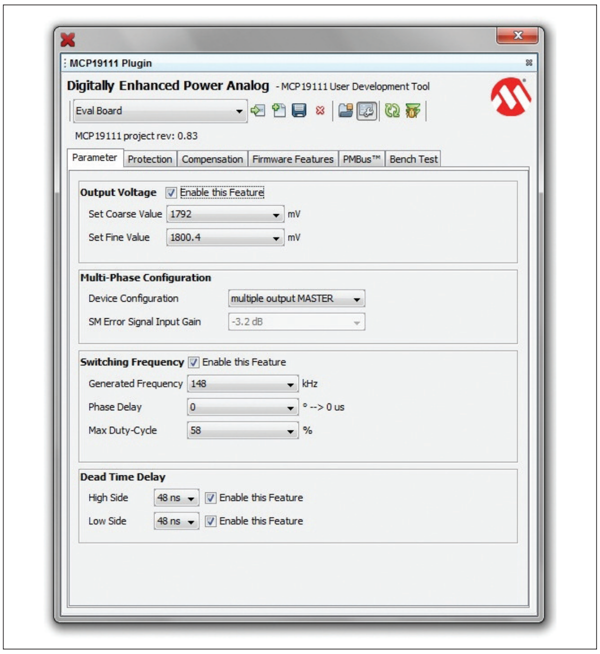


Figure 5: Graphical user configuration interface

causing serious EMI issues. To overcome this limitation of typical current mode controllers, the MCP19111 can be switched into pseudo voltage mode control by disabling the current loop resulting in a improvement of the output voltage and system stability.

Usability and tool chain

The list of enhanced features of the MCP19111 offers a number of options to configure and optimize the system. The open programmability of the MCU adds even more degrees of freedom. Therefore Microchip offers the Graphical User Interface (GUI) shown in Figure 4, which can be used to make certain adjustments and configurations without the need to write code. This GUI works with an open-source firmware, which can be modified and be used as a template to develop individual, more advanced features.

In addition to the configuration interface, Microchip offers a second GUI for test purposes, enabling the user to directly communicate with the device using the PMbus protocol (see Figure 5). This GUI is working with Microchip's PICkit Serial Analyzer (Part-Number DV164122), which is a generic low-cost USB-to-UART/SPI/I?C interface and can be directly used to monitor and debug the device during operation.

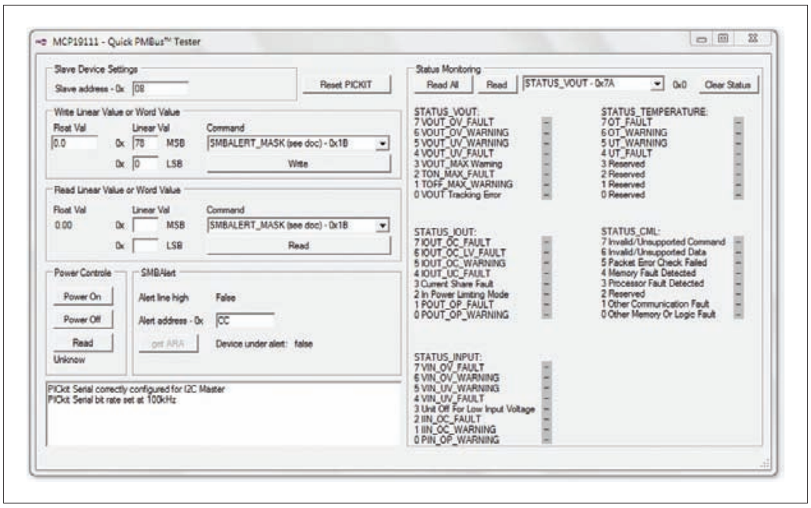


Figure 6: MCP19111 PMbusTM test interface

Conclusions

Although most of the techniques are known and some features can also be found on already existing parts, the MCP19111 family of devices opens a new chapter in the history of intelligent switching regulators. The density of dedicated features together with the free programmability makes the powerful difference. In the world of smart power controllers, the MCP19111 brings analog and digital control schemes closer together and removes existing limitations by making all features available and accessible to engineer and therefore forms the base of innovative, efficient and reliable high performance POL converters.

Compensation Methods in Voltage Regulators

Feedback signals are used in voltage regulator circuits in order to produce a controlled output voltage. When properly implemented, feedback will improve the performance of the circuit. A major contributor to proper implementation of a feedback circuit is the compensation network. This article will give an overview of some methods used to implement compensation in voltage regulators including techniques for automatic digital compensation. **Bruce Rose, Technical Marketing Manager, CUI Inc, Tualatin, USA**

An analogy to assist in understanding compensation in voltage regulators lies in the suspension system of an automobile. Operators of cars desire different styles of rides depending upon the use of the car. Riders in limousines would like to enjoy a smooth ride and not notice any external disturbances. At the other extreme, race car drivers would like their cars to respond quickly to the external forces of starting, stopping and turning. While both of these styles of cars may experience similar disturbances, different reactions of the cars to the disturbances are desired. As a result, the suspension systems of the cars are tuned to react in the desired manner to specific disturbances. A properly tuned suspension system will give the car its desired ride qualities. Tuning the suspension of a car is similar to adjusting the feedback compensation circuit of a voltage regulator.

Switching regulators

In order to achieve good power conversion efficiency, design engineers often employ switching regulators (Figure 1). Typical switching regulators consist of two primary functional blocks; a power stage and a control stage. The power stage conducts the current flow in the voltage regulator. It contains switching FETs, a circuit to control the switching of the FETs and an output filter which includes inductance and capacitance.

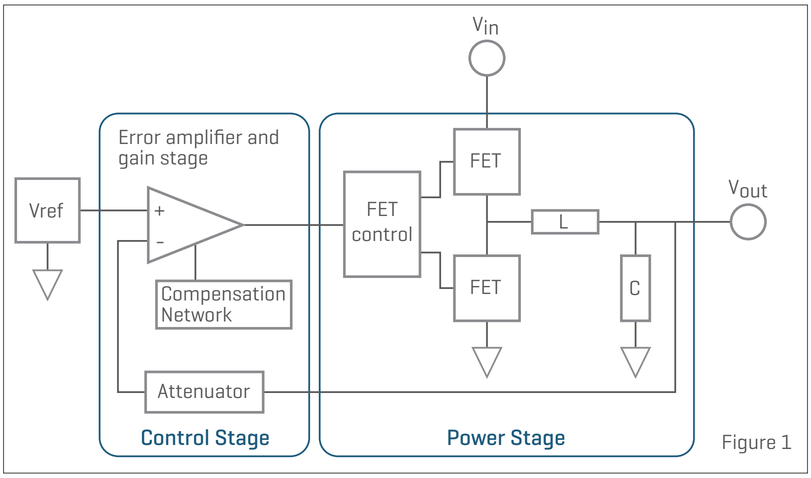
The control stage provides the signals to the power stage such that the desired output voltage waveform is produced by the switching regulator. The control stage consists of an attenuator, an error amplifier, a gain circuit and a compensation circuit. The switching regulator can either be built with discrete components soldered directly to the host circuit board or obtained from manufacturers that offer voltage regulator Point of Load (POL) modules with the components placed on a daughter circuit board which is then connected to the host circuit board. Some advantages of POL modules are that much of the voltage regulator circuit design has been done by the module vendor and the modules can occupy less space on the host board than would a discrete solution.

Compensating analog voltage regulators

In most analog switching regulators, internal nodes are brought external to the circuit so that the user can select the circuit compensation components. This external compensation feature allows the user to optimize the performance of the switching regulator for their application. Optimizing the voltage regulator transient response involves measuring or modeling the circuit and then calculating the values of the compensation components. The circuit is then modeled or measured with the compensation components installed. This process is often repeated many times until the desired result is achieved. Optimizing the compensation of a digital switching regulator is accomplished in a similar manner; however changes are made using firmware rather than physical components.

Proper implementation of the compensation network within an analog switching regulator requires engineers with special tools, skills and experience. If an analog switching regulator is measured during the compensation design phase, then the circuit board needs to be re-soldered many times. If the circuit is modeled and not measured, there is still the need to eventually solder together a physical circuit to measure the performance. The process of re-soldering the compensation components introduces a substantial level of risk to the design process. It is common that the wrong value of a compensation component is installed, another part of the circuit is accidently modified, or the circuit board is damaged during the design process. It is also possible that the circuits drawing power from the voltage regulator can become damaged due to improper compensation of the voltage regulator.

When any of these events occur, time delays and expenses are incurred to recognize the problem, identify a solution to the problem, and implement the repair. The above mentioned risks, procedures and required resources exist whether a discrete design of an analog switching regulator is implemented or a POL module



LEFT Figure 1: Analog switching voltage regulator

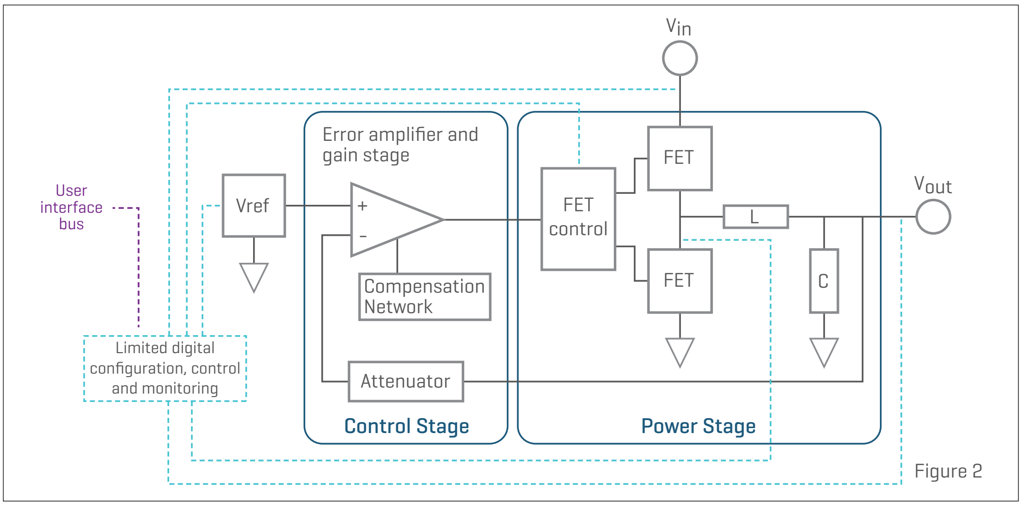


Figure 2: Analog switching voltage regulator with 'digital wrapper'

based upon an analog switching regulator is used.

One can think of the design of the analog switching regulator as a similar process to purchasing a kit car and then selecting and installing all of the suspension components. It takes specific tools, knowledge and experience to properly tune the suspension of a car. Adjusting the suspension in the car posses risks, including damaging the car while driving it with a poorly-tuned suspension, or breaking components while making suspension adjustments. In either case, time and resources will be required to repair the damage caused while tuning the suspension.

As a result of the increasing number of digital systems being implemented in today's designs, voltage regulator vendors are now offering analog switching regulators with 'digital wrappers' (Figure 2). The voltage regulator portions of these circuits are very similar to the traditional analog switching regulators. The digital wrapper enables the system to employ software to implement Configure, Control and Monitor (CCM) functions of the voltage regulator, in a limited manner. The ability to use CCM functions in a voltage regulator via software control is of benefit to the design team during the development phase and to the user of the final product.

Analog switching regulators with digital wrappers are being offered to design engineers for discrete designs and as POL modules. Some module vendors have chosen to include most of the compensation components internal to the module. The module user is then provided a single internal compensation node and is required to select only one resistor and one capacitor to adjust the performance of the module. The advantage of this process is that tuning the performance of the module is simpler than when the user must select all of the compensation components. A trade-off of this compensation technique is that the user is not able to select the complete set of compensation network components.

The ability to select all of the compensation components would enable greater optimization of the performance of the voltage regulator. The ability to select only a single resistor and capacitor is similar to selecting the shock absorbers for a car, but not being allowed to tune any other component in the suspension system.

Compensating digital voltage regulators

The technical evolution of voltage regulators started with analog switching topologies for increased efficiency, transitioning to the addition of digital wrappers for limited CCM functions. Today digital switching voltage regulators are available to design engineers (Figure 3), providing superior performance to earlier topologies. Similar to analog switching regulators, digital regulators require a control circuit and a power stage. The power stage for a digital switching regulator is similar to that for an analog switching regulator. The control circuit in a digital regulator is implemented with digital and mixed-signal circuits. An advantage of this topology is that extensive CCM functions can be implemented. The extensive set of CCM functions in a digital voltage regulator provides greater benefit than the limited CCM functions present in an analog switcher with a digital wrapper. Another advantage of digital switching regulators is that optimizing the performance of the circuit can be accomplished more easily and automatically.

The compensation function in a digital voltage regulator can be implemented as Proportional, Integral, Differential (PID) taps, which are coefficients used in the digital control circuit to define the response of the voltage regulator. An advantage of using firmware PID taps is that the designer can configure and control the performance of the voltage regulator with software. An infinite number of changes can be made to the response characteristics of the circuit without risk of damaging components or the circuit board. In addition, the behavior of the system can be monitored and the performance of the voltage regulator circuit can be re-tuned throughout the life of the product. This

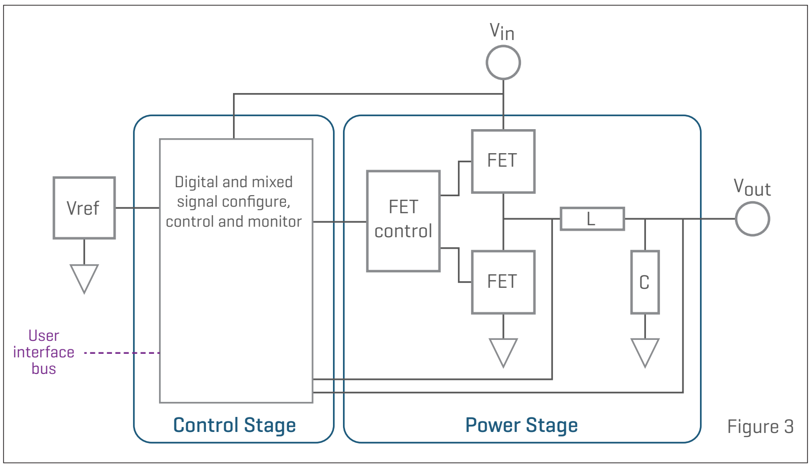


Figure 3: Digital switching voltage regulator

ability to easily modify the performance of the voltage regulator is similar to push-button suspension tuning which is available in some cars.

Auto compensation

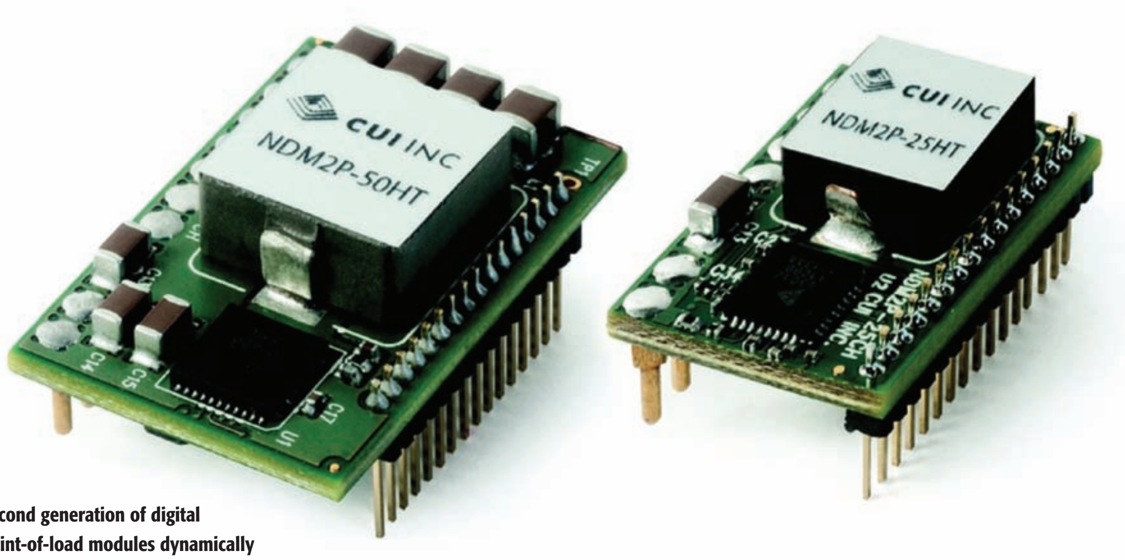
Some advanced digital regulator controllers offer the ability to automatically compensate the regulator for optimum performance by monitoring the characteristics of the output voltage waveform. One advantage of automatic compensation is that the circuit designer does not need any special tools, knowledge or experience to optimize the performance of the voltage regulator.

In a regulator with analog compensation components, the compensation must be set such that the output voltage characteristics are acceptable over changes due to initial component tolerances, aging, temperature, input voltage and many other factors. This means that the circuit is never operating at the optimum performance point. Digital voltage regulators with automatic compensation enable the voltage regulator to operate at peak performance regardless of changes in the system. Automatic compensation of digital voltage regulators can be thought of as having an expert mechanic always in the car to optimize the ride without any burden on the driver or passengers.

CUI offers multiple families of commercially available digital voltage regulator modules with automatic compensation. Proper compensation of voltage regulators enables users to realize optimum performance from their circuits. Tuning the performance of a circuit using traditional analog switching regulators involves a substantial level of risk. Vendors of some analog voltage regulator-based POL modules off er products that simplify the task of compensation by limiting the choices available to the user. Digital voltage regulators, on the other hand, enable firmware based CCM functions which permit the voltage regulator to operate at optimum performance.

All of these topologies require a design team with special tools, knowledge and experience in power supply design to create an acceptable solution. The multiple families of digital POL modules from CUI's Novum® Power line incorporate automatic compensation, allowing system designers ease of use and superior performance in next generation applications.

Digital Point-of-Load Modules Dynamically Set Optimum Stability



Second generation of digital point-of-load modules dynamically set optimum stability in real time as conditions change

CUI's new NDM2P offer true cycle-by-cycle compensation, autonomously balancing the trade-offs between dynamic performance and system stability. With the addition of these second generation modules based on Powervation's digital IC, CUI continues to offer a full portfolio of self compensating digital POL modules. With efficiencies above 93 % at half load, the NDM2P series is initially available in three compact DIP configurations; a 12 A, a 25 A and a 50 A. SMT and SIP versions will be available as well. Additionally, to support dual layout needs, the modules are footprint nested. The NDM2P series is available with an input range of 4.5~14 V DC and a programmable output range of 0.6~3.3 V DC. Features include active current sharing, voltage sequencing, voltage tracking, synchronization and phase spreading, programmable soft start and stop, as well as a host of monitoring capabilities. All features are dynamically programmable via PMBus commands or a simple GUI.

Power Electronics Finally Meet with Motion Control

The dynamic development of power and control electronics on the one hand and the demand for more versatile and efficient electric motor control on the other cause us to rethink how we configure and implement drive systems. Thus a highly flexible embedded controller has been developed to complement motor-bridge power modules, in order to better serve the demands of specialized electric motor drive and Motion Control systems. **Ted Hopper, MACCON, Munich, Germany**

There are many inverters on the market for standard variable-speed and automation applications but there is an increasing demand for tailor-made solutions, which can be economically adapted to match specific application requirements and to be cost-effective in low and medium volume.

Power electronic modules and motor control

IGBT Power stage stacks are now available from power electronics manufacturers, which integrate much auxiliary functionality; this includes integrated driver circuitry, current sensing and short-circuit protection. One such example is shown in Figure 1; this is a member of a large family of power stacks, configured as 3-phase H-bridges to supply motor phase currents from 100 A up to 400 A at supply voltages of 600 and 1200 V DC.

Further significant developments have taken place in industry, which have reached maturity during the last few years such as the acceptance of the soft-PLC; powerful, high-speed, bus-communication standards have become established, e.g. EtherCAT, Profibus, RT-Ethernet; the control algorithms of an inverter can now be fully executed in the digital domain, without performance restrictions: and high-speed FPGAs have become available, which can accommodate both hardware logic and microcontroller software. These developments support a new approach to inverter design, the "Embedded Motion" approach.

The term "Embedded Control" is now fully established in industry. A less common but equally important term in the field of electric motor drives is "Embedded Motion". Here the motor and its control/power electronics become an integral part of the target mechatronic system. Further the motor is supplied in kit-form to allow for direct mechanical integration.

Figure 1: Integrated IGBT Power stage stack (Infineon TechnologiesAG)

Embedded motion principle

Employing this "Embedded Motion" philosophy brings a number of advantages. As the motor is directly coupled to the load, two mechanical bearings, a shaft-coupling and considerable additional mechanics are no longer needed – thus the configuration is compacter and lighter. Also the motor-shaft is shorter (and no longer consists of two parts), it is therefore stiffer and has a lower inertia. This allows the servo-response of the system to be more dynamic and frequencies to increase. The servo-response is both quicker and more precise, less energy is required to run the system the motor and target system control can be implemented in the same logic on the same PCB connections thereby remain short (fewer connectors and cables) and EMC is improved better thermal management can be employed, as the integration environment is well known.

There are some applications, which otherwise cannot be successfully implemented, due to their special requirements (with respect to dynamic response, dimensions, mass, environment etc.). Last not least, this configuration will be the most economical in series production, as the choice and scope of parts and materials then used match the application precisely.

What constitutes an inverter?

Let us consider what a modern industrial inverter consists of; it is the sum of the following parts or functions (see Figure 2):

1. power switching devices to provide electric power to the motor (motor-bridge power module)
2. a mains supply including rectification and regeneration protection
3. a communication interface to a host computer or other devices in the control network

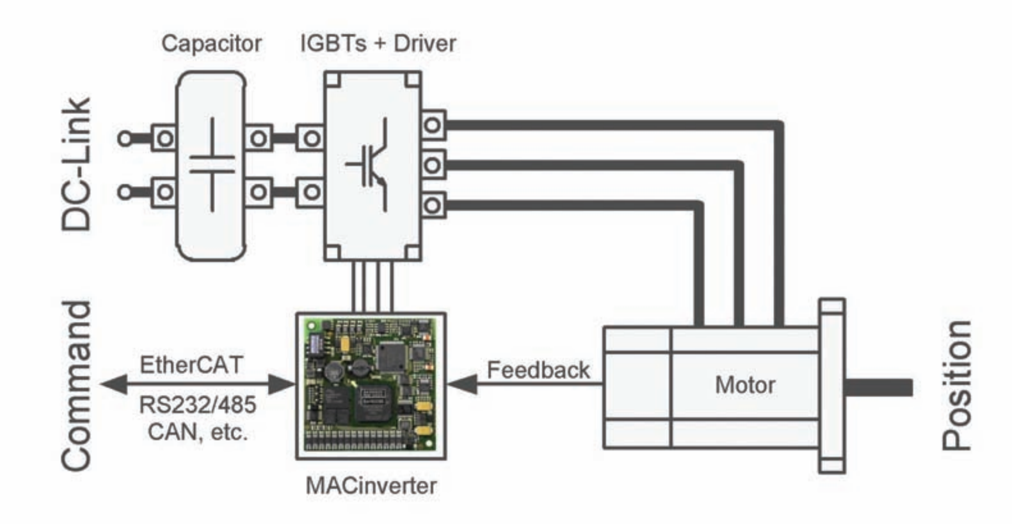


Figure 2: Parts of a motor inverter

4. an integrated PLC or Motion Control sequencer (optional)
5. digital motor control algorithms, fault & safety management
6. auxiliary functions such as housing and interface connectors.

The first two of these functions are largely served by the new power stacks. The next three can now be implemented on a dedicated embedded motion controller board, compatible with standard motor and feedback types, with such features as:

- real-time control implemented in a high-performance FPGA,
- high sampling and PWM frequencies,
- capacity for dedicated customer application functions (in the FPGA or microprocessor),
- extensive library of motor and feedback-control functions,
- powerful host interfaces: Ethernet, EtherCAT, CAN, RS232/422,
- multiple I/O capability (analogue and digital).

The sixth requirement (auxiliary functions - housing and interconnection) can now be implemented exactly to user needs, allowing for both form-factor and environmental specifications.

Embedded motion development platform

A specialized embedded controller (68.5 mm x 68.5 mm x 12 mm, 36 g) has been developed, which is matched to the design requirements of specialized electric motor drive and motion control systems. It incorporates all features needed to implement both simple and demanding electric motor drive systems (see Figure 3). It is compatible with DC, AC and DC-brushless motors and other motor types, e.g. SR and motors with dual or redundant winding systems. Two or more motor power bridges can be controlled from a single card and FET/IGBT power device drivers are switched directly with PWM-switching frequencies up to 50 kHz. Real-time and hardware related control functions are implemented in FPGA logic including torque, speed and position field-oriented control. A comprehensive library of motor-control and feedback signal processing algorithms are available. Feedback devices supported include resolver, incremental encoder (A/B/Z, sine/cosine), Hall–effect sensors, absolute encoders (EnDat, Hiperface, SSI, BISS, Netzer). Host-interfaces include Ethernet, EtherCAT, CAN, RS232/422, also multiple I/Os (analog as well as digital) are included.

Application examples

Combining this embedded controller with a ready power stack allow inverters to be implemented quickly and with minimum development risk, with a free-choice of functionality and to any power rating (currently up to 230 kW).

Examples for possible applications include single-axis, multi-level inverter to special interface and environmental specifications; dual-axis industrial inverter with integrated electronic gearing or back-lash compensation (for antenna control); variable-speed SR-drive; fault tolerant drives with integrated power-stage redundancy for reliability-critical electro-mechanical actuation systems in the field of more-electric aircraft; dual-axis valve actuation control of combustion engines (gas-driven generators); starter-generator control for alternative energy generation systems with mains power regeneration; or twin propulsion drive for an automobile rear-axle, including an electronic differential.

One further advantage of the design approach supported by this embedded controller can be exploited after implementation of the drive prototypes: It is then immediately possible to duplicate the hardware in its final form-factor and interface configuration at minimum expense, still using the same embedded controller board. Only after the application has been fully proven to the final user with the necessary number of prototypes need investment can be made in the industrialization of the final drive product for series manufacture.

Figure 3: Embedded motor controller board MACinverter®

Crack-Proofed High-Voltage Ceramic Capacitors

Syfer StackiCap™ surface mount multi-layer capacitors (MLC) are designed to provide high capacitance voltage (CV) in compact packages and offer the greatest volumetric efficiency and CV per unit mass of X7R ceramic capacitors. Syfer have developed a unique process. Combined with FlexiCap stress relieving terminations these parts have the potential to replace film and tantalum capacitors and make many stacked products obsolete. **Chris Noade, Marketing Manager, and Matthew Ellis, Application Engineer, Syfer Technology, Arminghall, UK**

StackiCap are suitable for a plethora of power electronics applications such as switch mode power supplies for filtering, tank and snubber, DC/DC converter, DC block, voltage multipliers etc. So far 1812 and 2220 case sizes have been launched and are commercially available, sizes up to 8060 are under development.

Downsizing potential

Offering significant increases in available capacitance StackiCap can offer significant downsizing over existing technology. Figure 1 shows the initial product range sizes of 1812 and 2220 alongside two development sizes, 2225 and 3640. 5550 and 8060 development sizes are not shown. Figure 2 shows a range of stacked and stacked leaded assemblies of sizes 2225, 3640, 5550 and 8060 up to a maximum of 5 in a stack. Figures 3 and 4 show examples of what can be replaced with a single StackiCap component. In the most extreme cases an 8060 1 kV 470 nF could be replaced with a single 2220 1 kV 470 nF and a 3640 1 kV 180 nF could be replaced with a single 1812 1 kV 180 nF, these are 10:1 and 7:1 footprint reductions respectively.

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 a 33 nF capacitance previously found only in the much larger 5550 case size. In the 1812 range, the 200 V part also features 1 µF capacitance, while the 1 kV device features 150 nF capacitance, previously only possible in larger size components.

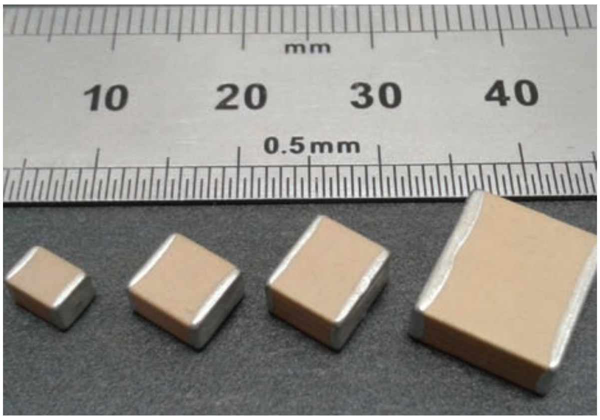


Figure 1: StackiCap sizes 1812 to 3640

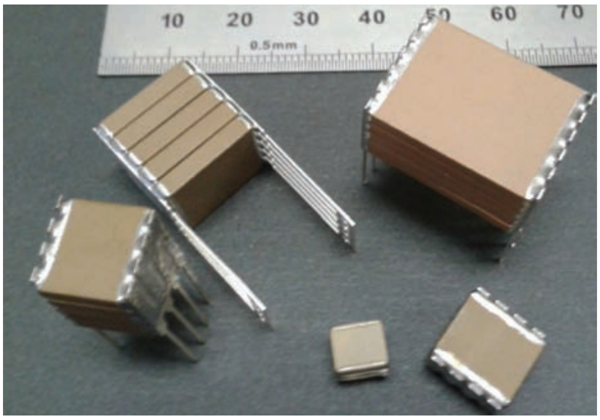


Figure 2: Various stacked assemblies up to 8060 5 stack

Historical limitations

The limits of design are defined by the failure modes and there are many failure modes which limit the extent to which mid to high voltage MLCC can be developed. There are extrinsic failure modes such as mechanical and thermal cracking but we will look at the intrinsic ones which are in the hands of the manufacturer.

The limiting factor for MLCC has changed over time, early MLCC were limited mainly by the quality and purity of the dielectric materials themselves with point defects and contamination (see Figure 5), limiting the maximum number of layers and the minimum thickness of those layers. As dielectric materials and materials preparation and processing improved the limiting factor became the dielectric strength of the material itself.

Once this point had been reached one could imagine that thicker and larger parts could be manufactured without fear of dielectric breakdown (Figure 6), or point failures, however a new failure mode appeared, electromechanical stress cracking. Commonly referred to as piezo electric it can also follow electrostrictive behavior (see Figure 7). This is the failure mode that has been the limiting factor for MLCC manufacturers for some time now, it affects most class II barium titanate base dielectrics and becomes an issue for larger size, 1210 upwards, and higher voltage,

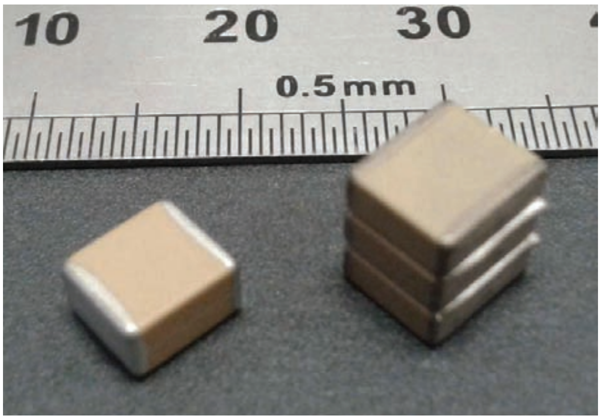


Figure 3: **2220 500 V 1 µF StackiCap™ and 2225 3 Stack 500 V 1 µF**

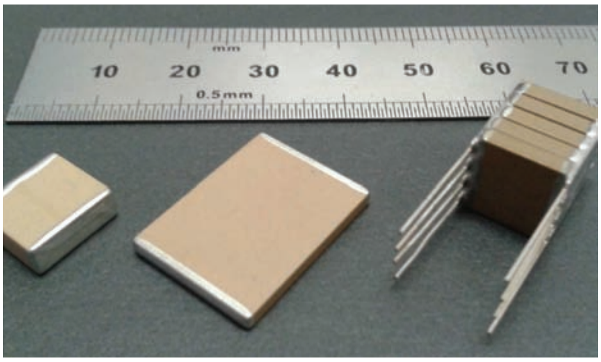


Figure 4: **3640 500 V 3.3 µF StackiCap with 8060 and 3640 5 stack alternatives**

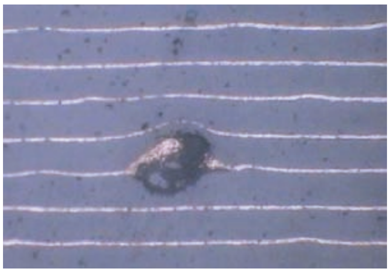


Figure 5: **Contamination defect**

Figure 6: **Dielectric breakdown**

200 V upwards components.

The crack typically runs through the centre of the component along one or two dielectric layers. Most solutions involve stacking capacitors together with lead frames in order to increase the available capacitance for a given footprint but this is labor intensive, costly and can lead to other reliability issues. Other solutions involve special dielectric formulations but these are usually a trade-off for dielectric constant and therefore the ultimate capacitance value available.

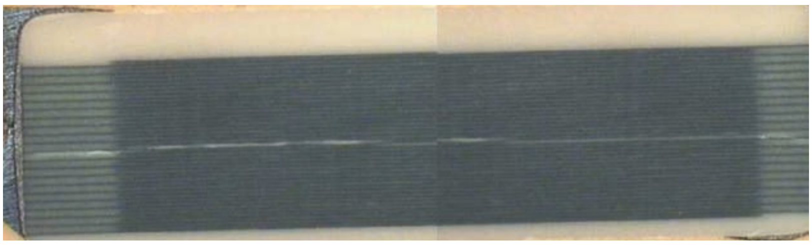


Figure 7: **Piezo stress crack failure**

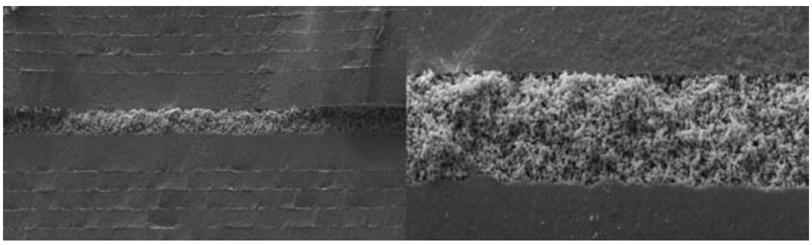


Figure 8: **SEM micrograph of fracture sections showing the stress relieving "spongy" layer**

The technology behind StackiCap

After a series of trials and iterations Syfer have developed a single chip solution to this electromechanical failure limitation. The novel and patent pending aspect, GB Pat. App. 1210261.2, is an inbuilt stress relieving layer which allows the capacitor to exhibit the electrical and physical behavior of multiple, thinner, components whilst exploiting the manufacture and process benefits of being a single unit. The stress relieving layer is made up of a combination of already utilised material systems and is formed during the standard manufacturing process (see Figure8). The layer is positioned in the place/s where mechanical stress is the greatest allowing for mechanical decoupling of the multiple component layers with 2, 3 and 4 "stack" versions trialled at this point.

With FlexiCap flexible termination material and no need to attach components together to form a stack there is no need for a lead frame allowing for standard tape and reel packaging with pick and place capability.

Extensive testing

StackiCap technology has been under development for some time, parts and materials have been subjected to Syfer's standard quality control and reliability regime. In addition to the standard inspection and tests performed during batch manufacture, a sample of batches is also randomly selected for additional routine endurance, humidity and bend tests. Reliability tests are also conducted by external test laboratories as part of maintaining product approvals and are also conducted to assess long-term product performance.

The released StackiCap range has passed all testing and has amassed over 2,000,000 hours of reliability test time. High Reliability testing is also ongoing with a full AEC-Q200 Rev D qualification under way for 1812 and 2220 case sizes, additional rel qualification testing can be considered on request.

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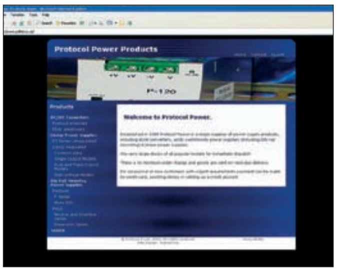

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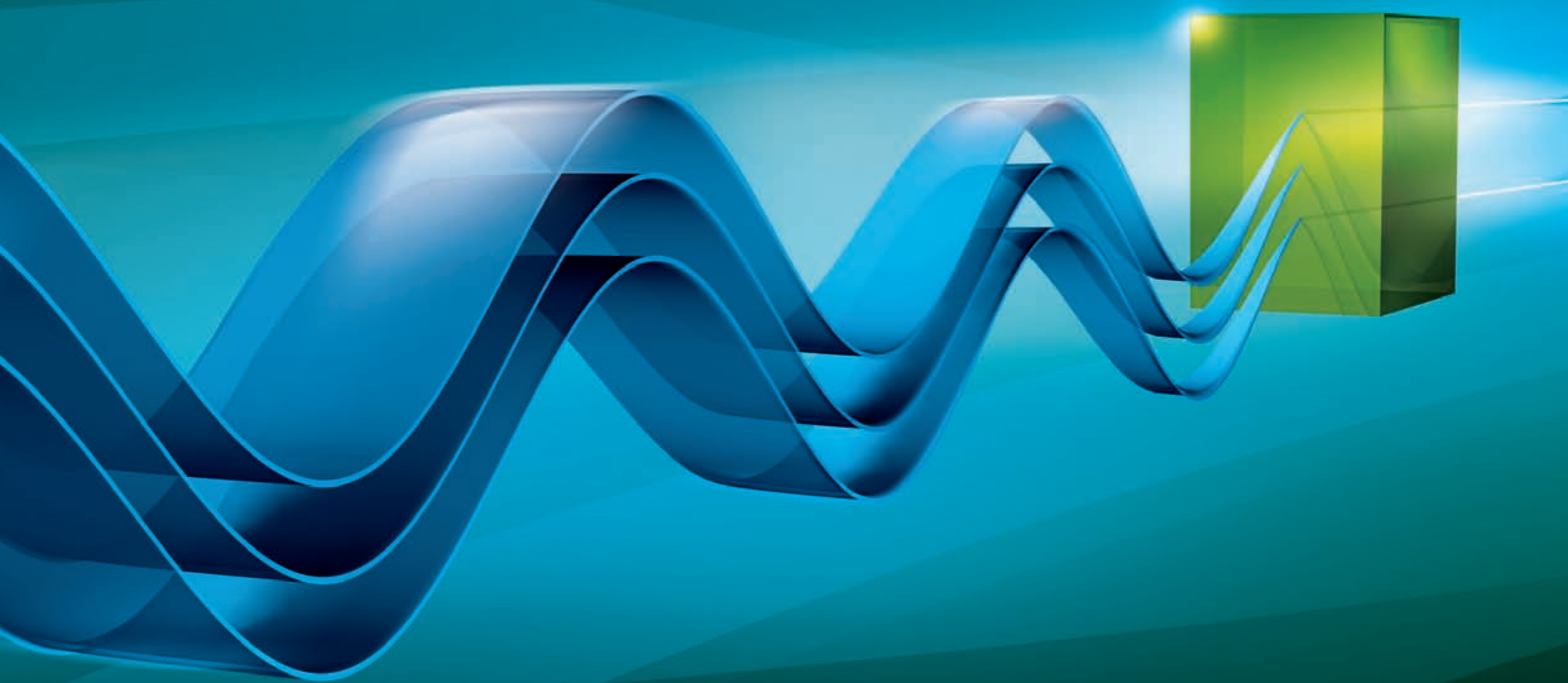

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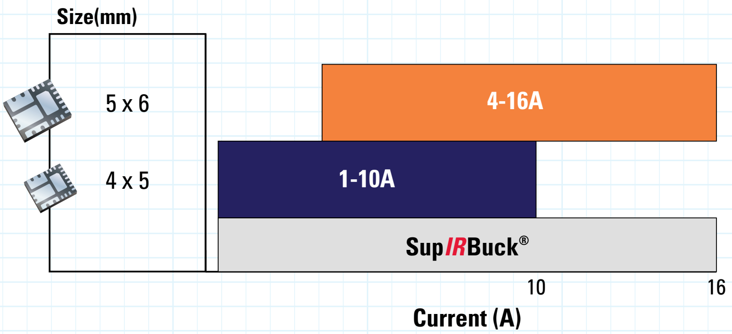

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