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Bodo´s Power Systems®

Electronics in Motion and Conversion

May 2014


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Read online and search for key subjects from all articles in Bodo's Power Systems by going to Powerguru: www.powerguru.org

The Gallery

Bodo´s Power Systems®

A Media
Katzbek 17a
D-24235 Laboe, Germany
Phone: +49 4343 42 17 90
Fax: +49 4343 42 17 89
editor@bodospower.com
www.bodospower.com

Publishing Editor
Bodo Arlt, Dipl.-Ing.
editor@bodospower.com

Senior Editor
Donald E. Burke, BSEE, Dr. Sc(hc)
don@bodospower.com

Corresponding Editor
Marisa Robles Consée,
Marisa@bodospower.com

Creative Direction & Production
Repro Studio Peschke
Repro.Peschke@t-online.de

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Summer here we come!

2014 started with a bang and several successful shows and conferences: APEC in Fort Worth, Texas, and PEMD in Manchester, the United Kingdom. New semiconductors in wide band gap material have been a major point of discussion and well presented – though there is still work to do when it comes to mature catalog products for general usage. But we're getting closer. Engineers from China were present at these conferences and undoubtedly we will soon see the results of their hard work in this technology.

PCIM Europe, coming up in May, is the next major power show in Europe. Please mark your calendars for what has become a tradition, the podium discussion that I will moderate at this year's PCIM Europe. This year I have chosen the subject **"Mature Wide Band Gap Semiconductors."** Experts in the industry will highlight the status of development, advanced solutions, and the steps being made to support new designs in volume. I'd very much enjoy seeing you at the **Fach Forum in Hall 6, Booth 340,** on Wednesday the 21st of May at 12:20.

Industry experts in both SiC and GaN will share important details surrounding the application critical aspects of using these devices in new designs. There will be a comparison to silicon to highlight benefits and draw a picture of future possibilities. We are expecting smaller size drives and power supplies, where the reduction of losses has been well presented and switching frequency can rise. These devices have increased the efficiency of converters in solar for some time now, and next up will be transportation and aerospace.

Other areas will follow, ranging from low voltage applications in handhelds to spanning-up to station-class with several kilovolts.

In recent years, Bodo's Power Systems magazine has regularly presented articles from the industry which signal that we are in the midst of a generational change, from established silicon to GaN and SiC.

And in addition to the exciting conference highlights at PCIM Europe 2014, we are looking forward to the white asparagus in Nuremberg, a regional specialty.

Communication is the only way to progress. We delivered twelve issues last year, each month, on time, every time. With this May issue we have published 66 technical articles amongst 372 pages this year. They are all archived and retrievable at PowerGuru. As a media partner, Bodo's Power Systems serves readers across the globe. If you speak the language, or just want to have a look, don't miss our Chinese version: **www.bodospowerchina.com.**

My Green Power Tip for May:
Share a ride or use public transportation - you will reduce emissions, and if you are driving yourself and parked or at a light, turning off your engine will help.

See you soon at PCIM in Nuremberg, and around the world.

Best Regards

Events

SMT Hybrid 2104,
Nuremberg, Germany, May 6-8
http://www.mesago.de/en/SMT/home.htm

PCIM Europe 2014,
Nuremberg, Germany, May 20-22
http://www.mesago.de/en/PCIM/home.htm

ISiCPEAW 2014,
Stockholm, Sweden, May 25-27,
www.acreo.se

eCarTec 2014, Paris, France
May 20-22 www.ecartec.de

Sensor + Test 2014,
Nuremberg, Germany, June 2-5
/www.sensor-test.com/press

Intersolar 2014,
Munich, Germany, June 2-6
www.intersolar.de/de/intersolar-europe.html

PCIM Asia 2014,
Schanghai, China, June 17-19
www.mesago.de/en/PCC/home.htm

Utility Energy Storage Europe,
London, UK June, 18-19
www.smi-online.co.uk/utility/uk/conference/distributed-energy-storage

Thermal Management 2014,
Denver CO, August, 6-7
www.thermalnews.com/conferences/

EPE ECCE 2014,
Lappeenranta, Finland, August 26-28
www.epe2014.com/

Jim Witham appointed as CEO

GaN Systems, a leading developer of gallium nitride power switching semiconductors, announced the appointment of Jim Witham as CEO of the corporation. GaN Systems' power conversion devices, based on its proprietary Island Technology®, are being commercialized in 2014 and the company is expanding globally. Co-founders Girvan Patterson and John Roberts will continue in their current roles as President and Chief Technical Officer, respectively.

Witham has over thirty years' experience in business development, international sales and marketing and operations management, and joins GaN Systems from Neoconix Inc., a manufacturer of high density, high performance miniature connectors. As President and CEO of Neoconix, he successfully implemented strategic changes which dramatically increased revenue and resulted in the company's acquisition by Unimicron Technology Corporation. Prior to Neoconix, Witham spent five years as President and CEO at Fultec Semiconductor and has also held VP Sales & Marketing positions at Aegis Semiconductor and Genoa Corporation. Other notable career highlights include senior executive positions at Raychem, including Director of Asia Sales & Marketing, based in Japan. As an Engineering Specialist at General Dynamics' Space System Divison during the eighties, Witham worked on fluid systems for the Space Shuttle and was on Mission Control for interplanetary missions. Witham holds an MBA from Harvard and both M.S. and B.S. with distinction in Mechanical Engineering from Stanford University.

www.gansystems.com

High-Fidelity HIL Modeling on FPGA is a Now a Reality Made Easy

OPAL-RT worked on the first hybrid and electric vehicle designed by Toyota. At that time, we succeeded in simulating the electrical motor at 10µs, which was a technological breakthrough. This demanding challenge required to push real-time simulation on CPU to its limits. Indeed, the main limitation of HIL simulation on CPU is the time required to transfer data between the I/Os and the CPU that are connected to the Field-Programmable Gate Array (FPGA). Transfers pass through the PCIe bus, with data transfer times in the microseconds, therefore it wasn't possible to lower the timestep below a few microseconds.

"By using the FPGA for the same process, we are now able to send data directly to the I/Os without needing to go through the PCIe bus, which enables a faster calculation step. This is why OPAL-RT pioneered real-time simulation on FPGA, being one of the few companies capable of addressing the challenges related to it, making possibilities of tests consequently endless." Jean Belanger, OPAL-RT CEO & CTO.

Perfect for simulating power electronic systems such as photovoltaic grid-connected converters or electrical motor drives with FEA-based motor models, eFPGAsim suite can be used for feasibility studies, protection, control system development and testing using hardware-in-the-loop (HIL) as well as power-hardware-in-the-loop (PHIL). This suite encompasses an FPGA based general purpose electromagnetic transient (EMT) solver implemented on an FPGA chip called eHS (electrical Hardware Solver), designed to accept and solve a variety of simulation problems on the FPGA using a simple circuit editor without complex VHDL programing. Time step below 500ns can be achieved for complex multi-level converter simulation. In addition, the release of RT-LAB XSG software provides the user with a state-of-the-art solution for advanced FPGA real-time and HIL system simulation of user developed models and control systems. Users generate custom application and specific models that can easily be implemented onto an FPGA device.

www.opal-rt.com

Intersolar China 2014 Celebrates Positive Results

Intersolar China took place in Beijing from March 26–28, 2014. For the first time, the exhibition and conference for the solar industry was held together with CIPV Expo China and Clean Energy Expo China. Upwards of 7,000 visitors to the China International Exhibition Center (CIEC) received information on technology, solar industry products and services, energy storage, grid technology, biomass and wind energy from around 300 exhibitors. In parallel to the exhibition, the Intersolar China Conference was held from March 25–27, 2014 in Beijing's Kempinski Hotel, where 68 speakers and 384 attendees discussed the latest market developments and new technologies in the solar industry.

Intersolar China 2014 gave cause for great satisfaction among organizers and attendees alike. With representatives from 48 countries, the exhibition yet again provided an international meeting point for the solar industry in 2014. Between Intersolar China and its accompanying exhibitions, some 300 exhibitors were on hand to provide information about technologies as well as products and services in the fields of photovoltaics, solar thermal technologies, wind energy, biomass, grid technology and energy storage systems.

www.intersolarchina.com

6.5kV 285A Press-Pack IGBT

IXYS UK, IXYS Corporation's (NASDAQ:IXYS), high power subsidiary, announced the launch of a new 6.5kV press-pack IGBT. The new 6.5kV device is asymmetrical blocking with a fully rated anti-parallel diode included within the package. DC collector current rating is 258A with a repetitive peak current rating of over 500A, further extending the power range of IGBT power switches.

The device is housed in a fully hermetic press-pack package with 66mm diameter copper electrodes and an overall package diameter of 100mm. The internal construction is based on the same high reliability construction as IXYS UK's well established 4.5kV product lines, but with a larger individual die size to optimise die active area and the overall efficiency of rating within the package. As with all IXYS UK's press-pack IGBT products, the new device is inherently robust with phenomenal thermal cycling endurance, double sided cooling and ruggedness in failures without package rupture.

The part number for the new device is T0258HF65G and a full data sheet is available on IXYS UK's web site:

www.ixysuk.com

High-Insulation Power Supplies – Strategic Power Electronics Components

Since the start of the year, Siebel Elektronik GmbH has been presenting itself in an entirely new guise. A new building in the Kredenbach industrial zone in Kreuztal near Siegen has been constructed on a "greenfield site". Production, logistics, development and the laboratory now share one workplace. It has been possible to restructure and optimise the workflow.
What is very apparent at first glance is the new design of the company logo – this also symbolises this next step in the development of the up-and-coming company. 510 m^2 of production space and useful floor space have been newly created and now provide 14 employees with an attractive place to work.
The product range offered by Siebel Elektronik GmbH extends from the development and production of small switched-mode power supplies from 20 W through to 70 kW in the case of IGBT inverters. In addition to complete systems, individual control components with individual software are also developed. "We cover the full spectrum from devising concepts and developing hardware and software through to prototyping and commissioning," explains managing director Dr Henrik Siebel. "This means we have a deep understanding of the application and this helps us to offer customers the optimum solution for them."

"An important production line that we manufacture is single-channel and multi-channel devices for the potential-free power supply of industrial electronics, in particular for IGBT and IGCT applications", continues Dr Siebel. "The insulation voltages here are between 18 kV and 50 kV – and they are free of any partial discharge. This is an important characteristic distinguishing us in the market, which is moving more and more in the direction of multi-level topologies. A large number of international customers already appreciate our expertise in high insulation resistance. Development work never stops of course and we are currently already working on expansions to this product range."
Head of production Marion Dietrich is proud to show off the new manufacturing facility: "The employees are absolutely delighted with their new place of work. Thanks to the new building, we have of course been able to plan all of the work processes in an optimum way. The consolidation of development, laboratory and production also creates synergies. We notice this every single day."
GvA Leistungselektronik GmbH is the globally authorised distribution channel for the single-channel and multi-channel power supply systems of Siebel Elektronik GmbH.

www.gva-leistungselektronik.de

President & CEO, Chairman Appointed

Mitsubishi Electric Corporation
Masaki Sakuyama

Mitsubishi Electric Corporation appointed Masaki Sakuyama as the company's new President & CEO, effective April 1, 2014. Sakuyama will replace Kenichiro Yamanishi, who will assume the position of Chairman. Sakuyama was born in Hyogo Prefecture in 1952. Joining Mitsubishi Electric Corporation in 1977, he first served as an engineer in the company's Kobe Works. He became Mitsubishi Electric's Executive Officer and Group President of Energy & Industrial Systems Group in 2008, and Senior Vice President and General Manager of Corporate Strategic Planning Division in 2010. In 2012, Sakuyama was promoted to Executive Vice President and Group President of Semiconductor & Device Group.
Yamanishi was born in Osaka Prefecture in 1951. He joined Mitsubishi Electric Corporation in 1975, and was named Executive Officer and Vice President of Corporate Total Productivity Management & Environmental Programs in 2006. In 2008, he became Senior Executive Officer and Group President of Semiconductor & Device Group. Yamanishi was appointed President & CEO in 2010.

http://www.MitsubishiElectric.com

Leverages Expertise to Charge Ahead in Power Management

Intersil Corporation announced plans to leverage the company's deep technology portfolio and strong track record of innovation to focus on power management solutions for applications ranging from cloud computing to mobile devices. Under new management, Intersil returned to profitability, and successfully aligned its business to address the power management market. The company's renewed focus sets the stage for Intersil to bring the next wave of products to market addressing the most challenging power management issues in systems, including efficiency, battery life, reliability and intelligence.
"When I joined Intersil in March of 2013, it was with a great deal of optimism given the strong heritage and technical capability of the company," said president and CEO Necip Sayiner. "On my first anniversary as CEO, I am extremely proud of what our employees have accomplished in a very short time. By putting the company on sound financial footing and then concentrating our efforts on strategic areas where we have highly differentiated technology, we are positioning Intersil to become a leader in the next generation of power."
Intersil is leveraging a deep portfolio of intellectual property, and a history of design and process innovation, to enable the industry's highest performance, most efficient, easy-to-use, and consistently reliable power management IC solutions. The company is uniquely positioned to bring a number of key technologies to the $10 billion power management market.

www.intersil.com

Intelligent Digital Power™ Solutions

Powervation Ltd. has discussed its Intelligent Digital Power solutions for cloud/datacenter server infrastructure, high performance computing, power modules, and communications infrastructure, at APEC in Fort Worth, Texas. In addition to various booth displays of power management solutions and customer reference designs, Powervation has hosted technical sessions on topics related to digital power for computing and communications applications.

www.powervation.com

Exhibit at PCIM Europe 2014

Dynex Semiconductor Ltd is pleased to announce that it will be exhibiting at PCIM Europe 2014 Nuremburg from 20th – 22nd May, Hall 9 Stand 404, showcasing the latest high power devices and power assemblies for the worldwide high power electronics market.
On this stand you will find power products manufactured in the UK by Dynex alongside those produced in China by Zhuzhou CSR Times Electric.
Dynex Semiconductor Ltd, a leading UK high power semiconductor manufacturing company with extensive custom design, and research and development facilities, is a subsidiary of Zhuzhou CSR Times Electric based in Hunan Province in the People's Republic of China, a leading manufacturer of railway power electronic systems with a long history of manufacturing high quality high performance power semiconductors to the exacting standards of the railway industry.
PCIM Europe Hall 9 Stand 404

www.dynexpower.com

Opportunities for Power Semiconductors at SEMICON Europa 2014, October 7-9

At the Alpexpo, Grenoble, France for the first time, SEMICON Europa will showcase device makers and companies bringing the latest energy efficiency applications and innovations to market. The Energy Efficiency segment will showcase cutting-edge energy technologies leading the way in areas including electronic systems for high, medium, and low voltage; power semiconductors, power management ICs, and passive components; power supplies and batteries; energy harvesting solutions; smart grids technologies; and software.

www.semiconeuropa.org

Teun Bokhoven is Conference Chairman of the 29th European Photovoltaic Conference

The 29th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC 2014) taking place from 22 to 26 September 2014 at RAI Convention and Exhibition Centre in Amsterdam, The Netherlands, will be chaired by Teun Bokhoven. The five-day Conference is complemented by the three-day Exhibition, held from 23 to 25 September 2014.
Teun Bokhoven is President of the Dutch Renewable Energy Federation and has over 25 years of experience in the international solar energy sector. He established a number of solar energy companies in Europe and he is involved as solar market expert in several global initiatives like the UNDP. He was one of the founders of the Dutch solar trade association Holland Solar and the European Solar Thermal Industry Federation (ESTIF). In the Netherlands he is President of the Dutch Renewable Energy Federation (Duurzame Energie Koepel), an umbrella organisation for all renewable energy sector associations (solar, wind, bio-energy, etc.). In that capacity he played a key role in the recent establishment of the Dutch National Energy Agreement on "greening the economy".

www.photovoltaic-conference.com

www.photovoltaic-exhibition.com

Key Statistics of World Wind Energy Report published

On the occasion of the World Wind Energy Conference WWEC2014 in Shanghai, WWEA has presented the key statistics of the World Wind Energy Report 2013:

- World wind energy capacity reached 318'529 MW by end of 2013, after 282'275 MW in 2012.
- 35'550 MW of new wind capacity was added, the smallest growth since 2008, and after 44'609 MW in 2012.
- The growth rate reached only 12,8%, the lowest level since modern wind power utilization has started around the world.
- Wind power contributes close to 4% to the global electricity demand.
- In total, 103 countries are today using wind power on commercial basis.
- China was still by far the leading wind market with a new capacity of 16'000 MW and a total capacity of 91'324 MW.
- The US market saw a dramatic slump and installed only 1 GW, after 13 GW in 2012.
- Asia has now the same installed capacity like Europe (119 GW) and is expected to overtake Europe in 2014 as largest wind continent.
- The most dynamic markets with highest growth rates can still be found in Latin America and in Eastern Europe as well as for the first time in Africa, where Morocco showed a growth of 70%, the second highest growth rate of all countries, just behind Chile (76%).
- In some countries, wind power reached very high shares in the electricity supply; in Denmark (34%) and Spain (21%), wind energy has become the largest source of electricity; also Portugal (more than 20%), Ireland (more than 16%) and Germany (9%) have reached high portions.
- 7,4 GW of offshore wind was installed by end of 2013, and close to one million small wind turbines.
- For the year 2020, WWEA sees a wind capacity of more than 700'000 MW as possible.

www.WWindEA.org

Compact and Efficient Electromotor

German researchers present the prototype of an electric motor that may shape the future of electromobility: Small, light and efficient. The electric motor was created and constructed by the four German partners in the European research project "MotorBrain": Infineon Technologies, Siemens, the Institute of Lightweight Engineering and Polymer Technology at the Technische Universität (Technical University) Dresden and ZF Friedrichshafen. The prototype is being presented at the Hannover Messe "MobiliTec" fair stand of the German federal government (Hall 27, Stand H51).

The MotorBrain prototype is a highly integrated electric motor that unifies the most important components of the powertrain for an electric vehicle. The researchers have succeeded in designing a highly compact electric motor with only three-quarters the size of models from 2011, the year when MotorBrain began. The electric motor prototype now being presented could easily fit in a conventional-sized laptop or notebook backpack. And on top of that, it's lighter than before. By the integration of motor, gear drive and inverter the MotorBrain partners were able to cut down the weight of the powertrain by approximately 15 percent, from 90 kilograms to less than 77 kilograms. Reduced size and weight will benefit the future car owner: A lighter electric vehicle that brings battery power "to the street" more efficiently and has a longer range than the electric vehicles of today. A medium-sized vehicle with MotorBrain electric motor and performance of 60 kilowatts (equal to about 80 hp) would be able to drive a good 30 to 40 kilometers farther than today's electric vehicles with their average range of approximately 150 kilometers per battery charge.

Furthermore, the partners succeeded in building the MotorBrain prototype without using rare earth metals, which are currently a fundamental cost driver in hybrid and electric vehicles. Today rare earth metals are an important component in the permanent magnet of any electric motor, generating a particularly strong, constant magnetic field. The stronger the magnetic field, the higher the performance capabilities of the motor. However, obtaining rare earth metals is extremely complicated and environmentally harmful. Also, rare earth metal prices are high and fluctuate widely. The MotorBrain electric motor therefore utilizes readily available and less expensive ferrite magnets. The lower performance level of ferrite magnets compared to those with rare earth metals is compensated for by the specially developed high-RPM (revolutions per minute) rotor of the MotorBrain electric motor.

You'll find more information on MotorBrain and the participating research partners at

www.motorbrain.eu

www.infineon.com

Winners of 2013 Global Operations Excellence and 2013 European Supplier Excellence Awards

TTI, Inc. has announced that Vishay is the winner of its 2013 Global Operations Excellence Award, which goes to the supplier who earns recognition for outstanding performance in all three TTI regions (Americas, Europe and Asia). Six companies - Bourns, Kemet, KOA, Littelfuse, Molex and Vishay – qualified for the prestigious global award, which is assessed on a matrix of quality measurements that include on-time delivery, receiving quality, customer-reported quality, administrative quality and operations and business systems. In addition, there are performance measurements such as sales and growth as well as management support. Measured on all these criteria by TTI's global regions, Vishay was the top-scoring supplier.

Focusing in on Europe, TTI recognized eight of its suppliers in its 2013 Supplier Excellence Award Program, for not only meeting but exceeding the required criteria. Murata, Bourns and Molex were the top three performers, each achieving Platinum Level: Murata and Bourns for a consecutive year, while Molex moved up a level during 2013. Of these three, Bourns achieved the highest overall score and was the recipient of TTI's 2013 Diamond Award. Kemet Electronics was also recognized for maintaining Silver level, Vishay for moving up to Silver level and TE Connectivity for maintaining Bronze Level.

www.ttieurope.com

Power Management Selection Guide 2014 available now

Infineon Technologies has released the 2014 edition of its Power Management Selection Guide. It provides customers with application as well as product focused information, thus supporting their decision on the right solution for their specific system. According to IHS, Infineon has been the global market leader in power semiconductors for ten consecutive years. Target applications are servers, telecom systems, computers, game consoles, smart phones, cellular infrastructure and lighting solutions. "Being a recognized leader with product families such as Cool-MOS™ or OptiMOS™ for over a decade, Infineon has greatly strengthened its system competence," says Andreas Urschitz, President of the Power Management & Multimarket division of Infineon.
Infineon`s Power Management Selection Guide for download:

http://www.infineon.com/powermanagement-selectionguide

ECPE Events in 2014

- ECPE Tutorial
  'EMC in Power Electronics'
  3 - 4 June 2014, Barcelona, Spain
  Chairmen:
  Dr. E. Hoene (Fraunhofer IZM),
  Prof. Dr. J.-L. Schanen
  (INPG-LEG-ENSIEG - G2ELab)
- ECPE Workshop
  'Advanced Multicell / Multilevel Power Converters'
  1 - 2 July 2014, Toulouse, France
  Chairmen: Prof. T. Meynard (Univ. of Toulouse), Prof. J.W. Kolar (ETH Zurich)
- ECPE/Cluster Tutorial
  'Part I - Thermal Engineering of Power Electronic Systems (Thermal Design and Verification)'
  22 - 23 July 2014, Erlangen, Germany
  Chairmen:
  Dr. U. Scheuermann (Semikron),
  Dirk Malipaard (Fraunhofer IISB)
- ECPE Tutorial
  ‚Power Electronics Packaging'
  24 - 25 September 2014, Delft, Netherlands
  Chairmen: T. Harder (ECPE)
  Dr. U. Scheuermann (Semikron),
- ECPE Workshop
  'Innovations in Passive Components for Power Electronics Applications'
  9 - 10 October 2014, Berlin, Germany
  Chairmen: Dr. S. Weber (EPCOS)
  Prof. W.G. Hurley, (Nat. Univ. of Ireland),
- ECPE Tutorial
  'Thermal Engineering of Power Electronic Systems - Part II (thermal management and reliability)'
  14 - 15 October 2014, Nuremberg, Germany
  Chairmen: Prof. E. Wolfgang (ECPE),
  Dr. U. Scheuermann (Semikron)

The up-to-date ECPE Calendar of Events 2014 with all ECPE Workshops and Tutorials is available on the ECPE website:

www.ecpe.org

Industry's Best in Class Series of 1200V SiC Transistors

United Silicon Carbide's breakthrough xJ series of 1200V JFET's are the industry's lowest $R_{DS(on)}$ SiC transistor device. This market milestone for silicon carbide enables best in class converter and inverter system efficiency through incorporating the lowest figure of merit (FOM) switch commercially available. The depletion mode xJ JFET series takes advantage of silicon carbide's significantly superior performance over silicon, offering the user the best wide bandgap switch at standard 175°C T_j max. When appropriately packaged, the xJ series is capable of operating at temperatures of 250°C and beyond. The xJ series is targeted for use in power conversion circuits where efficiency counts. Applications such as high-end Server and Telecom SMPS, PC Silver box and solar inverters all demand the performance of SiC JFET's to meet the latest efficiency standards and regulations, with motor drives, uninterruptible power supplies (UPS), electrical vehicle (EV) and other consumer AV markets all embracing the SiC advantage.

Both the 45 mOhm and 80 mOhm product are available in TO247 and die form.

www.unitedsic.com

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www.ttieurope.com

Power Module Development in Frankfurt Germany

In its Frankfurt-venues Fuji Electric Europe established capabilities and capacities for customer-specific Power Modules design. So-called EUROPEAN-DESIGN-and-TECHNICAL-CENTER (EDTC).

Shortening the distance between European Customers and Fuji's Development respectively Production in Far East was one of the goals identified by FEE's 1st President of European origin Mr. Peter Hermann Maier when he took over the lead in FEE.

Hence a team of 4 design-engineers has started operation in this January in Fuji's premises in Frankfurt consisting of
2 Japanese-Engineers with several years of experience in Power-Modules and to transfer their know-how and experience to
2 local R&D-engineers supported by
4 experienced Application Engineers

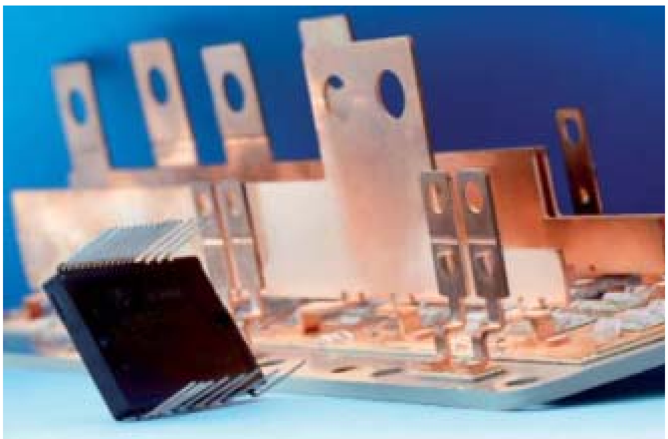

Figure 2: IGBT-Modules from 8A to 3600A (600, 1200, 1700, 3300V)

In close co-operation with the European Sales and Application-Engineering this team will quickly:

- Identify customers' requirements
- Adapt existing components to meet those requirements
- Develop solutions and
- Provide specification and samples

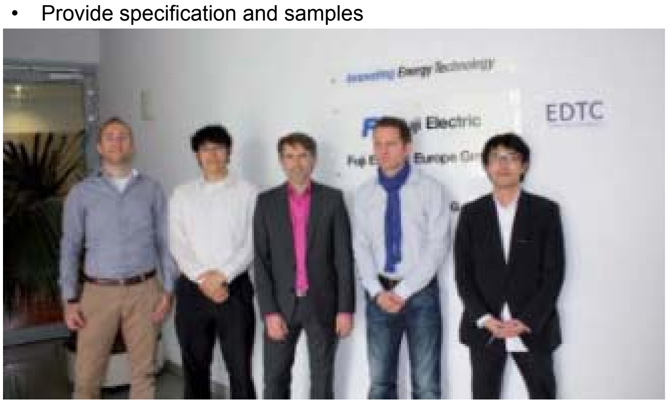

Figure 1: From left: S. Werner, T. Harada, T. Heinzel (Manager), M. Lerch, T. Hitachi.

Based on the existing Technologies there will be nearly no limitation for product variety!

- 600V, 1200V, 1700V, 3300V-IGBTs
- Trench-Gate/Field-Stop 6th Generation-IGBTs
- 6th Generation FWD
- Econo, Standard, HPM, Prime-Packages
- Al2O3 or AlN-DCB

www.fujielectric.de

Northern Germany Leading for Intelligent Renewable Energy

Schleswig-Holstein and Hamburg will apply for the 100 percent renewable energy regional test.
Both states of Germany will apply together for winning the Federal State sponsored project.
Wind Power and Solar together with Bio Gas Generators are targeted to serve 100 percent of the demanded electrical energy for a specific test region. It is a perfect match to have the wind power from the agriculture area of Schleswig-Holstein serving the need of energy in Hamburg a major sea port and industrial area. Senator Horch from Hamburg and Minister Meyer from Schleswig-Holstein presented their view at the Fraunhofer ISIT. The Fraunhofer ISIT already has the Competence Center for Renewable Energy and has a strong link to related industrial customers.

www.isit.fraunhofer.com

IEEE PES Nari Hingorani Custom Power Award for Harshad Mehta

Dr. Harshad Mehta has been selected as the 2014 recipient of the IEEE PES Nari Hingorani Custom Power Award! This award, from the IEEE Power & Energy Society (PES), recognizes an individual who has made a major contribution to the state-of-the-art in Custom Power technologies and their applications. The IEEE Custom Power concept applies to power electronic (static) controllers in 1 kV through 38 kV distribution systems as Static VAR Compensators and other Controllers; their hardware, software and application development. Award recipients are selected through a competitive, vetted nomination process. The award and recognition will take place at the IEEE PES General Meeting in National Harbor, MD (Washington, DC Metro Area).

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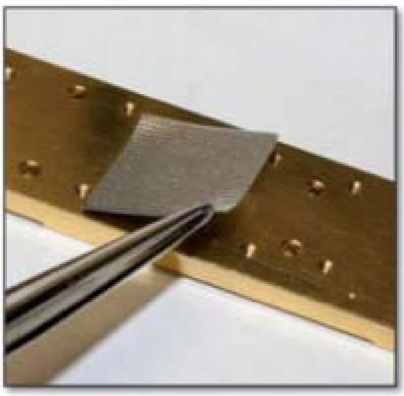
Celebrating 80 Years: From Simple Fabrications to Nanotechnology

When Indium Corporation was founded in 1934, the company focused on developing basic fabrications using indium metal, such as wire, ribbon, and simple alloys. Today, Indium Corporation's expanded product line serves markets ranging from energy delivery to semiconductor assembly to thermal management to electronics assembly. Their products include solders, fluxes, thermal interface materials for power electronics and NanoFoil®, to name a few.



"Indium Corporation has become known for solving challenges that others haven't been able to figure out," said Rick Short, director of marketing communications. "That comes from our curiosity as scientists and engineers, but is also a testament to our commitment to seeing things through to a conclusion."
With about 750 employees globally, Indium Corporation continues to lead and support the advancement of technologies.
Senior Product Manager for Engineered Solders Tim Jensen shared his reflections, "As phones, computers, tablets, and other electronics decrease in size but increase in added functionality, heat dissipation is critical. One of the products that Indium Corporation already offers to meet changing technologies is our Heat-Spring® thermal interface material, which offers thermal conductivity and compressible capabilities that overcome thermal challenges."
From state-of-the-art power electronics to nanotechnology, Indium Corporation is already developing the products to enable the next technological revolutions.

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Win a MCP3913 AFE Evaluation Board!

The Microchip MCP3913 ADC Evaluation Board (Part No ADM00522) for 16-Bit MCUs provides the opportunity to evaluate the performance of the MCP3913 six-channel AFE. The MCP3913 device is a 3V six-channel AFE, containing six synchronous sampling delta-sigma ADCs, six PGAs, phase delay compensation block, low-drift internal voltage reference, digital offset and gain error calibration registers, and high-speed 20 MHz SPI compatible serial interface. The MCP3913 AFE is capable of interfacing with a variety of voltage and current sensors, including shunts, current transformers, Rogowski coils and Hall-effect sensors.

The evaluation board also provides a development platform for 16-bit PIC® based applications, using existing 100-pin PIC microcontroller Plug-in Module (PIM) systems that are compatible with the Explorer 16 and other high pin count PIC® based demo boards. The system comes with a programmed PIC24FJ256GA110 PIM module that communicates with the Energy Management Utility software for data exchange and ADC setup via a USB connection to the board.

For your chance to win a Microchip MCP 3913 kit, visit:

http://www.microchip-comps.com/bodo-mcp3913

and enter your details in the online entry form.

Improved System Efficiency, Increased Power Density and Superior Stability

Microsemi's first SiC MOSFETs will be launched in May 2014.

There will be 1200V products that start the line of SIC MOSFETs:

- 1200V SiC MOSFET: 40A, 80mΩ
- 1200V SiC MOSFET: 50A, 50mΩ

Microsemi will offer both products in TO-247 or SOT-227 packages.

SiC MOSFETs cover a great area of application. The current density has significant improvement over silicon devices. Higher operating temperatures are possible.
This opens a number of new applications that had not been possible before.
Benefits are clearly seen in designs that have critical aspects in weight.
Higher operation frequency by SiC MOSFETs will reduce magnetic components size and weight of the systems solution. So aviation and transportation have strong benefits.
SiC MOSFETs were touted to be a high temperature power MOSFETs and Microsemi lives up to these expectations and rates the SiC MOSFET at 175°C Tj.

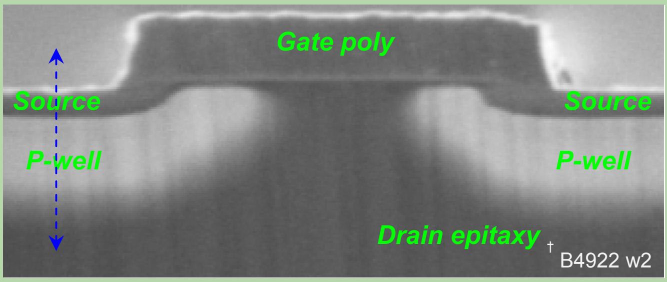

Figure 1: Vertical SiC Power MOSFET Demonstrated

Important parameters are to be looked at when rating a MOSFET at increased temperature are that SiC MOSFETs should be "normally off" at that temperature, which means Vth is a positive value, preferable higher than 1V.

The R_{dson} has a reasonable and not too large increase with temperature

- SiC MOSFETs are aimed for high frequency applications (100KHz or higher). Lower gate resistance provides freedom to the end user, allowing for either low or high values of the external gate resistance. Microsemi Rg is close to 1 ohm while competitors' have Rg is in the range of 5-6 ohm or higher.
- One FOM is the maximum frequency of operation, defined by Fmax =((Tj-Tc)/Rth –Ron*Ic^2*D) / (Eon +Eoff)
  And due to the low Rdson, low Rth and high Tj, Microsemi's SiC MOSFET has a very high Fmax.
- The dual metal scheme allows one to use the entire active area for MOSFET channel and therefore specific Rdson (Rds-sp) will be lower (R_{dson} x Area).
- Eliminating the gate pad P-doped area eliminates the hole current coming out from underneath the gate pads in the conventional design and improves the dV/dt capability of the MOSFET (for a given parasitic NPN design less hole current means higher dV/dt to generate the current that would trigger the latch up).

From processing point of view, high voltage termination (borrow from Microsemi's SiC Schottky Barrier Diode) has many hours of HTRB with no degradation of the leakage.

HV termination is passivated with a proprietary solution that has proven more reliable that the standard polyimides used by competitors.

See Microsemi at PCIM Europe at the eurocomp Booth Hall 7 -202

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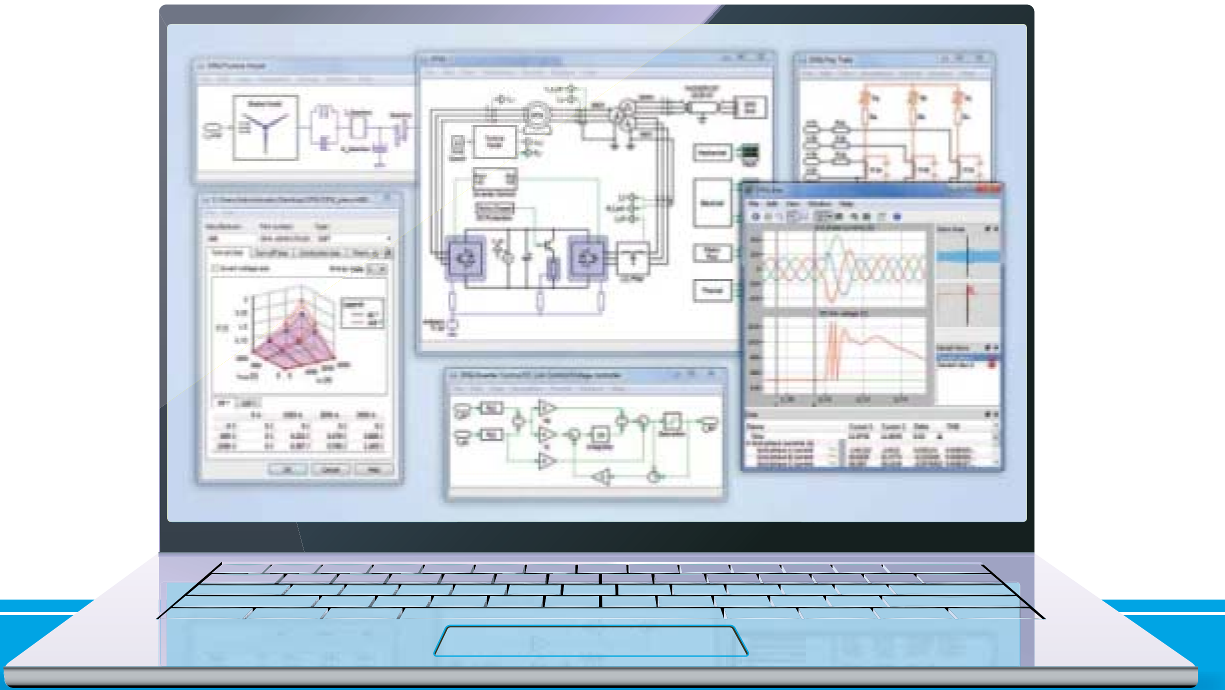

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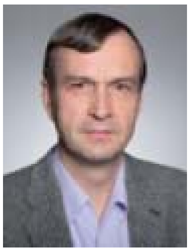
From Chip to System

Success of interdisciplinary working power electronics community

By Andreas Lindemann, Otto-von-Guericke-Universität, Chair for Power Electronics, Magdeburg, Germany



Understanding and applying device physics in conjunction with availability of suitable process technology has permitted to continuously develop and optimise power semiconductor devices. The ongoing progress has led to devices already coming quite close to ideal switches, with Silicon devices bearing the highest volume and maturity at lowest cost and Silicon Carbide (SiC) or recently Gallium Nitride catching up. To make chips useable, packaging is required, which to a considerable extent determines the behaviour of the resulting power semiconductor components mainly regarding electrical properties influenced by parasitics, thermal behaviour and reliability. Packaging is based on material science and microsystems technology. The components will be placed in circuits; basic circuits like phaselegs to build choppers, H- or three phase-bridges are known since a long time; besides there is a huge variety in particular of resonant circuits, and from time to time also new topologies or combinations of those become relevant for power electronic applications such as the modular multilevel converter (MMC) for high voltage, e. g. in high voltage DC (HVDC) transmission. Finally, the circuits will often not be visible on system level - which is a known issue to promote power electronics - but they are indispensable for system operation. To make them work there, an understanding of the system is required, which determines control and operational conditions of the converter and also requirements like reliability. Power electronics is applied in a huge variety of systems, e. g. from small power supplies via photovoltaic inverters up to HVDC or from small drive converters in appliances via medium to large industrial or traction drives. Power electronics engineers are aware that they are working on a key technology which is required virtually everywhere.

The aforementioned chain from chip via packaging and circuit to the system reflects the structure of power electronics community: There are very specialised players like companies focused on chip production, universities or research institutes being experts in a particular area and also corresponding conferences or publications for their specialists' technical exchange. Other players act in multiple neighbouring areas, but there is hardly any one-stop-shop possessing complete competence in all areas. To reach the application it however is obviously necessary to bridge the gaps between the different areas, which requires a network structure. This is implemented not only in industry but also on several institutional levels, e. g. nationally in Germany by VDE-ETG (Energietechnische Gesellschaft in VDE) with its committee Q1 occupied with power electronics, very successfully on European level by ECPE (European Centre for Power Electronics) or even more internationally by IEEE-PELS (Power Electronics Society of IEEE). A power electronic network of course has many interfaces, e. g. to users of power electronics, such as electrical drive community - recently also focusing on electrified power trains of cars - or utilities as suppliers of electric energy. It is beneficial that this institutional network has been implemented due to initiatives and efforts of many industrial, scientific and personal contributors, and that it is common practise to use it.

Networking of players who in depth work in their area of expertise obviously is the foundation of the success of power electronics in the market, because this way all steps from chip to system can be realised, thoroughly solving the related problems and finally creating useful products customers are willing to invest in. Besides, only the network is visible enough to attract funding for fundamental and applied research; further - in spite of the lack of engineers in parts of the world - it helps to draw interest of young talents to power electronics and the related career opportunities.

These considerations have practical consequences for daily work also in the environment of research and teaching at university as shall be illustrated using the example of the Chair for Power Electronics at Otto-von-Guericke-Universität Magdeburg, Germany: It is a competence centre of ECPE, taking on the duty to volunteer in the aforementioned associations. An important part of research is carried out in projects funded publically or by industry. Those are substantially focused on the application of new devices in power electronic circuits and systems, thus bridging the gaps between devices and circuits, taking into account the requirements on system level. Several projects can be assigned to the area of electromagnetic compatibility (EMC), where comprehensive additional expertise is obtained through cooperation with the local Chair for EMC. Challenges in this area often result of the combination of fast switching devices - with e. g. SiC devices reaching switching times in the lower nanosecond range - and parasitic elements which even are partially coupled. Further investigations are focused on reliability of power semiconductor components taking into account the operational conditions in the particular system they are dedicated to be used in, such as an electrified drive train of a road vehicle. The need to increase power density and reduce cost has led to considerable novel packaging technologies which are about to enter the application and require specific qualification. Finally, an understanding of systems is always needed, which is a strong motivation to carry out research projects on new power electronic circuits and systems, such as MMC for HVDC. While calculations and simulations can be executed on the real power level, an experimental setup for HVDC needs to be downsized for realisation in university laboratory. Nevertheless, transferring theoretical results to real hardware is an important part of the piece of art to implement operable power electronic systems and thus indispensable for solid project work. Fortunately there is a deep interest of students to labour in this area: They will later go to industry as engineers and power electronics experts; if they successfully obtained a doctoral degree, they even have collected deeper experience in project work. This way university fulfils its task to educate young talents; a research-based cooperation with industry has proven to be beneficial for both sides which closes the circle to the above thoughts about networking.

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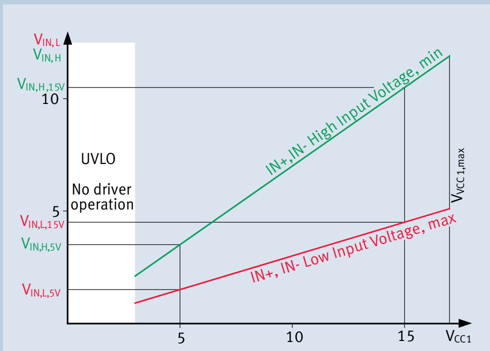

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Electronics Industry Digest

By Aubrey Dunford, Europartners

SEMICONDUCTORS

What is the outlook for year 2014 semiconductor market growth? Forecasts in the last few months range from about 4 percent (WSTS and Mike Cowan) to 20 percent (Objective Analysis). Half of the forecasts are in the 7 percent to 9 percent range. Semiconductor Intelligence's latest forecast is 10 percent.

Renesas Electronics announced the results of its early retirement program for employees in Japan, announced on February 19, 2014. 696 employees will voluntarily taking early retirement. As a result of implementing the early retirement program, Renesas Electronics expects to incur a special loss of approximately 3.0 billion yen in the fourth quarter ending March 31, 2014.

GaN Systems, a Canadian developer of gallium nitride power switching semiconductors, announced the appointment of Jim Witham as CEO. GaN Systems' power conversion devices, based on its proprietary Island Technology, are being commercialized in 2014. Cofounders Girvan Patterson and John Roberts will continue in their current roles as President and Chief Technical Officer, respectively. Jim Witham has over thirty years' experience, and joins GaN Systems from Neoconix, a manufacturer of miniature connectors.

Power Integrations, a Silicon Valley-based supplier of components used in high-voltage power-conversion systems, announced a verdict in one of its ongoing patent infringement lawsuits against Fairchild Semiconductor. A jury found that Fairchild willfully infringed two of Power Integrations' patents, and awarded Power Integrations damages of $ 105 M. Based on the finding of willfulness, the Court could enhance the award up to three times the amount specified by the jury. The jury also denied all counterclaims by Fairchild alleging infringement by Power Integrations.

Worldwide sales of semiconductor manufacturing equipment totalled $ 31.58 billion in 2013, representing a decrease of 14 percent, so SEMI. Spending rates declined for all the regions, except for China (+30 percent) and Taiwan (+11 percent). For the second year in a row Taiwan remained the region with the highest amount of spending with $ 10.57 billion in equipment sales. The North American market surpassed South Korea to claim the second place with $ 5.26 billion.

PASSIVE COMPONENTS

January PCB sales in Germany were up by 7 percent yearon-year, so the Zvei. Revenue per working day was 19 percent above the average of the year 2013. Order visibility was also strong for the month. Compared to last year, there was a 32 percent increase in orders for January this year. The book-to-bill ratio was at 1.14, the third consecutive month it reaches more than 1. The number of employees was nearly three percent over January 2013.

Würth Elektronik eiSos announced that its connector division will be jointly managed by Romain Jugy, who will be responsible for production and development as Head of Product Management, and by Josef Wörner, who will be responsible for the global sales of connectors in his position as Head of Sales.

OTHER COMPONENTS

Bosch became the top manufacturer of MEMS sensors and actuators in 2013, pulling out of a virtual tie with STMicroelectronics the previous year, and making history in the process as the first company to reach $ 1 billion in market revenue, so IHS Technology. Bosch boasted revenue of $ 1.0 billion, up from $ 794 M in 2012. It grew 26 percent during the year, four times more than the industry average. Automotive accounted for 74 percent of MEMS revenue for Bosch in 2013. Most of the manufacturer's growth, however, came from Bosch Sensortec, which focuses on consumer and mobile applications.

DISTRIBUTION

Anglia Lighting, a specialist distributor of LED lighting technologies to the architectural market, has appointed Jason Middleton and Anthony Zvirblis, two dedicated business managers to strengthen its relationships with manufacturers, contractors and installers of LED lighting systems. Jason Middleton, as business manager (South UK) and Anthony Zvirblis, the new business manager (North) reports to Andrew Pockson, divisional marketing manager at Anglia Lighting.

Specialist passive components distributor DMTL (Distributed Micro Technology Ltd) has become the sole UK distributor for Viking Tech, a manufacturer of thin and thick-film passive devices including resistors and inductors. Although DMTL has partnered with Viking over the past three years, the decision to appoint the company sole distributor for the UK means DMTL is now the only official source for Viking's components.

Plessey Semiconductors has entered into a distribution agreement with Matrix Electrónica for the Iberian market for Plessey's GaN on Si LED products. Plessey's Gallium Nitride on Silicon LEDs are produced using standard silicon-based semiconductor manufacturing processes in contrast with existing LEDs which use expensive sapphire and other exotic materials. Matrix is an electronics distributor and provider of complete advanced electronic solutions. Matrix is headquartered in Madrid with offices across Spain, Portugal and Chile.

This is the comprehensive power related extract from the «Electronics Industry Digest», the successor of The Lennox Report. For a full subscription of the report contact:
eid@europartners.eu.com
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Smart Materials for Power Conversion, Energy Harvesting and Smart Grid Applications

By Jeff Shepard, President Darnell Group

Smart materials are beginning to emerge that will change the way power and energy systems are designed and produced. Piezoelectric energy harvesting is already a well-established commercial technology. It will continue to grow and will be joined by new smart-materials-based devices including synthetic jets, actuators, nonmagnetic transformers, MEMS-based power switching, and more. Smart materials will be an added focus at this year's Darnell Energy Summit (DES '14), http://energysummit.darnell.com/, to be hosted September 23-25 in Richmond, Virginia.

DES '14 will be a combined event featuring the Eleventh Darnell Power Forum (DPF '14) + the Sixth Green Building Power Forum (GBPF '14) + the Fifth Smart Grid Electronics Forum (SGEF '14). With a single registration, you will be able to attend any sessions of interest during these simultaneous leading-edge events. Plus you'll have access to the combined Exhibit Hall and will have an opportunity to network with an outstanding group of international experts in a wide range of power electronics, dc building power, micro grids, and smart grid technologies.

Synthetic jets based on smart materials could provide a thermal management breakthrough for next-generation systems. With a piezoelectric diaphragm driven up and down hundreds of times per second by an ac power source, a synthetic jet pulls in the surrounding air (or other fluid) into a chamber and then expels it.

When used with air as the working fluid, a synthetic jet can provide a highly-targeted and high-velocity flow of cooling air. Synthetic jets made using advanced piezoelectric composite materials can be very thin (fractions of an inch) and extremely rugged. Although the mechanism is fairly simple, extremely fast cycling can require high-level engineering to produce a device that will last in industrial applications.

Nonmagnetic transformers are another area of emerging smart materials technology. For example, Face® Electronics, LC of Norfolk, Virginia has developed and patented an extraordinarily powerful piezoelectric transformer (PT) called the Transoner. These electrical energy transmission devices are electromechanical, not electromagnetic. Transoners are useful in applications involving power conversion, power switching, and wide band signal processing.

Unlike the more common Rosen type PTs that are presently on the market, Transoner has many times the power capacity (80W and more) - with superior power density and emit no electromagnetic interference. Transoners have two distinct modes of operation, resonant mode and non-resonant mode.

In the resonant mode, Transoners exhibit high voltage gain and significant power transfer. Useful for power conversion and power switching, these Power Transoners can be designed to be either isolating or non-isolating. In the non-resonant mode, Wide Band Transoner is suitable for telecommunications or signal processing applications from voice to high speed data transmission.

MEMS based power switching could open new opportunities for replacing mechanical and solid-state relays (SSRs). At the GE Global Research Center a group of researchers are advancing MEMS (Micro-Electro-Mechanical Systems) technology to create ultra-small switches that could have an ultra-large impact on system design that will drive mobile devices of the future.

Prototype device testing shows that GE's RF MEMS switch can help enable increased data transfer speeds, enhanced signal quality, longer battery life, and the advanced RF designs required of LTE-Advanced devices. Power switching devices made with GE's Metal MEMS process are capable of handling greater than 1kW in a tiny form factor. For mobile applications, the technology can be scaled down and miniaturized.

The MEMS metal switches, which are no bigger than the width of a human hair, can control the flow of electricity to an array of electrical systems – from high-power devices that use kiloWatts of power, to an ordinary light bulb. Future applications of the technology are far-reaching. Switches are used in everything from hand-held electronics, to industrial equipment to protection devices.

For example, a MEMS-based power switch could be used to provide arc-less circuit protection combining microsecond switching with contact resistance lower that the best SSRs and the capability to handle large amounts of energy at 400-500 Volts.

What separates GE's MEMS switch from other MEMS technologies is the unique material set developed by GE researchers that allows the switch to operate for billions of cycles under extreme operating conditions, such as elevated temperature, while maintaining extremely low contact resistance. GE has expressed an interest in licensing its power MEMS technology.

Actuators and flow-control devices can also be fabricated with advanced piezoelectric composites. For example, Thunder™ actuators from Face International Corp. are based on a piezoelectric composite technology originally patented by NASA. Face's trademark Thunder is an acronym for THin Layer UNimorph Ferroelectric DrivER.

An important feature of Thunder actuators is the versatility of operation in addition to the extraordinary large deflections. Thunder elements can be operated in many different ways pertaining to mounting, stacking configuration and voltage application. And the large deflection capabilities mean that Thunder devices can drive large actuation forces.

The method of operation can be chosen depending on the type of application with force and displacement being the two major governing physical quantities. The tabs provided with standard Thunder actuators provide a means for mounting. The method of mounting changes the force and displacement characteristics of these actuators. Thunder actuators produce comparatively higher force together with larger displacement compared to other traditional piezoelectric actuators.

Smart materials for energy harvesting represent another important area of technology development. During the past year, it has become obvious that the energy harvesting (EH) market has not grown as anticipated. There are a variety of reasons for that situation, the primary one being a lack of cost-effective solutions. The incumbent solutions are simply much too expensive to enable mass adoption.

That is set to change in a major way in 2014. For example, the impact of the battery-free option for ZigBee Green has already begun appearing in the form of products designed to support the anticipated growth of the market for EH-powered devices.
Texas Instruments has introduced five new next-generation power management integrated circuits that efficiently acquire and manage microwatts (uW) to milliwatts (mW) of power harvested from light, heat or mechanical energy sources. The bq25570, bq25505, TPS62740, TPS62737 and TPS62736 claim the industry's lowest levels of active quiescent current and enable battery-free operation to wireless sensor networks, monitoring systems, wearable medical devices, mobile accessories and other applications with limited access to power.
And Fujitsu Semiconductor Limited announced the release of two new power management IC products developed to utilize energy harvesting, the MB39C811 dc-dc buck converter and the MB39C831 dc-dc boost converter. Sample shipments for the two new products are scheduled to start in June of this year. The MB39C811 buck converter features a quiescent current of just 1.5µA and achieves world-leading results in ultra-low power operation. Moreover, the MB39C811 represents the world's first simultaneous use of energy generation from both light and vibration using only one power management IC device.
These are only a few of the exciting new technologies to be presented at DES '14. This year's event will span the entire range of new technologies for next-generation power and energy system solutions. DES '14 will include discussions of SiC, GaN, GaAs, composites, ferroelectrics, piezoelectrics, and other advanced/smart materials. The application focus will be broad and will include: power conversion, motion control, energy harvesting, energy storage, micro grids, wireless power, smart systems, thermal management, and more. DES '14 will be a combined event featuring the Eleventh Darnell Power Forum (DPF '14) plus the Sixth Green Building Power Forum (GBPF '14) plus the Fifth Smart Grid Electronics Forum (SGEF '14).
DES '14 will feature the next-generation power electronic devices, architectures and systems. Separate calls for papers have been issued for each of the constituent events. Each of the individual events will maintain its unique identity and will continue to serve different groups of stakeholders.
These co-located events will bring together thought leaders across the areas of advanced power electronics, energy management, micro grids, the smart gird, and related topics of global importance. DES '14 will leverage the successful track records of the separate events to create powerful opportunities for synergy.
DPF '14 will again be an exciting international event that focuses on "advanced power conversion technologies" needed for the successful development of next-generation power systems. There is tremendous synergy possible from discussions broadly focused on power management, energy efficiency, advanced components, energy storage, new power architectures, and more.
DPF is a solutions-oriented event, with a strong emphasis on practical advances in power electronics. In addition to a strong focus on today's "best practices," DPF looks forward toward next-generation solutions and advances.
GBPF '14 will consider all aspects of building power including high-voltage and low-voltage dc distribution, hybrid ac and dc distribution architectures, and dc micro grids. A convergence of technologies is occurring that will change how buildings are powered. These technologies include the continued rapid growth of distributed generation (DG) resources; the emergence of high-efficiency lighting technologies; wireless building automation systems; demand-side management of building energy use by electric utilities; and more.
Control, Communications and Security will be three of the major themes of SGEF '14. The successful deployment of the smart grid will be dependent on numerous technology and standards developments for electronic equipment. For the smart grid to have benefits, it must be able to reliably communicate to the downstream loads and also be able to turn these loads on/off or turn them up/down as appropriate.
Details for all of the individual Power Forums as well as the overall Darnell Energy Summit can be found on the web at: http://energy-summit.darnell.com/ . Abstract for papers are currently being accepted and exhibit spaces and sponsorship opportunities are available.

www.darnell.com

PCIM Europe 2014: Growth Engine Renewable Energy

It's an established fact that the electrical energy consumption continues to grow and even more applications will be based on electricity in the next decades. Around 40 percent of the world's power needs are currently met by electrical energy and that proportion is expected to rise as countries cut carbon emissions and shift to renewable energy sources. As the trend towards electrification and renewable energies increases, enabling technologies such as power electronics are becoming ever more important.

By Marisa Robles Consée, Corresponding Editor; Bodo's Power Systems

Power electronics is an umbrella term that encompasses components and systems involved in converting and controlling the flow of electrical energy. However, it is a demand that production, distribution and use of electrical energy are done as efficient as possible. That's why two major technologies will play important roles in the next couple of years. One is the change in electrical power production from conventional fossil and nuclear energy sources to renewable energy sources. Another is to use high efficient power electronics in power generation, power transmission/distribution and end-user application.

This year's trade show PCIM Europe 2014 which will be held in Nuremberg from 20 to 22 May focuses on the latest trends in power electronics components and systems for use in the wind and solar energy sector. The exhibition and conference together play their role in the ambitious project to significantly increase the proportion of renewable energies in generating electricity. About 400 companies are expected to exhibit. In the three halls 6, 7 and 9 and over an area of approximately 20,000m², the key companies in the sector will showcase their products and services to an international trade audience. "The additional exhibition hall together with improved visitor flow will provide visitors with a concentrated overview of the market", states Lisette Hausser, Vice President Mesago PCIM.

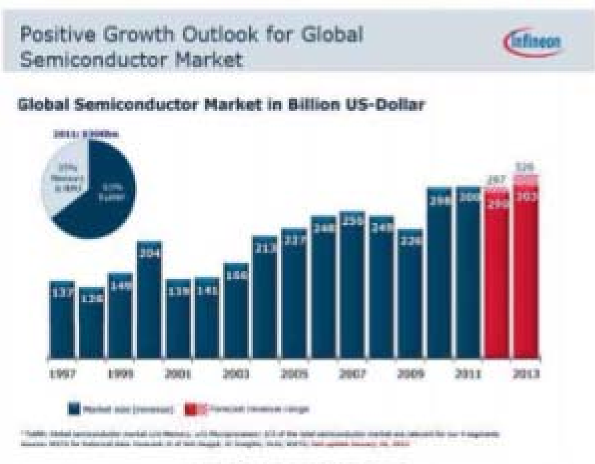

Figure 1: Optimism for the near future: The semiconductor market will continue to growth. (Picture: Infineon/Lorenz)

Visitors will be able to attend vendor presentations and contribute to expert discussions on the latest developments in wind and solar energy at the free industry forums. Infineon Technologies will, for example, tackle the topic "Power Semiconductors in Energy Efficient Smart-Grid Installations" at the industry forum. Trade visitors will also learn about the technological challenges "Energy harvesting, long-distance energy transfer and efficient energy consumption" represent for the "German Energy Turnaround". Presentations, expert discussions, project presentations and market overviews will be delivered by trade associations, the trade press and companies at the Industry Forum in hall 6. The Exhibitor Forum in hall 9 will also offer more than 50 vendor presentations from exhibiting companies on their latest developments and innovations.

Conference offers feature session

A conference morning higlight will be the three keynote speeches "Progress in Power Semiconductor Devices and Applications" delivered by Dan Kinzer of Fairchild Semiconductors, "Ultra High Voltage SiC Power Devices and Its Impact on Future Power Delivery System" by Alex Huang of NSF Freedm Systems Center and "E-Mobility 2020: Power Electronics, a Key Technology for the Effective Deployment of Electric Vehicles in a Low Carbon Society" by Enrique J. Dede of ETSE University Valencia.

A practice-oriented exchange of ideas between developers and users of power electronics are at the core of the more than 250 presentations, three keynote speeches, six seminars and ten tutorials. In a feature session "New and Renewable Energy Systems" experts will, for example, report on the development of a "Hybrid Power Generation System", which could provide an independently and environmentally-friendly energy supply in a residential area. The session "A Low Cost Photovoltaic Maximum Power Point Tracking Buck Converter for Remote Cell Phone Charging Applications" looks at how photovoltaic hybrid systems can be used to centrally generate the total energy supply for remote areas from renewable energies.

On the two days before the conference commences, experts will share their knowledge on the principles and specific topics of power electronics in six half day seminars and ten full day tutorials. For the first time, the program will include the tutorial "Power Electronics and

Control for Grid Integration of Renewable Energies and Energy Storage Systems”. This tutorial serves the growing demand for training in power electronics and solutions for renewable energies.

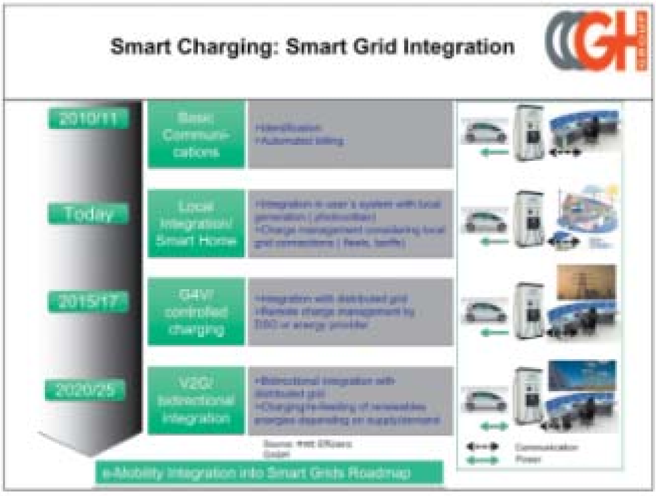

Figure 2: From smart charging to the smart grid integration. (Picture: RWE/Lorenz)

Faster, greener smarter

“The semiconductor market is expected to recover throughout 2014”, Prof. Leo Lorenz, General Chairman of the Advisory Board of PCIM Europe, is convinced. The worldwide semiconductor market is forecasted to be up 4.1% at US$320 billion in 2014 surpassing the historical high of US$300 billion registered in 2011. For 2015, the market is forecasted to be US$328 billion, up 3.4%, predicts WSTS. All product categories and regions are forecasted to grow positively in each year, with the assumption of macro economy recovery throughout the forecast period. By end market, wireless and automotive are expected to grow faster than total market, while consumer and computer are assumed to remain stagnant.

Societal Megatrends for the next Future are mainly all around e-Mobility: Within a very short period of time, electric vehicles have moved from the category of curiosities, science projects, and concept cars into a fully commercialized market with an entire industry of automakers and power suppliers supporting it. The billions of investment dollars spent by so many big players makes it clear that vehicles powered by the grid will comprise a significant transportation segment that may eventually rival traditional gas combustion technology in order to move people and goods from city to city, in an economically viable, energy independent and sustainable way. By 2020, the e-mobility market – electric and hybrid vehicles – is supposed to represent between 5% and 10% of the world automotive market. In Europe, France and Germany are setting up ambitious government programs in order to position themselves as leaders in the development of electric vehicles.

Figure 3: Lisette Hausser (Vice President Mesago PCIM), Prof. Leo Lorenz, (General Chairman of the Advisory Board of PCIM Europe) and Petra Haarburger (President Mesago PCIM) presented the highlights of this year’s PCIM Europe 2014. (Picture: Schäfer/K&E)

Electric vehicles may be a solution to managing international energy issues, but like their fossil fuel powered siblings, they still need to refuel. As such, a whole service industry has emerged to serve the recharging needs of electric vehicle drivers. Like a new board game, this new industry has new players, a new set of rules and a new playing field. Thus, it is crucial that the spread of EVs and EV chargers is managed in a responsible way to minimize impact on the electric grid while still providing consumers with the wide array of recharging options. To enable this rapid configuration and adapt to new and emerging business models, the future of EV charging lies in “intelligent charging solutions,” where networked chargers are linked seamlessly with the grid and the charging system operators.

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Power Conversion: The End of the Road for Silicon

By Alex Lidow Ph.D.; Efficient Power Conversion

KEY TAKE AWAYS
- Silicon has reached theoretical limits of performance in power conversion.
- Gallium nitride (GaN) and silicon carbide (SiC) will displace much of the $12B market for silicon power MOSFETs.
- There is product in production today that is 5-10 times better than the theoretical limit of silicon.

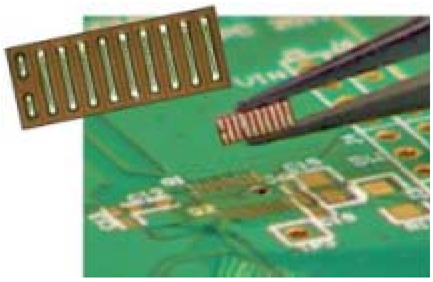
Electricity is present in our day-to-day lives in just about everything we do. From cell phones to refrigerators to the cars we drive, electricity is required to perform an intended function in order to achieve a desired result. As the middle class continues to improve their standard of living in the emerging economies, demand for electricity is expected to grow significantly. In fact, the worldwide demand for electricity is expected to grow by approximately 75% over the next 25 years.

The Power Conversion Process
Many electrical devices start with a wall socket and require that AC power be converted and regulated along the path to its end use. This stream of conversion may involve converting from AC to DC, then DC to DC (several times). Each device and each function within each device requires electricity to be precisely reformatted to allow efficient performance. This precise reformatting of electricity is what the "power conversion process" means.

At the heart of power conversion systems are power semiconductor transistors designed with exact specifications to accomplish particular tasks. The more precisely a transistor's specifications are aligned with a particular application, the more efficiently it converts electricity.

The Invention of the Power MOSFET
The power transistor had an industry-changing innovation over 35 years ago with the introduction of the power MOSFET. These silicon-based power transistors enabled high efficiency power conversion to become a commercial reality.

Power MOSFETs precisely control electricity by chopping the flow of electrons into small packets of energy with minimum losses. These packets of energy are then reassembled into the exact format needed to supply the exact power demanded by the user. The silicon-based MOSFET has had a great run, but now this technology is close to reaching its performance limits. Silicon cannot switch fast enough nor provide the power efficiencies required for today's demanding applications.



The Obsolescence of the Power MOSFET
In the power MOSFET there is a basic tradeoff between conductivity, specified as on-resistance, "R", and the amount of charge required to turn the device from the ON to the Off state (or OFF to ON), typically referred to as "Q". This tradeoff drives the figure of merit called RQ product — the device's on-resistance multiplied by the charge. Emerging applications, as well as evolutionary improvements to existing applications, require an RQ product that significantly exceeds the capabilities of the power MOSFET.

There are several technologies emerging that are destined to replace the silicon power MOSFET as the power semiconductor transistor of choice. Currently, the most promising technologies are GaN (gallium nitride) and SiC (silicon carbide). Both GaN and SiC technologies are wide band gap materials that offer the advantages of higher power densities, higher voltages, lower leakage current, and the ability to operate at higher temperatures.

These wide band gap technologies can theoretically shrink the size of the transistor and the RQ product by more than a factor of 100 compared to silicon. Today there are commercial GaN products already on the market that are 5-10 times better than silicon, and improvements are happening at a pace reminiscent of Moore's Law.

Both GaN and SiC technologies will displace silicon as the base material for power transistors. They will take their respective positions in the next few years by displacing silicon power MOSFETs, and their close cousin the IGBT, in the $12 billion power conversion market.

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High Power IPMs (HiP) Simplify Design

Reduce Design Time and Minimize Space Requirements

In the last 10 years or so there has been a major trend towards the adoption of motor drive inverterization for appliance motors propelled by government regulations to increase efficiency as well as demand for added functionality of appliances from consumers.

By Llewellyn Vaughan-Edmunds and Andrea Gorgerino, International Rectifier

Intelligent Power Modules (IPMs) have become the designer's choice for appliance and low power industrial motor drives for household mains, as they simplify system design and production handling compared to discrete solutions. With the continuous push towards higher efficiency motor drives, IR is now extending its range of IPM to higher power and 3- phase input systems.

The Drive towards Higher Efficiency

One of the largest consumers of electricity is the electrical motor drive. These drives consume approximately 45% of all total global electricity consumption. Currently the majority of motor drives in the industry run at fixed frequency speed. By moving to a variable-speed drive system, as much as 30% of energy can be saved. In Europe alone, by transferring to electronic variable speed drive control and energy-efficient motors, Europe's CO_2 annual emissions could be reduced by 69 million tonnes (CEMEP).

Governments around the world have introduced regulations that require an increase in efficiency in applications such as industrial pumps, fans and various motor drives. In North America, the USA Department of Energy (DOE) released the Energy Policy Act (EPAct), which was granted authority to set minimum efficiency standards for certain classes of electric motors. Effective from 1997, these motors sold in the USA have to meet energy efficiency ratings above the NEMA (North American National Electrical Manufacturers Association) standard. In 2006, the NEMA PremiumTM standard was updated and introduced a higher level of efficiency standard for motor drives.

Europe also set a regulation (IEC 60034-30,) for motors, which divided efficiency levels into 3 classes of efficiency; IE1 (standard), IE2 (high) and IE3 (premium). IE1 and IE2 are very similar to the NEMA standard and IE3 similar to the NEMA PremiumTM.

China also recently introduced the GB18613-2012 standard, starting from September 2012. For selected motor types within a power range, a grade level based on efficiency (Grade 1,2,3,4) is assigned, which has very similar test protocols to the IEC 60034-30 standard.

Expansion of IPM Power Range Helps Designers Achieve Highest Efficiencies

From the release of the first generation of IPMs in 2003, to the recently released µIPM™, IR has continuously lead the way in intelligent power modules targeted for the appliance sector. With the latest introduction of the HiP (High Power) IPM, IR is extending its range into higher power industrial applications that typically require 3-phase input systems (380V typical).

Figure 1: IR's latest HiP IPMs achieves high efficiencies in industrial drives

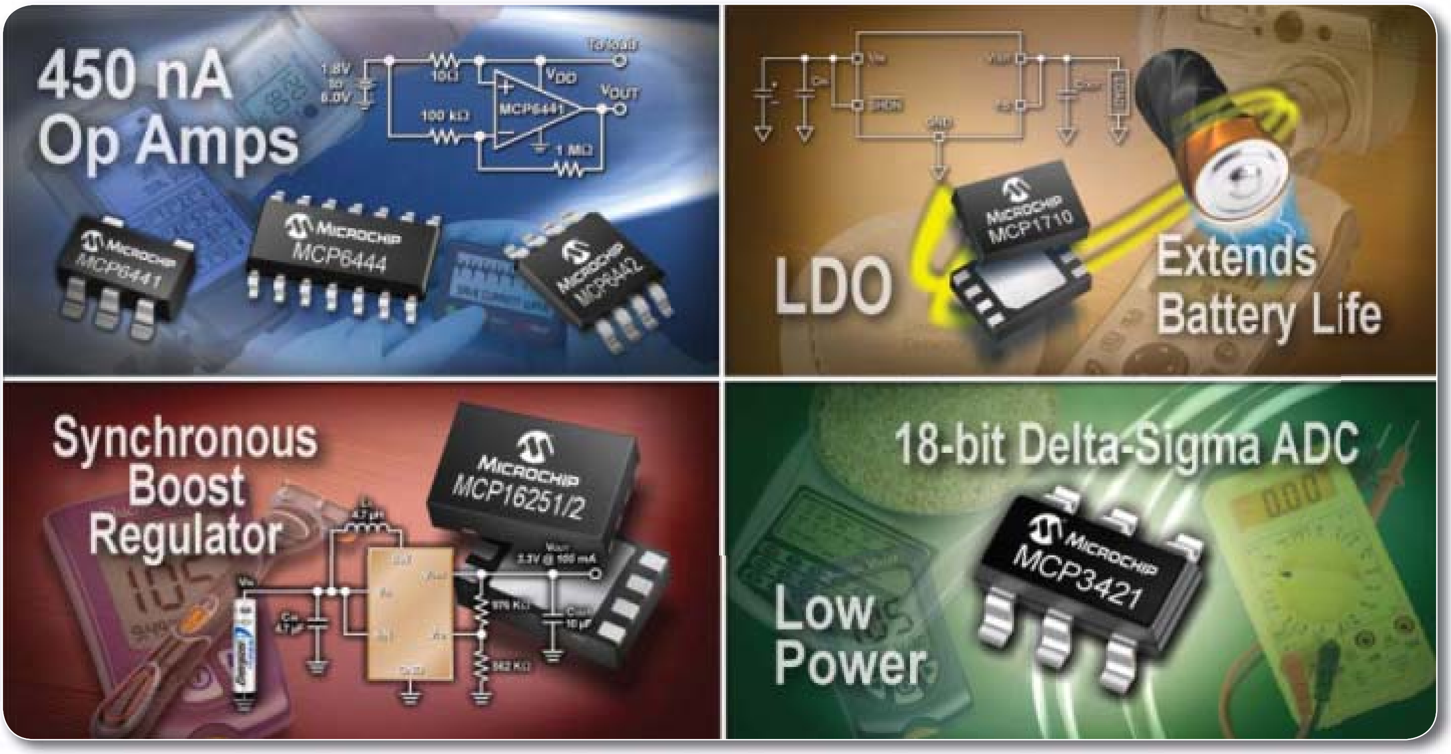
Simplified Design Reduces Design Time and Minimizes Space Requirements

IR's HiP IPMs integrate six IGBT dies, each with its own discrete gate resistor, six commutation diode dies, one three-phase monolithic level-shifting driver chip, three bootstrap diodes with current limiting resistor and an NTC thermistor for over-temperature protection. This complete package allows the designer to quickly integrate the power stage into their complete system. Additionally the reduction of part count contributes significantly to a quicker manufacturing process and a more simplified supply chain.

The IGBTs and complementary high-voltage gate driver IC have been characterized together to operate at an optimal performance. The inverter stage is directly connected to a micro/DSP while the Open Emitter configuration offers compatibility with different current sensing topologies (e.g. phase shunts, single DC bus shunt). The family of IPMs offers different power levels in a standard footprint, which allows for flexibility and scalability in system designs.

Does Your Design Require Low Power Analog?

Microchip has the answer ...



Microchip offers a broad portfolio of low power analog products that support a wide variety of applications. With over 800 unique stand-alone analog products covering thermal management, power management, battery management, mixed-signal, linear, interface and safety and security.

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- 450 nA quiescent current per channel
- Operating voltage down to 1.4V
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MCP16251/2 Sync Boost Regulator

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- > 100 mA output with 1.2 VIN 3.3 VOUT

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MCP342X

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- Up to 18 bit resolution
- Operating voltage down to 2.7V

GET STARTED WITH YOUR LOW POWER ANALOG DESIGN TODAY!

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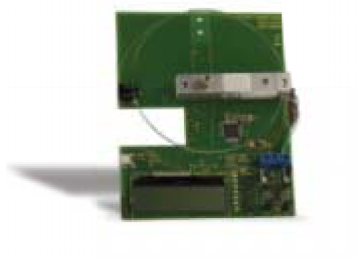

MCP3421 Weight Scale Demo Board (MCP3421DM-WS)

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Excellent Thermal Performance Increases Power Density

This new family of HiP IPMs is using a DBC substrate, similar to that used for high power industrial modules. Direct Bonded Copper (DBC) substrates have become the de facto standard in industrial modules thanks to their numerous advantages.

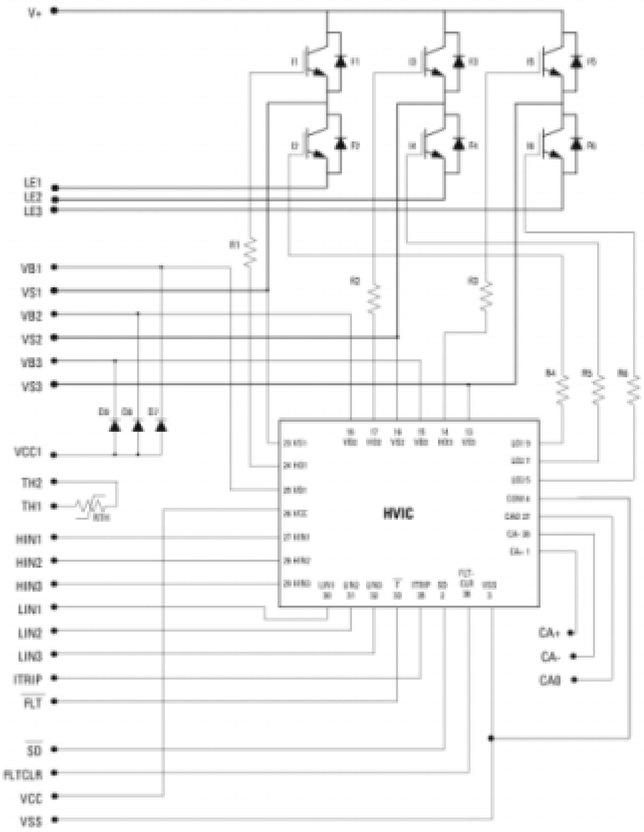

Figure 2: Schematic of HiP IPM integrates complete power stage

A DBC substrate consists of a layer of ceramic insulator bonded between two layers of copper, providing electrical insulation and excellent thermal path to a single heatsink (see figure 3). With its good thermal conductivity and excellent dielectric properties, the ceramic layer within the DBC provides the silicon chips the essential electrically isolated thermal path with negligible impact on the overall thermal performance of the assembly.

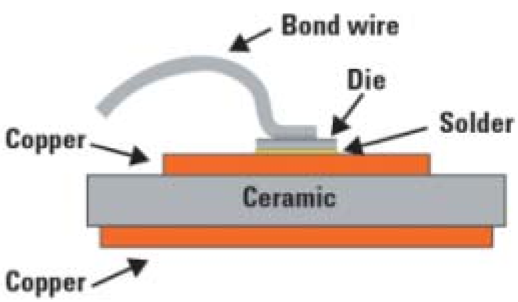

Figure 3: Profile of a DBC substrate shows electrical isolation and low thermal resistance

DBC substrates are well suited to applications with high temperatures, high currents and high voltages. They also offer advantages in terms of reliability due to the high isolation voltage capability and to a coefficient of thermal expansion which is a good match for that of silicon.

Optimized Gate Driver and IGBT

The integrated gate driver HVIC and gate resistors are specifically chosen and characterised to insure a maximum of 5kV/us. This is achieved by tuning the HVIC sink/source drive currents and RG to reduce transition overlap and control dv/dt. This offers the best trade-off between reducing switching losses to enable operation up to 20kHz, and staying within EMI guidelines.

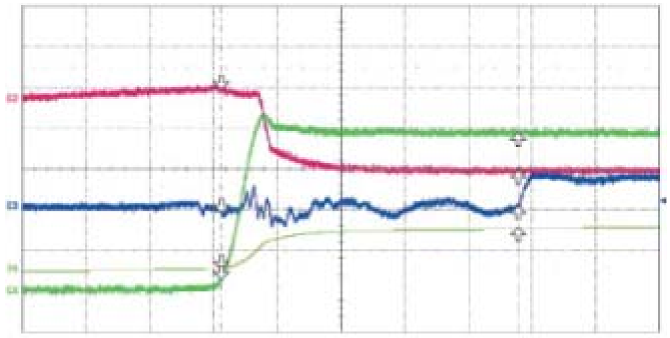

Figure 4- Turn OFF waveform at 780V, 10A (Red: current, 5A/div; Green: Voltage 200V/div; Time: 200nS/di)

IR's Generation 7 1200V trench-gate, field stop thin wafer IGBT technology has been optimized for industrial applications at 16kHz. This is the typical frequency for light industrial systems where audible frequency is still a concern. With very low $V_{CE(ON)}$, soft switching characteristics and 10us short circuit rating, it offers higher system efficiency and rugged transient performance for increased reliability, making them well suited to harsh industrial environments. For example, IR is developing HiP IPMs with Gen 7 IGBT technology, from 10 to 30A (IRAM437-1012A (10A), IRAM437-1512A (15A), IRAM437-2012A (20A), IRAM437-3012A (30A)).

IR's latest IGBT release, Generation 8, is optimised on lower switching frequencies, below 10kHz, therefore provides the lowest $V_{CE(ON)}$ in the industry and offers excellent soft switching characteristics. The HiP IPM family will extend into this technology in the coming months.

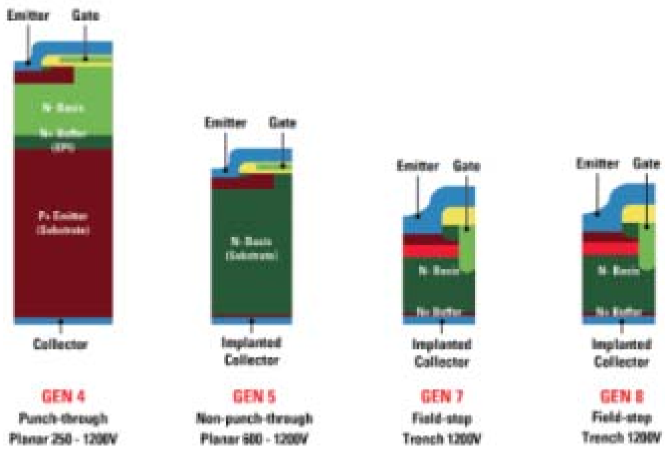

Figure 5: IR's IGBT 1200V Technology Roadmap

Enhanced Reliability

Complete package integration of the power stage significantly increases reliability of the system. Lowering the circuit inductance compared to discrete solutions results in voltage spike reduction and the ability to operate at higher switching frequency with lower switch losses. EMI emissions are minimized due to shorter connection routing and optimized component layout.

As a result of the NTC thermistor being integrated on the same DBC substrate as the IGBT, which provides improved temperature correlation, the IGBT temperature can be continuously monitored by providing the NTC thermistor temperature dependent voltage to the microprocessor. This voltage also feeds the internal shut down function of the driver which terminates all 6 drive signals when activated. In the event of an over current caused by a stalled motor or other fault condition, the active low signal from the micro controller turns off the external N-channel MOSFET and overrides the temperature signal causing instant shut down.

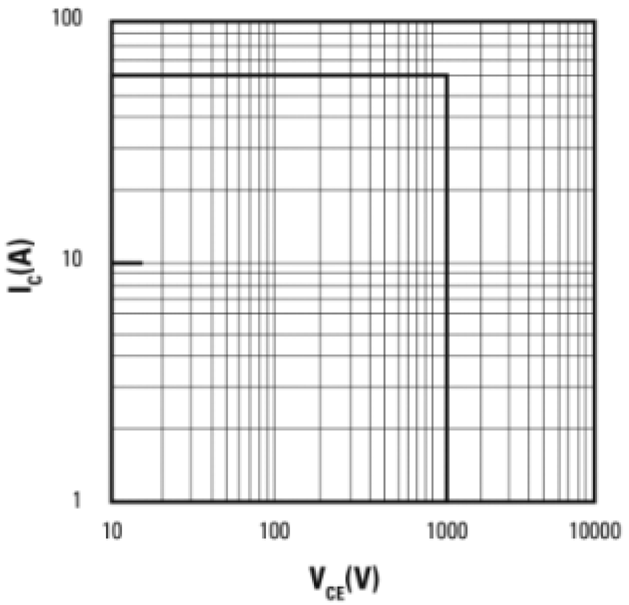

Figure 6: IGBT square Reverse Bias SOA, T_J= 150°C, V_{GE}= 20V

The Gen 7 technology is capable of achieving a minimum of 10us short circuit rating, making them ideal for hard-starting, high in-rush current motor drive circuits. These IGBTs devices are guaranteed with a “square” reverse-bias safe operating area (RBSOA) up to 175°C for enhanced avalanche energy ratings (ruggedness).

Conclusion

As demand for electricity rises, it must be utilized efficiently with a focus on reducing carbon footprint, whilst understanding how to improve system efficiencies of next generation motor drive systems.

IR’s extension of high power IPMs allows designers to simplify their design, improve system reliability, and improve EMI, whilst reducing board space and design cycle time. With IR’s leading silicon and packaging technologies, the HiP IPM family offers an answer to the ongoing efforts to improve efficiency and reduce environmental effects.

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Optimized Solutions for Competitive Resonant Appliances

The Next Generation RC-H5 IGBT Optimized for Induction Cooking and Resonant Applications

Inverterization is growing rapidly especially in the field of switched mode power supplies and consumer drive applications due to the demand for more efficient products. Discrete IGBTs are used as the preferred power switch covering most of these applications from 60W to 3.6kW. Interest in home appliances using IGBTs in resonant switching conditions is also increasing for the same reason.

By Thomas Kimmer, Infineon Technologies AG

Today's appliances like inverterized induction cooking stoves, microwave ovens, rice-cookers and continuous flow water heaters are more popular than ever before. These products not only offer the consumer improved energy efficiency, but also offer convenient features like fast heating times and quick, variable temperature control. These application examples require specific optimized power devices in place of the standardized IGBTs used in hard-switched drives applications.

With a new family of IGBTs Infineon introduces the next generation of reverse conduction IGBTs, RC-H5. This new series for single-switch and half-bridge topologies is further optimized for usage under resonant or soft-switching conditions. The IGBT portfolio is complemented by the new generation of EiceDRIVER™ driver ICs with the 1EDL compact series for general usage as a low-side switch and the 2EDL series for half-bridge applications. The portfolio of the IGBT and the matching driver IC is shown in Table 1.

Continuous Collector Current At T=100°		600V/650V	1100V	1200V	1350V	1600V
IGBT and Diode				IHW15N120R3		
	20A	IHW20N65R5*		IHW20N120R3 IHW20N120R5*	IHW20N135R3 IHW20N135R5*	
	30A		IHW30N110R3	IHW30N120R3	IHW30N135R3	IHW30N160R2
	40A	IHW40N60R IHW40N60RF IHW40N65R5*		IHW40N120R3	IHW40N135R3	
	50A	IHW50N65R5*				
EiceDRIVER™		1EDL compact* (2EDL compact)	1EDL compact*	1EDL compact*	1EDL compact*	1EDL compact*

*NEW

Table 1: Infineon's IGBT and driver portfolio for resonant applications

The main focus of the new 1200V/1350V RC-H5 family is on single-switch induction cooking appliances with the benefit of a well-balanced cost/performance trade-off, which results in an overall system cost optimization for the designer. The new series allows the reduction of the bill-of-material (BOM) by savings in the passive components, such as the amount of copper used in the chokes by decreasing the inductance value. It is also possible to increase the coil diameter with less turns to allow a significant increase of the system-efficiency due to less resistive losses. The increase in efficiency is due to 30% reduction of switching losses compared to the previous version. Through the combination of these two optimizations, the best cost/performance balance can be achieved. The highest efficiency standards can be reached without increasing the material cost, and it might even be lowered. A sample topology where the IGBT is used as a single-switch inverter is depicted in Figure 1.

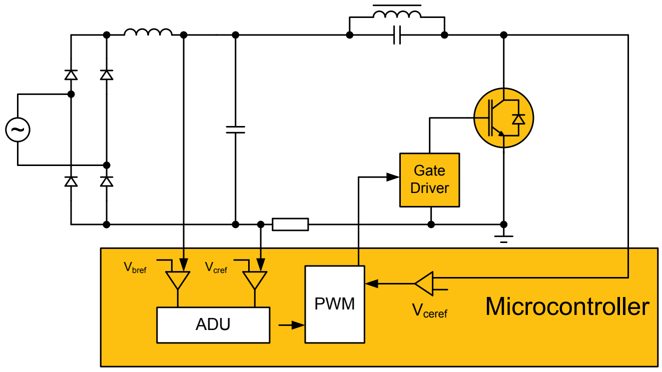

Figure 1: Quasi-Resonant Inverter (single-switch) that is used for Single-Ended induction cooking hobs

The new single-switch RC-H5 family offers the system not only cost/performance savings, but also a simpler handling of the power device. One important aspect of the chip design was to optimize the IGBT to improve the EMI behavior of the system. As an example the chip's

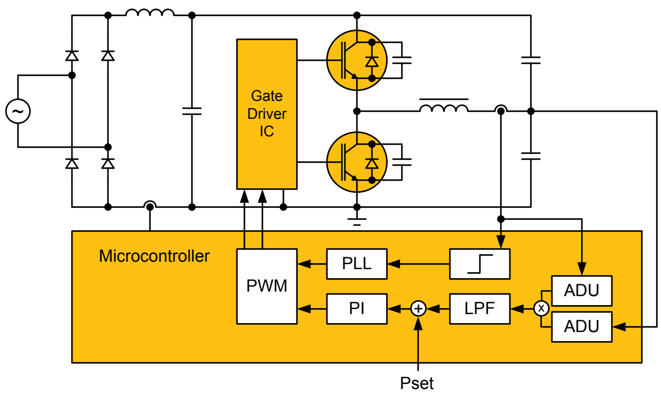

Figure 2: Half-Bridge Inverter that is used in Half-Bridge based induction cooking hobs

current electrical behavior results in a low tail current in combination with a soft di/dt ($t_{d,off}$). The system result is an EMI behavior that comes with less effort in the filtering at the input stage.

The single-switch RC-H5 series is complemented with a new generation of IGBTs, the half-bridge RC-H5 series. The half-bridge RC-H5 is optimized for induction stoves and can easily cover the full power range from 300W to 3.6kW, without the need of going into a burst mode where the system has to go into a pulsed turn-on turn-off behavior. The topology of this application is depicted in Figure 2.

The new half bridge RC-H5 series has enormous advantages compared to older 600V RC-IGBT technologies. The new devices combine the superior features of low conduction losses and low switching losses given by the high speed characteristics. The reduced total losses can increase the system efficiency by 30% in a 40kHz resonant-switching-design. This IGBT family is now even more flexible because it can also be used in hard-switching conditions. The power losses when turning on the devices have been reduced significantly by reducing the effect of a high Q_{rr} and a dependency of the V_F to the applied gate-voltage as shown in Figure 3. The significantly reduced Q_{rr} while turning on the IGBT allows the resonant system to be operated across a wider range even when not operating in over-resonant conditions.

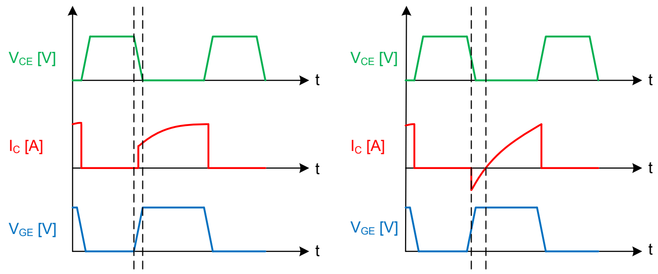

Figure 3: New RC-H family in 650V shows hard-switching capability (left) and a low dependency of the V_{GE} vs. V_F (right)

Furthermore, because of its superior loss behavior the new family can easily be used to get more output power by directly replacing a previous generation, due to the same package and similar EMI-behavior. The portfolio in 1200V/1350V and 650V offers 20A devices for utilization in inverterized microwave ovens or smaller induction heaters with output power below 1.8kW. The 40A and 50A versions of the 650V IGBT family are suitable for systems with higher output power.

The optimal design of the new family makes these devices suitable not only for purely soft-switching applications, but also allows them to be used in applications where the IGBT can run into some hard-switching conditions. As an example these conditions can appear at the turn-on phase of the system during duty-cycle variation.

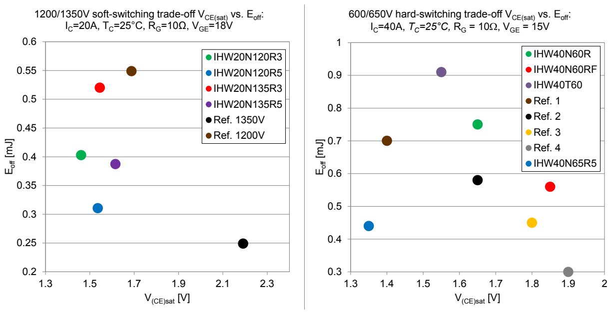

Figure 4: Trade-off diagrams 1200V/1350V (left) and 600V/650V (right) for resonant application VCE(sat) vs Eoff

The diagrams in Figure 4 show the superior electrical performance trade-off of the RC-H5. This curve defines the IGBT power losses related to the $V_{CE(sat)}$ and the E_{off}. The resulting junction temperature in combination with the used R_{thj-c} and the R_{thc-a} will result in low values. The resulting temperature of the T_j (junction temperature) is a key issue for the reliability of the IGBT. The optimization of the chip-size and the active area of the IGBT-cells of the monolithically integrated IGBT/diode combination are highly tuned to allow low temperatures in high power and low power conditions. The combination of advanced soldering processes with the perfect fit of the TO-247 package, offers a component that is ideally suited for resonant circuits. This reduces the size of the heatsink and the effort of the fan needed to cool the power semiconductors. The new series gives designers superior thermal behavior in the application and keeps the overall ambient, heatsink, and case-temperature low.

Reliability is a key issue for home appliances where the RC-H5 series stands out. The 1200V/1350V IGBTs show less current spikes during capacitive charging during the turn-on. The value has been reduced by 10%. Furthermore new processes in the chip allow the device to handle external stress moments like lighting surges better than ever. For the new 650V version the blocking voltage and the resulting breakdown voltage were increased by 50V without any sacrifice in the conduction and switching behavior. It also offers these improvements in 1200V as it is the highest performance device in the family; it ideally fits in systems that can handle the surges by advanced control algorithms. With an eye on reliability the new family thus provides outstanding values and helps to design a system protected from outside disturbances.

Infineon's new power switches are targeted specifically for the needs of each application, and the RC-H5 is the next step in this optimization for home appliances. Ideal system solutions are also available by combining with the compact EiceDRIVER™ Compact family and the industry optimized XMC1000/XMC4000 ARM® Cortex™-M microcontroller technology.

For further information on the complete portfolio, including product briefs, selection guides, datasheets and application notes please visit: www.infineon.com/igbt, for specific material on the new RC-H5 series: www.infineon.com/rch5 Information on the EiceDRIVER™ compact family and the XMC family can be found here: www.infineon.com/eicedriver and www.infineon.com/xmc

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Real Life Innovation with Practical Applications

The story of Danfoss Bond Buffer

Back in 2010, the market was buzzing with anticipation following the release of a seminal white paper describing the future potential of copper wire bonding. At Danfoss Silicon Power, we were excited by the prospect of a new generation of semiconductors, where a protective layer of copper was added to the chip allowing the use of superior copper wires.

By Siegbert Haumann, Danfoss Silicon Power

Back in 2010, the market was buzzing with anticipation following the release of a seminal white paper describing the future potential of copper wire bonding. At Danfoss Silicon Power, we were excited by the prospect of a new generation of semiconductors, where a protective layer of copper was added to the chip allowing the use of superior copper wires. The implications were enormous. The more we looked into the technology the more we realized that this could be a real game changer for the industry. We anxiously waited for the first semiconductors to enter the broader market.

Figure 1: A protective layer of copper was added to the chip allowing the use of superior copper wires

While we waited, our engineers and technicians began their own series of trials – experimenting with different solutions, where adding protective copper layer to the die allowed the use of more efficient copper wires. It turned out to be harder than it appeared - the delayed presence of the new promised solution on the market suddenly made sense:

We realized that any front-end wafer-based solution would probably be limited in its application (thin wafers) - and only be mastered by a select number of suppliers of power semiconductors.

It was therefore unlikely that it would solve the challenges we saw looming in the market: Cost competitive solutions allowing the use of ever smaller chip sizes and an increased demand for longer lasting modules that are more durable against power and temperature cycling – especially in the automotive and renewable energy sectors.

Innovation is more than a word

At Danfoss Silicon Power, there's a tendency to remain focussed on at a challenge until a solution is found. The word "innovative" is sometimes overused in our industry, but with all modesty, the work that went on behind closed doors at our research lab in Flensburg, in cooperation with University of Applied Science (Fachhochschule Kiel, Germany) , between 2011 and 2013 genuinely broke new ground in power module thinking.

By 2012 we were confident that we'd found a solution. We called it the Danfoss Bond Buffer (DBB). Developed to fulfill ambitious power module lifecycle requirements of the automobile and renewable energy markets, our new solution went beyond what could be achieved with today's bonding and joining technologies.

In many industrial and automotive applications, reliability and longevity of components is critical. Traditional solutions suffer from limited reliability due to solder fatigue and failing aluminium wire bonds.

By using unique silver sintering techniques rather than traditional soldering - and using copper instead of aluminium wires, along with the new Danfoss Bond Buffer technology, we created modules with outstanding reliability and significant performance. The design of the DBB was dimensioned for the thermo mechanical optimum to reduce the mechanical stress due to CTE mismatch.

The innovative combination of the copper bond buffer, copper wire and sintered joints lead to a much longer lifetime and/or higher current density. Other significant advantages include additional thermal capacity, better short circuit performance and lower forward voltages. (For more information attend the oral session at PCIM 2014, Tuesday

Figure 2: Due to the improved vertical current flow, there is no longer a need to place a stitch bond on the semiconductor

20th May at 15.00h, where the paper “Influence of Danfoss Bond Buffer and Cu-Wire bonds on the Electrical Switching Behaviour of IGBTs” will be presented by Dipl.-Ing (FH) Guido Mannmeusel, Danfoss Silicon Power) As the copper layer has a large cross-sectional area, which increases the vertical current flow, the DBB provides a uniform current density distribution in the semiconductor. Due to the improved vertical current flow, there is no longer a need to place a stitch bond on the semiconductor.

The results are convincing. DBB technology offers unmatched reliability – at least ten times higher than previously seen, plus extreme lifetime, increased power density and cycle capability. Test revealed better reliability up to 15 times better compared with state of the art power modules – and to a power of 60 times compared to industry standards. And to top it all, it’s applicable to pretty much any power semiconductor available.

By using DBB technology you can achieve 30% roughly longer life, lower cost improved reliability depending on your product needs.

Ideal for tomorrow’s automotive applications

The market is growing for hybrid electric vehicles (HEVs) and producers are hungry for competitive advantages. But the HEV market is still immature, and customer motives are different to those in the regular automotive sector. Legislation is driving OEMs to lower the CO2 impact of their entire fleet. Higher-end manufacturers simply cannot meet these new requirements, as they have no smaller, economy models in their portfolio. The only way they can conform to new legislation is by offering some of their fleet as hybrid standards.

In addition, early adopters, driven by a desire to minimize their environmental impact, are willing to pay for their conscience. The truth is though, that the cost add-on for the electrification won’t pay back for 5 to 8 years. These consumers account for a mere 3-4% of market. Most automotive consumers still perform a basic ROI analysis on their new car purchase and expect payback in 2 to 3 years.

As a consequence, manufacturers want to dramatically lower the cost for the electrification of a vehicle – and get the ROI down to 2 years. If they can achieve this, then their products viability is drastically increased, attracting a broad market and with that, drive economies of scale.

In the automotive industry, extreme power cycling requirements are

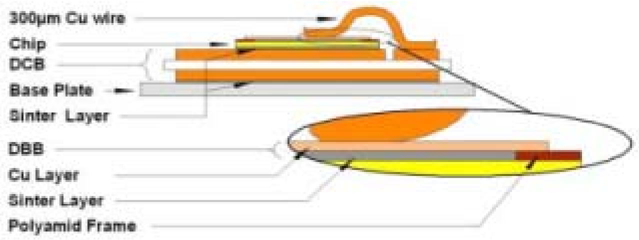

Figure 3: Danfoss Bond Buffer technology solves these problems by allowing the use of higher temperatures and use of less silicon area for comparable power output

hard on traditional aluminum wire solutions. The typical solution is derating the power module by adding additional silicon area. But silicon and vehicle space are expensive - so using less silicon while maintaining reliability is the key. Danfoss Bond Buffer technology solves these problems by allowing the use of higher temperatures and use of less silicon area for comparable power output.

Increased reliability for the wind industry

A wind turbine has an average lifetime of 20-30 years. Wind turbines have extremely tough power cycle issues especially on the generator side of the inverter, but failure is not an option. Downtime is expensive and maintenance and repairs - especially in offshore parks and remote regions - can be complicated and costly. Reliability is the key issue at every level. A DBB solution can offer longer life of up to 30% or a solution with less silicon.

With the combination of the improved thermal efficiency offered by Danfoss’ ShowerPower® cooling technology and DBB technology you get the perfect solution for using less modules in a given stack. This is especially crucial for turbines, where weight and size are physically limited. In a typical example - with around 24 chips in a module - with a 3 MW turbine, the magnitude of savings in this hypothetical case could mean a reduction of one in five stacks.

For reliable lifts and hoist applications

Lift and hoist applications also have extreme requirements for power cycles and long lifetime. Safety here is obviously paramount. In a normal hotel lift, for example, regular starting and stopping precisely at every floor means excessive driving around zero frequency - which is extremely tough on traditional aluminum bonds. For safety reasons, manufacturers are obliged to de-rate the module to ensure the lifetime or number of power cycles required. The impact is cost. A DBB solution limits the silicon required, while still maintaining life time and critical safety requirements demanded.

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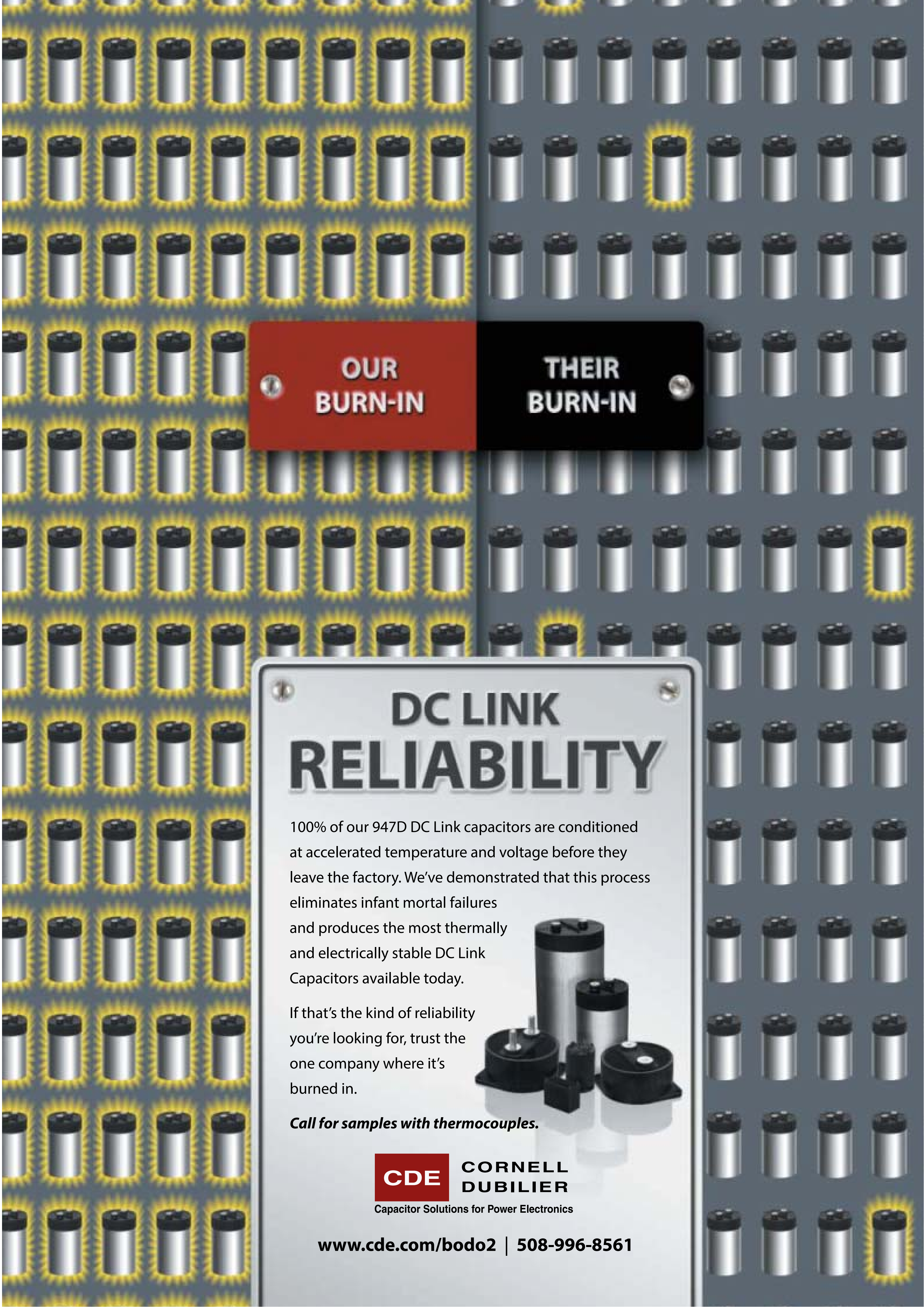
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600V GaN-on-Si Device's Extended Lifetime Testing Show High Levels of Reliability Results

Developing the next generation power semiconductors for efficient electricity conversion is an important task for a sustainable economy. The adoption of any new semiconductor device is based upon the confidence that the device will improve system performance and not degrade during the life of the targeted application.

By Carl Blake, Kurt Smith and YiFeng Wu of Transphorm, Inc.

Until now, the results for 600V GaN devices in Extended Lifetime testing have not been available. Customer confidence has been based upon the performance of the early samples, followed by beta samples that had passed most qualification tests and, finally, by JEDEC-qualified samples which have been produced only by Transphorm Inc. With the availability of qualified devices, it has become possible to perform meaningful extended lifetime testing to predict lifetime for these new devices.

Power devices using GaN are still in their early adoption phase, so questions remain regarding the reliability of these devices. Unfortunately, there is also a great deal of misinformation circulating about GaN devices, mostly due to failures of devices that have never passed even a basic JEDEC-type qualification. This has raised the question: Are the failures due to the material or the device design?

To address these questions we have taken examples of high-voltage GaN devices that have passed the typical 1,000 hour stress tests and have subjected them to long-term elevated stress testing. This article reports the results beyond the first 1,000 hours of stress testing. It also provides insight into the quality and intrinsic reliability of these first-generation, high-voltage GaN power devices.

Building a Strong Foundation

Before any meaningful extended life-testing could commence, it was necessary to establish a baseline stable process that could successfully pass a series of tests, such as those defined by JEDEC, to determine if silicon devices are suitable for use in commercial applications. The goal of these tests are shown in Table 1.

Name of Test	Purpose of Test
HTRB: 480 V 150 °C, 1000 hrs.	[Electric field / thermal stress]
HAST: 85% humidity, 33 PSI, 130 °C, 100 V, 96 hr.	[Corrosion]
Temperature cycling: -55 °C to 150 °C, 1000 cycles	[TC mismatch]
Power cycling: 25 °C to 150 °C, 5000 cycles	[WB & interconnect]
High temperature storage life: 150 °C, 1000 hr.	[Inter-metallic stability]

Table 1: JEDEC qualification tests and goals

The graph shown in Figure 1 illustrates the traditional bathtub curve used to describe the failure distribution over time. During the early development of Transphorm's EZ-GaN™ product family, a high early failure rate showed problems in both the design and manufacturing. By 2010 those problems had been reduced sufficiently so that the formal qualification process could begin.

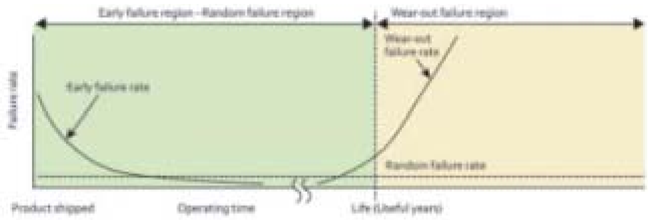

Figure 1: Bathtub curve

Early results of the tests (Table 1) showed that the tests related to packaging produced results similar to the existing silicon type devices, and it became clear that the most difficult test to pass would be high-temperature reverse bias (HTRB) test. This was reasonable to expect since the number one issue that needed to be solved with the GaN power devices was "Trapping" -- as has been previously reported by multiple groups attempting to develop such devices. An early indication of trapping was current collapse of dynamic Ron, both of which Transphorm solved in 2009.

As we learned during the development of the EZ-GaN™ product family, the testing, mentioned previously, was very effective in identifying weaknesses that required changes in the device design in order to eliminate the failure modes that were identified. In 2012, Transphorm's GaN-on-silicon carbide (SiC) products successfully passed these

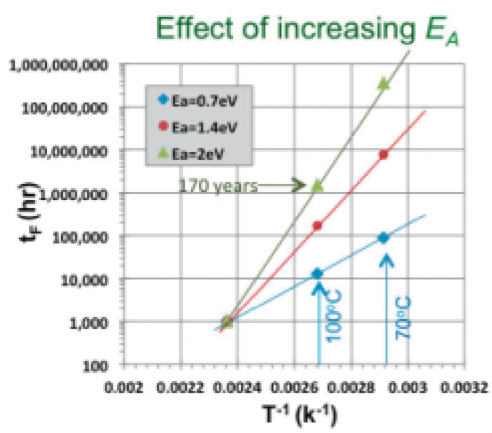

Figure 2: Effect of increasing Activation Energy E_A on end of life activity

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basic tests, which was followed in 2013 with the successful qualification of its 600V GaN-on-Silicon (Si) products [1].

The Extended Life testing program began with the accelerated electric field testing at multiple voltages to determine the electric field acceleration factors. The predicted effect of a higher activation energy for GaN (Figure 2) shows longer life at similar operating temperatures because GaN has more margin at these temperatures. The voltage test was selected because it is more critical than temperature and because long-term high-field stress had been the most difficult test to pass during the development phase of the 600V devices. This test is still in progress, having generated failures at the 1150V and 1100V while the testing at 1050V continued. These preliminary test results can be used to predict an expected lifetime, but the third data point is needed to confirm the predicted life and the validity of the testing. Testing at further higher voltages was not possible because it introduced additional failure modes that would not be encountered when the device operated at its targeted 600 volts.

Results

In parallel with the tests to determine the activation energy for the 600V HEMT (high electron mobility transistors) devices, the HTRB continued until either 50% of the devices failed or the testing reached 10,000 hours and the high temperature operating life (HTOL) was also extended over a longer period.

In March 2014 the results for extended HTRB, HTOL and highly accelerated voltage and temperature tests, which are ongoing, had the following results:

HTRB testing has now passed 8,000 hours and shows approximatly 2% failures (Figure 3.)
HTOL has passed 3,000 hours at 175°C and shows no measureable degradation in either leakage current or on resistance.

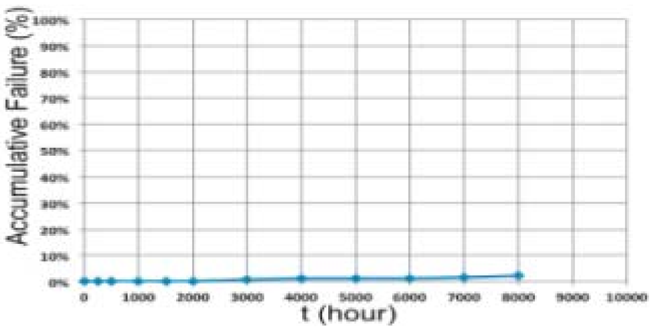

Figure 3 – HTRB results

These results are very significant because even for matured Si devices, it is note worthy to achieve such a high level of robustness. It also illustrates the fact that the design metrics used for the initial devices was conservative enough to overcome any weakness in the new device technology, and the performance now matches the original target of the design team.

The results of the voltage acceleration testing can be used to predict the lifetime of the product family. Using the inverse power law model, the predicted lifetime, as shown on the right side of Figure 4, is greater than 100,000,000 hours. While this result is consistent with the predicted lifetime of GaN RF HEMT devices, it is an excellent confirmation that the GaN 600V device's stresses have been managed as planned and that the buffer layer is performing as designed. This allows the EZ-GaN™ product family to lead the way in commercializing the use of GaN HEMT devices in power conversion applications.

Conclusions and Future Work

Extended lifetime testing beyond the JEDEC qualification standards has strengthened the overall understanding of reliability in GaN 600V power devices. The tests described in this article are continuing to provide data, while customer adoption is ramping up. Additional

Figure 4 – Predicted Life results

testing at multiple temperatures to determine the acceleration factor, including tests above 300^{o}C, will be performed to project the lifetime based upon temperature acceleration. These tests will be used to establish the recommended operating temperature of the GaN devices, since it is known to be a higher temperature material than silicon. But for that application, the packaging will become the most significant issue to overcome.

Also, additional testing at high currents and various temperatures will continue to determine at what point electromigration becomes an issue.

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Y.-F. Wu, J. Gritters, L. Shen, R.P. Smith, J. McKay, R. Barr and R. Birkhahn, "Performance and Robustness of First Generation 600V GaN-on-Si Power Transistors", *Proceeding, 1st IEEE Workshop on Wide Bandgap Devices and Applications*, S1-002, Ohio, Oct 27-19, 2013.

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CIPS 2014 - A Race towards the Lowest Inductive Power Module

292 engineers and scientists attended the conference, 24% more than 2012

Attendees came from 17 countries in Europe, America and Asia with 22 participants alone from Japan. The 8th International Conference on Integrated Power Electronics Systems (CIPS 2014) was held on 25-27 February 2014 in Nuremberg as part of the ECPE Annual Event. The Conference is organized by ETG, the Power Engineering Society within VDE, and by ECPE, the European Center of Power Electronics. IEEE PELS and ZVEI are technical co-sponsors.

By Prof. Eckhard Wolfgang, ECPE, and Prof. Dieter Silber, Univ. Bremen, Technical Chairs CIPS 2014

The program of this year's conference coverd 80 papers: Three keynotes, 9 invited, 39 oral and 29 poster papers. A good balance of contributions was achieved: 21 were from industry, 20 from industry and academia, and 39 from academia and research institutes (e.g. 6 from Fraunhofer institutes).

Prof. Johann Kolar/ ETH Zurich explained in the 1st keynote speech his thoughts on "What are the big challenges and opportunities in power electronics". Here a brief summary:

Power semiconductors, gate drive, and packaging: Some major changes already happened like the introduction of GaN system integration and Ag sintering. In addition there is a continuous improvement in packaging concerning parasitic inductances, improved heat management and reliability. The main future challenges for module manufacturers are 3D electromagnetic "quiet" packages, integrated programmable gate drives and passive filter components and lifetime simulation and testing. General users will have to deal with a significantly higher level of integration (e.g. embedded integrated power boards) and with fundamental changes in design, manufacturing and measurement techniques.

Magnetics and capacitors: generally only gradual improvements can be expected. For magnetic devices a careful design is absolutely mandatory which also includes an improved thermal management. In general high frequency operation will become more important due to the use of SiC and GaN power semiconductors.

New topologies and modulation/control schemes: The basic concepts are known since several decades, but there are some exceptions like multi-cell converters and three-phase isolated AC/DC buck converters. The message is – go with the most basic structures and avoid to integrate several functions. This keeps degrees of freedom for the design and control and will help to ensure low costs and to increase reliability.

Virtual prototyping: this remains most challenging regarding modeling and simulation of EMI and reliability. More work is needed especially for model order reduction and multi-stress analysis and testing.

Figure 1 shows his summary which means a shift of paradigm from the focus on switches and topologies towards passives and future smart distribution systems where not "Power Conversion" but "Energy Management", not "Converter Analysis" but "Converter – Source or Load Interaction Analysis", and not "Converter Stability" but the "Stability of Converter Systems / Clusters" will be most important. Of course lower costs for converters and systems will be of paramount importance as well.

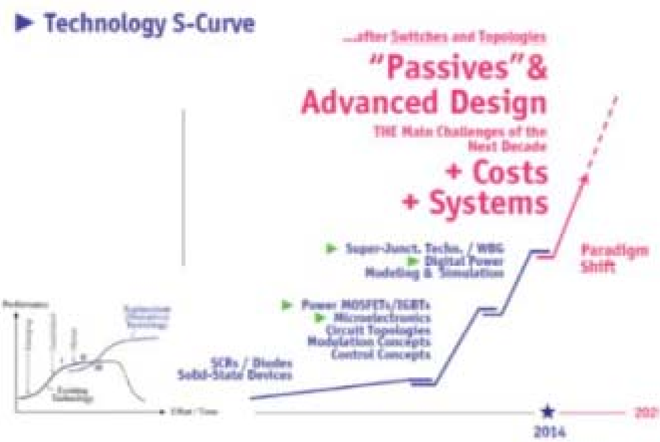

Figure 1: Prof. Johann Kolar's view into the future for which he expects paradigm shifts

In the second keynote speech Prof. Abhijit DasGupta/ CALCE, University of Maryland – one of the pioneers of the Physics of Failure approach – reported on his studies to excite electronics using a novel multi-degree-of freedom electrodynamic shaker. In conclusion he showed that nonlinear dynamic phenomena play an important role in damage accumulation under vibration excitation.

In the third keynote "Present and Future of GaN Power Devices" Prof. Daisuke Ueda/ Advanced Technology Research Laboratories, Panasonic, Japan, explained how the specific properties of GaN can be used best for integrated systems. Major steps in development have been the Gate Injection Transistor GIT, which enables normally-off operation. The Natural Super Junction diode has no trade-off between blocking voltage and on resistance because the number of AlGaN and GaN layers can be increased without sacrificing the blocking voltage. The most recent development is the Drive-by-Microwave technology which delivers the PWM signal as well as the driving power necessary at the same time. Finally, a direct liquid hermetic immersion package is explained in which the GaN devices are inside a heat pipe structure and covered by e.g. ethanol. The outlook is that GaN on Silicon has the potential for lowering the energy losses as well as system size and finally cost.

The more frequent use of wide band gap devices and systems calls for very low-inductive interconnects and packages. 8 contributions discussed different solutions for advanced power modules, three of them coming from industry (Infineon, Semikron (see Figure 2) and Toshiba). In his invited paper Dr. Eckart Hoene/ Fraunhofer IZM, explained in detail the assembly of a SiC JFET half-bridge module (Figure 3 and 4). The resonance with a frequency of 240 MHz leads to an inductance value of 870 pH, including the inductance of 300 pH for the current sensor. By designing packages properly parasitic effects like over voltages during switch-off, ringing, parasitic switch-on and EMI generation can be overcome so that semiconductors are the limiting factor again.

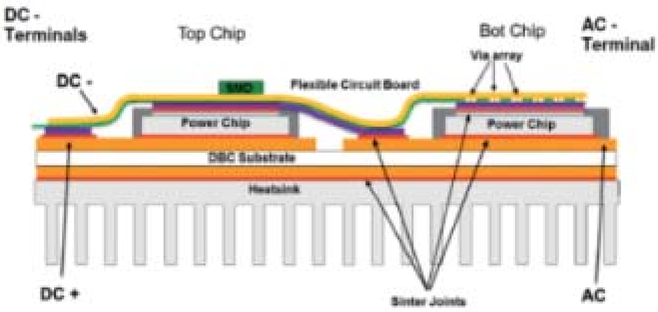

Figure 2: Semikrons 3D SKiN device with multilayer power routing (P. Beckedahl)

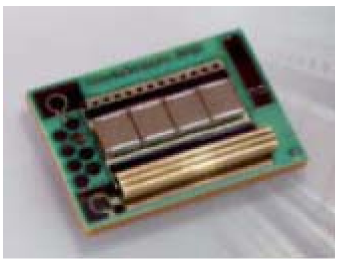

Figure 3: Assembled module with 570 pH DC link inductance (E. Hoene, Fraunhofer IZM)

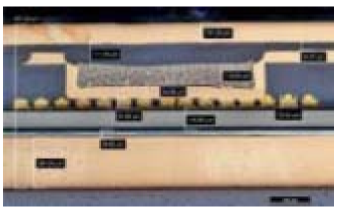

Figure 4: Cross section of module with capacitors and a current sensor

Prof. Dushan Boroyevich/ CPES, Virginia Tech, described recent developments regarding active filters to suppress conducted EMI signals. One of his conclusions is that current advancements in systematic EMI mitigation techniques and design procedures are turning the EMI filter design and integration from "art" into "science".

Dr. Reinhold Bayerer/ Infineon, presented “Transient hygro-thermal-response of power modules in inverters-mission profiling for climate and power loading”. This topic becomes more and more important because the number of outdoor applications increases, like in wind and solar energy. The moisture profiles can be gained by using a hygro-thermal equivalent circuit containing controlled capacitors and resistors. Condensation of water can be covered by controlled Zener diodes or active circuitry.

Dave Saums presented a comprehensive description on “Practical aspects of testing methods for thermal interface materials”. He outlined differences in principal testing procedures and how generally to interpret and make use of the data, especially in comparison to vendor-provided data.

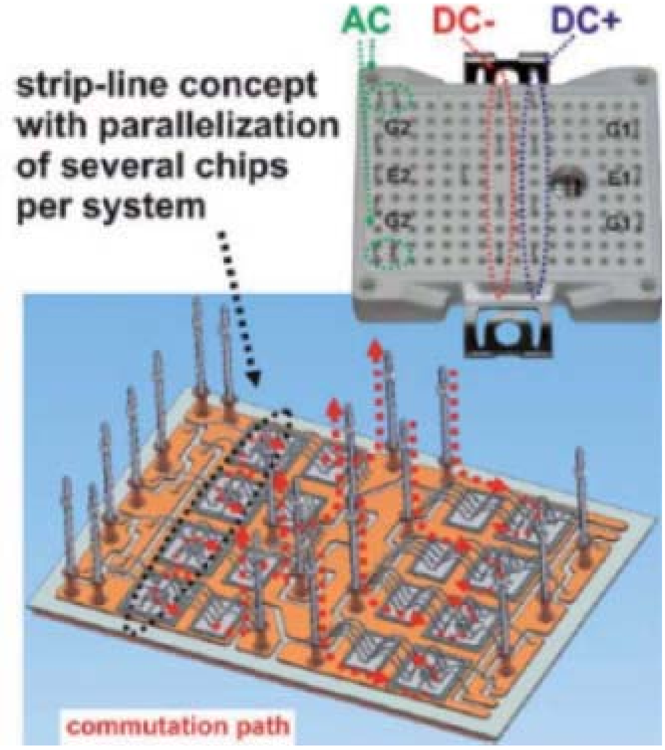

Figure 5: Infineon’s low-inductive inverter concept in an EasyPack 2B (C. Müller, Infineon)

As in the previous CIPS conference there were two awards:
The VDE best poster award of 1000 € in recognition of an outstanding paper presented in the dialogue session. The award committee selected “Impact of the control on the size of the output capacitor in the integration of Buck converters”, presented by Jorge Cortes, Universidad Politecnica de Madrid

Figure 6: Photo from the Conference Dinner at the Historical City Hall Nuremberg

The ECPE Young Engineers Award promoting young engineers presenting papers at CIPS. The award of 1000 € was split between two winners:

Bianca Böttge et al/ Fraunhofer IWM for “High resolution failure analysis of silver-sintered contact interfaces for power electronics”, and

Christian R. Müller et al/ Infineon for “Low-inductive inverter concept by 200A/1200V half bridge in EasyPack 2B – following strip-line design” (Figure 5).

The photo Figure 6 was taken at the Conference Dinner which took place at the Historical City Hall Nuremberg. It shows in the first row from left: Prof. Daisuke Ueda/ Keynote speaker/ Panasonic; Prof. Dieter Silber and Prof. Eckhard Wolfgang/ Technical Program Chairs; Dr. Eckart Hoene/ Fraunhofer IZM; Second Row from left: Dr. Kimimori Hamada/ Toyota Motor Corp., Prof. Hiromichi Ohashi, AIST/ both members of the Steering Com.; Prof. Cian O`Mathuna/ Tyndall National Institute; Thomas Harder/ ECPE General Manager; Prof. Dushan Boroyevich/ CPES, Virginia Tech; Prof. Josef Lutz/ TU Chemnitz; Dr. Reinhold Bayerer/ Infineon; Prof. Frede Blaabjerg/ CORPE, Univ Aalborg.

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New Packaging Technology enabling High Density Low Inductance Power Modules

While chip technology (IGBT, SiC MOSFET) is evolving step by step allowing for higher current densities, faster switching and higher junction temperatures, the applications become more and more limited by the power module packaging technology itself. By using a multilayer flex foil applied in a sintering process vs. traditional bond wires, current design boundaries are pushed far out.

By Oliver Tamm, Head of R&D Sintered Modules, Semikron

Power systems engineers face always the same issues. While new chip generations allow for higher switching currents, higher operating chip junction temperatures and higher power densities, the final system performance is heavily dictated by the power module package. The stray inductance in the commutation path forces the engineers to lower the switching times to limit the overvoltage. Higher switching frequencies, which would allow for an overall much more dense inverter design, are not possible because of the associated high dynamic losses. Limited thermal durability of bond wires and solder joints makes it impossible to reach the operation temperature limits of new gen silicon without significantly reducing life time. But there is light on the horizon as power module packaging technology is undergoing significant enhancement to address these issues. Semikron has introduced the next gen 3D SKiN® technology allowing for higher densities and enabling new applications especially in the fast switching domain. By using a multilayer flex foil instead of bond wires and applying silver diffusion sintering to the whole stack consisting of heat sink, DBC, silicon and flex foil, density, reliability, stray inductance and thermal performance is pushed into new dimensions given system designers more freedom to squeeze more performance out of the silicon and footprint.

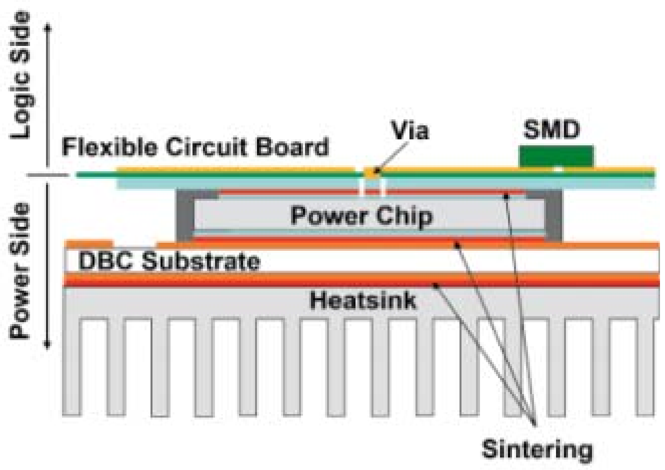

Figure 1: Schematic cross section of the first gen SKiN® module

First Gen SKiN®

The first gen SKiN® technology has been introduced in 2011 [1]. Main motivation was to replace solder joints and bond wires by silver diffusion sinter joints to significantly improve reliability pushing power cycles up to 700k @ dT 110K and with that pushing silicon operation temperature closer to the chip limits without sacrificing module life time.

Figure 1 depicts a schematic cross section of such a module. Solder joints are replace by silver diffusion joints. Bond wire connections of the chip top side are replaced by a sintered flexible Cu foil. In fact the foil contact is based on an advanced 2 layer flex board. While the lower layer of the flex carries the main high power current the upper layer takes care of low power auxiliary and sensor signals.

Silver diffusion sinter joints have superior thermal stress durability as their solidus temperature is app. 960°C which is far away from the maximum operation temperature of the silicon devices. Furthermore while bond wires can only make contact to about 20% of the total metallized chip surface, the sintered flex foil exhibits a die contact area of up to 85%. The increased contact area and the thick metal layer improve the heat distribution, the surge current capability and in combination with the highly durable silver diffusion sinter joint it has greatly improved power cycling capability of such a device[2][3].

In the first SKiN® module generation ~650mm^2 of silicon area could be placed on an DBC area of ~2400mm^2 including all necessary control and terminal contact areas which counts up to a silicon to DBC utilization of ~ 28%.

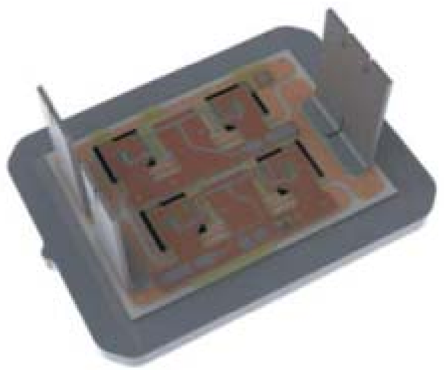

Figure 2: First gen SKiN® module comprising of 4 x IGBTs and 2 x FWDs

As the thermal performance of the sintered stack (heat sink, DBC, chip, flex foil) is superior (~ 30% better vs. standard modules) it leaves significant headroom in various water cooled based applications to push for more silicon into the same footprint and with that significantly lower the overall costs. But how to place more silicon into the same footprint if the DBC is already fully populated with silicon, main power traces, terminal contact areas etc. ?

Opening the next dimension: 3D SKiN®
The solution is straight forward but of course challenging: Move the DC-minus power trace resources from the DBC into a flex foil copper layer which is above the silicon chips. All real estate on the DBC which has been used for DC-minus power traces is now available for placing additional silicon. The 3D SKiN® was born.

The upper layer of the flex foil (yellow color) is used to form a module wide DC-minus power plane which can be connected to lower layers by the use of vias at any position of the module. The lower layer of the flex foil (purple color) bridges chip top sides to the appropriate DBC traces. The DBC itself has mainly only two conductor islands AC and DC-plus which furthermore makes the DBC design very simple and mechanically very robust. Moving from a pure single lateral layout towards a multilayer layout leads to a significant change in the module internal power routing. The chips are no longer arranged side by side from DC to AC terminal to form a half bridge configuration. The new architecture clusters the Bot switch to the AC island and the Top switch to the DC-plus island.

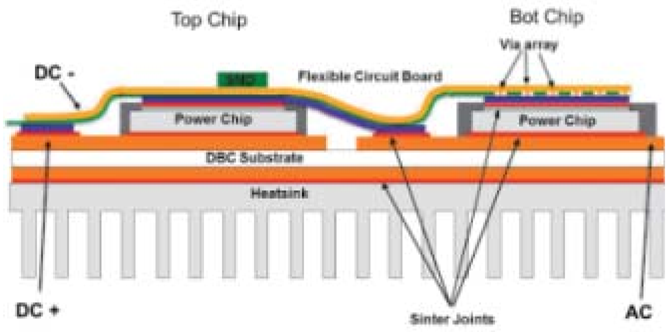

Figure 3: Schematic cross section of the 3D SKiN® stack up

Figure 4: 3D SKiN® module comprising of 6 x IGBTs and 6 x FWDs

The additional real estate on the DBC makes it possible to add ~50% of silicon (e.g. three instead of two IGBTs per switch). Due to the low Rth of the sintered stack the amount of added silicon nearly calculates into proportional increase of current, assuming that the water cooling flow is adopted accordingly to deal with the higher amount of power dissipation per module.

The density of the module is superior. Figure 4 depicts an example of a 650V half bridge module with 600A of nominal current. A similar design using 1700V IGBTs is rated @ 270A, all on a DBC area of ~2400mm^2. The DC-minus plane (grey color) covers ~80% of the DBC area, allowing for an balanced current distribution over all silicon devices.

As free meals are usually seldom of course also the 3D SKiN® technology has its challenges. The electrical design needs much more considerations vs. traditional bond wire architectures or vs. the first gen SKiN® architecture. Controlling and guiding the electrical fields around the chips is more complex and the design needs to take care of appropriate cooling of the DC-minus flex layer. But the latter is also a strength. Due to its flatness, the flex foil can be designed in a way that it is tightly coupled with the DBC allowing for efficient cooling. Together with the high durable sinter joints, junction temperatures of up to 200°C become feasible and with that 3D SKiN® is very well prepared for the next chip generations.

Figure 5: 1,5 MW three phase SKiiPX power module based on first gen SKiN modules.

System benefits

Systems which are adopted to this new 3D SKiN® technology can be boosted up without changing the fundamental mechanical footprint. As an example, Semikrons SKiiP® X system [4] which is based on the first gen SKIN® technology and which already marks a huge step in the industry in respect to density and modularity, may see a further power increase of up to 50% without changing the outline of the overall assembly.

Each phase in Semikrons SKiiP® X system comprises of 3x3 SKiN modules. In total 27 SKiN modules are used for a 3 phase system.

With the implementation of the new 3D SKiN® the power rating of the same assembly can be pushed far above 2 MW.

Electrical advantages

A further very important improvement comes with 3D SKiN®: Over a large area of the module, DC-plus and DC-minus power traces are placed above each other with minimal distance. This architecture results in a significant reduction of the module internal stray inductance. Compared to the first gen SKiN® designs the internal stray inductance (excluding the terminals) is reduced by ~60% which for the mentioned module sums up to ~1.3nH [5]. Of course the DC terminals add significant stray inductance on top of this, but this also indicates where future generations of 3D SKiN® will go: Eliminating the stray inductance towards the link capacitors allowing for ultra high speed, low loss switching modules and with that also being able to fully leverage new chip technology based on ultrafast switching SiCs. Stay tuned…

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Selecting the Best Power Device for Power Electronics Circuit Design through Gate Charge Characterisation

The improved performance of recent power devices is enabling higher frequency and more compact switching power supply designs. Emerging new devices such as super junction MOSFET or GaN FET are soon expected to replace the traditional devices such as silicon MOSFET or IGBT. Switching power supplies operating in higher frequency from a few hundred kHz to more than 1 MHz have been developed and are available using these innovative power devices.

By Hisao Kakitani and Ryo Takeda – Agilent Technologies International, Japan Ltd.

Market and technology trends in power electronics

High frequency operation reduces the cost of power circuits by shrinking the magnetic component size. This, in turn, results in smaller and lighter circuit designs. However, high frequency switching increases the power device loss. The main power loss in a switching power supply is the loss associated with the power semiconductor devices. Therefore, selecting the optimum low power devices is essential when designing power electronic circuits.

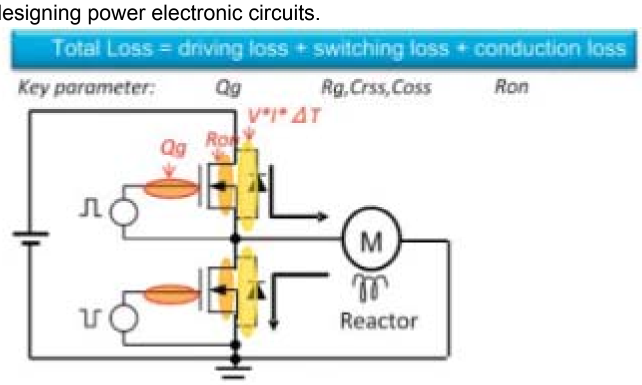


Figure 1: Loss in Power Devices is the main factor of total circuit loss

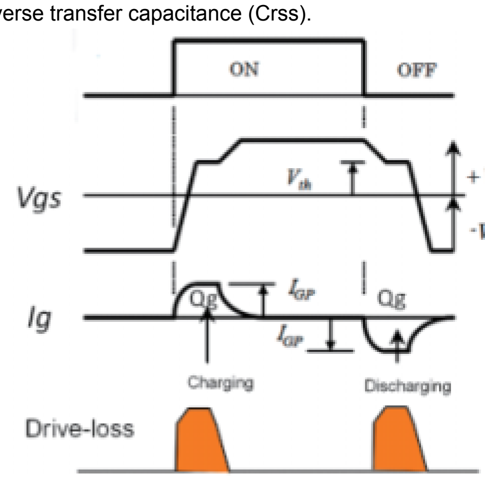
Figure: 2 Increasing driving loss and switching loss

Required evaluation for optimum power device selection

Selection of the correct power device for a power electronics circuit requires a detailed assessment of many parameters. Blocking voltage, leakage current and thermal characteristics are all important factors from reliability point of view. Saturation voltage, threshold voltage, trans-conductance and peak current are important from operation point of view. Minimizing power loss is essential to the overall design of an efficient power electronics circuit.

Power device losses can mainly be categorized into three elements; driving loss that is generated when driving the power device; switching loss that is generated when the device is turned on or off and conduction loss that is generated while the device is turned on (Figure 1). Conduction loss is dominant for switching frequencies below 10 kHz. Driving loss and switching loss become dominant as the switching frequency increases (Figure 2). Each type of power loss can be calculated via inherent device parameters.

Driving loss can be calculated from gate charge (Qg). Switching loss can be calculated from gate resistance (Rg) and device parasitic capacitances (or gate charge characteristics) while conduction loss can be calculated from on-resistance (Ron). It therefore follows that test equipment that can characterize these parameters is necessary for power loss evaluation. Device parasitic capacitances are broken down into input capacitance (Ciss), output capacitance (Coss) and reverse transfer capacitance (Crss).



$$P(driveloss) = f * Qg * Vgs$$

Figure 3: Driving Loss by Gate Charge

Selection of a power device that has a good balance between on-resistance and device parasitic capacitances is the first step in the design of an efficient power electronics circuit. Gate charge is defined as a total amount of charge that is required to fully turn on a power device. It can also be seen as a parameter that represents the non-linear characteristics of device input capacitance, (Ciss = Cgs + Cgd). Both on-resistance and device parasitic capacitances are important in high switching frequency power devices with small FOM (Figure Of Merit), which is calculated as a product of Qg and Ron.

What is Gate Charge?

Gate charge is the total amount of charge to turn on a power device. In other words it is the time integration of current flowing into gate terminal when the device transforms into the on-state. Driving loss is then calculated as product of gate charge, gate voltage and frequency.

As shown in Fig.4, gate charge characteristics are drawn as a continual curve that consists of three segments with different slopes.

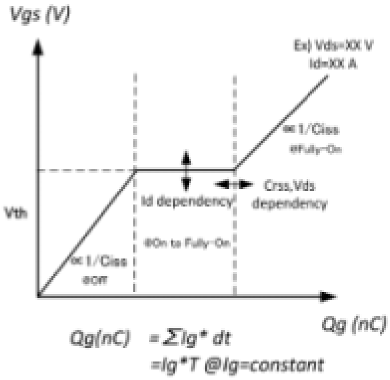


Figure 4: Theoretical understanding of Qg Curve

If gate current (Ig) is kept constant the gate charge is a product of Ig and time (t). Then, the Qg curve is obtained by making sampling measurement on gate voltage (Vgs). The first segment of the Qg curve represents Vgs rise where Ciss_off is being charged by Ig while the device is off. It is represented as Vgs = (1/Ciss_off)*Qg. Because Cgs is, in general, much bigger than Crss it can be approximated as Vgs = (1/Cgs)*Qg. The gate charge for this segment is called Qgs. When Vgs increases above threshold voltage (Vth) the drain (or collector) current starts to flow. Vgs in this segment is increased until the drain current reaches the rated current in the Id-Vgs characteristics.

In the second segment with flat slope, where the device is changing state from on to fully-on, Vgs is not increased because all the Ig current flows into the Crss.

Figure 5 shows the capacitance characteristics of a transistor and Figure 5 (d) shows the voltage dependency of Crss. Changes in Crss can be classified into two distinct areas:

When Vds>Vgs Crss is increased according to the decrease of Vds. The amount of increased Qgd1 charge is:

$$Qgd1 = \int_0^{Vds-Vgs} Crss * dV \quad \text{Vds>Vgs,} \qquad (1).$$

Qgd1 is called mirror charge.

In the Vgs> Vgd state Crss is significantly increased by channel forming under the Gate due to the device turn-on. The increase of Qgd2 charge is:

$$Qgd2 = \int_{Vds}^{Vgs} Ciss\_on * dV \qquad (2).$$

The value of Ciss_on is obtained from the Vgs – Ciss characteristics as shown in Fig5(c). The charge in this segment is called Qgd. The size of Qgd depends on drain (or collector) voltage in off-state and the on-state of Crss.

$$Qgd = Qgd1 + Qgd2 \qquad (3).$$

The Qgd value limits the device switching performance.

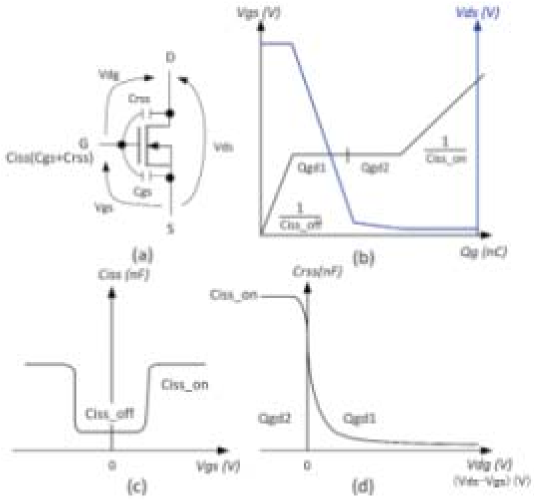


Figure 5: Qg Characteristics by non linear Crss-Vdg Characteristics

In the last segment the device is fully turned on and charging of Ciss_on is resumed. Vgs is represented as Vgs = (1/Ciss_on)*Qg.

Design points for Driving Circuits.

Circuit designers utilize gate charge characteristics to design gate drive circuits and to calculate driving loss. They set the gate driving voltage by considering device performance, dispersion, unexpected device turn-on and then read out total amount of charge from Qg curve. For example, let's assume that the Qg curve shown in Fig. 6 is obtained with Vds=600 V and Id=100 A. If the gate is driven from 0 to 15 V the read out Qg is 500 nC. The driving loss is 0.15 W if the switching frequency is 20 kHz: [*P(driving loss) = f * Qg * Vg = 20k * 500n * 15]*. In addition, if you expect 100 ns rise time then at least 5 A [500 nC/100 ns] of drive current is required. Insufficient drive current delays switching speed resulting in increased switching loss. Maximizing drive current is an important parameter in drive circuit design.

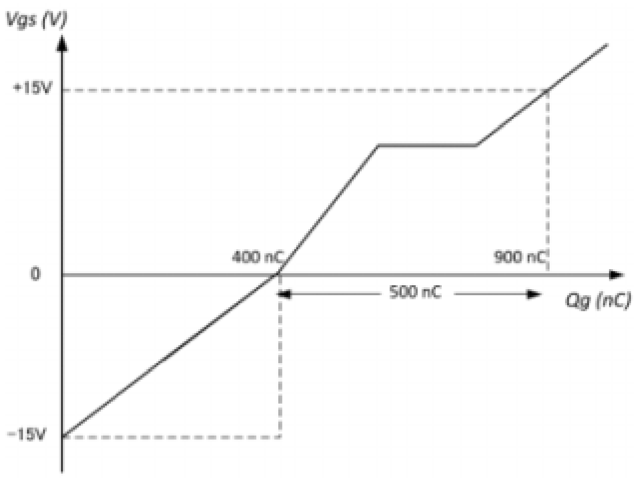


Figure 6: Qg Characteristics from negative Vgs

It is generally recommended to drive the gate voltage of an IGBT from a negative value in order to avoid unexpected turn-on. The correct total Qg value is obtained from the sum of the Qg values in both the negative and positive voltage regions. For example in Fig.6 the gate voltage is swung from -15 V to +15 V and 400 nC has to be added to Qg resulting in a total drive loss of 0.27 W: [*P(driving loss) = 20k * (400n + 500n) * 15]*.

The Qg curve in combination with the device output voltage characteristics enable detailed analysis and optimization of a switching mode power device.

Relationship between Switching Time and Gate Charge
A switching time calculation based upon a first order transient response of gate charge characteristics, gate series resistance (Rs) and input capacitance (Ciss) is often used. Rs is the sum of device gate resistance (Rg) and an external resistor attached to the gate.

Gate voltage Vgs, at a given time t, is represented using the gate drive voltage VGS, as follows:

$$Vgs(t) = VGS\left\{1 - e^{-\frac{t}{Ciss*Rs)}}\right\} \qquad (4)$$

Therefore, t is given as:

$$t = (Ciss * Rs) * \ln\left\{\frac{VGS}{VGS-Vgs}\right\} \qquad (5)$$

Time constant is given as :

$$\tau = (Ciss * Rs)\ @\ 63.2\%\ of\ \mathrm{VGS} \qquad (6)$$

Substituting Qg = Ciss * Vgs into equation (5) yields:

$$t = \left(\frac{Qg}{Vgs}\right) * Rs * \ln\left\{\frac{VGS}{VGS-Vgs}\right\} \qquad (7)$$

Utilizing (7) above the difference between t1 and t2 is as follows:

$$t2 - t1 = \left(\frac{Qg2-Qg1}{Vg2-Vg1}\right) * Rs * \ln\left\{\frac{VGS-Vg1}{VGS-Vg2}\right\} \qquad (8)$$

Td(on), Tr, Tf, and Td(off), as listed on a device datasheet, are calculated from (8) by substituting the corresponding data of; gate voltage, drain voltage and drain current versus Qg. The device manufacturer application note needs to be referenced for the definition of each switching time parameter.

Equations (9) through (12) are switching time formulas defined by gate voltage and drain voltage.

Turn On Delay time, Td(on): from 10% of VGS to 90% of VDS

$$td(on) = \left(\frac{Qg2-Qg1}{Vg2-Vg1}\right) * Rs * \ln\left\{\frac{VGS-Vg1}{VGS-Vg2}\right\} \qquad (9)$$

Rise time, Tr: from 90% of VDS to 10% of VDS

$$tr = \left(\frac{Qg3-Qg2}{Vg3-Vg2}\right) * Rs * \ln\left\{\frac{VGS-Vg2}{VGS-Vg3}\right\} \qquad (10)$$

Turn Off Delay time, Td(off): from 90% of VGS to 90% of VDS

$$td(off) = \left(\frac{Qg6-Qg5}{Vg6-Vg5}\right) * Rs * \ln\left\{\frac{Vg6}{Vg5}\right\} \qquad (11)$$

Fall time, Tf: from 10% of VD to 90% of VDS

$$tf = \left(\frac{Qg7-Qg6}{Vg7-Vg6}\right) * Rs * \ln\left\{\frac{Vg7}{Vg6}\right\} \qquad (12)$$

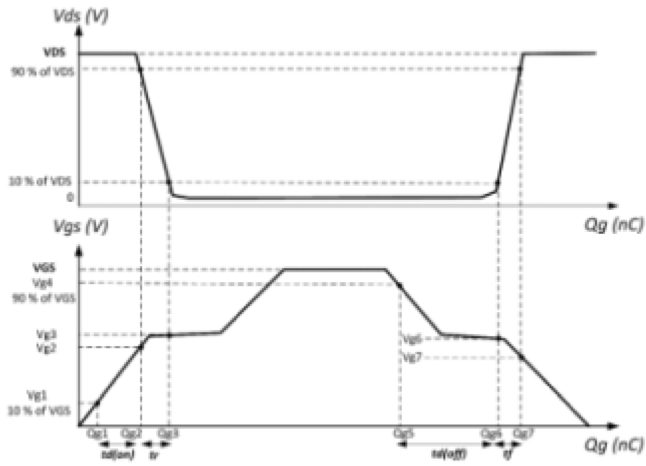


Figure 7: Switching time calculation derived from Qg characteristics

Relationship between Switching Loss and Gate Charge
Switching charge (Qsw) is defined as the total charge in the period for which the drain voltage and the drain current are crossed. It is approximately equal to the mirror charge (Qgd1) of equation (1). In DC-DC converter design there is an established calculation of switching loss derived from Qsw.

The product of gate current (ig) and switching time (Tsw(on) or Tsw(off)) is Qsw which allows the following switching loss calculation for both device turn-on and turn-off. In the case of a purely resistive load, Id and Vds crosses at the midpoint. In the case of an inductive load, the phase of current and voltage is different and the loss factor changed. A pictorial representation is displayed in Fig.8.

$$Tsw(on) = \frac{Qsw}{ig} = Rs * \frac{Qsw}{VGS-Vgp} \qquad (13)$$

$$Tsw(off) = \frac{Qsw}{ig} = Rs * \frac{Qsw}{Vgp} \qquad (14)$$

$$Psw(inductive) = \left(\frac{1}{2}\right) * VDS * ID * \left(Tsw(on) + Tsw(off)\right) * f \qquad (15)$$

$$Psw(resistive) = \left(\frac{1}{4}\right) * VDS * ID * \left(Tsw(on) + Tsw(off)\right) * f \qquad (16)$$

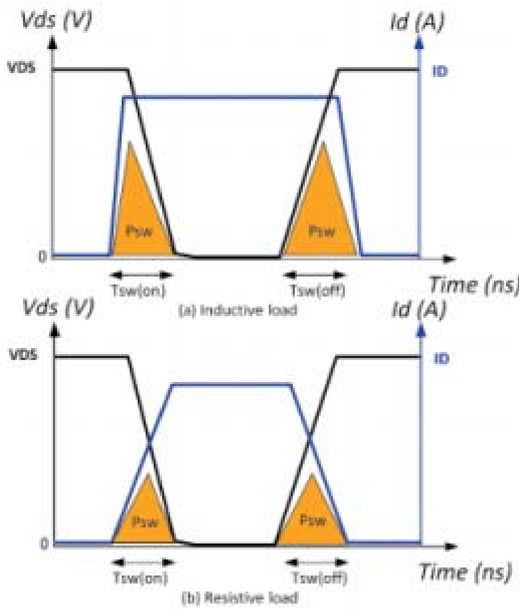


Figure 8: Switching loss

Challenges to measure Gate Charge

A test circuit to measure a Qg curve is often shown on a device datasheet. Fig.9(a) shows a circuit with constant current source, Fig.9(b) shows one with resistive load while Fig.9(c) shows one with an inductive load. In the case of Fig.9(b) it is difficult to obtain the corner point between the first and second slope as the current has voltage dependency.

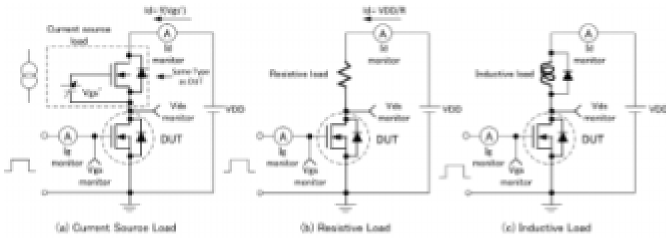


Figure 9: Gate Charge measurement circuits

Although all three circuits appear simple it is difficult to design a Qg test environment for the following two reasons:
A stable power supply to provide accurate time dependent output voltage and current.
A gate drive circuit which can accurately measure time dependent current and voltage.

To measure Qg a stable high power supply is necessary. For example to supply 120 kW at 600 V it is necessary to supply 200 A current. Designing a stable power supply with this capability is difficult. Qg measurement observation requires only pulsed power to capture the switching transient response. Accordingly, current discharged from large capacitor is sufficient as a power supply. However, safe fabrication of such a system is difficult.

In order to evaluate Qg accurately a constant current source gate drive circuit is required. Qg is the product of constant current and the time. The Qg curve can be simply obtained by sampling Vgs over time. The slew rate of a gate drive voltage source should be well controlled otherwise device switching occurs too quickly and transient characteristics become difficult to measure.

Many device manufacturers own dynamic test systems dedicated to Qg measurement. However, it is difficult for circuit designers to access such a test system due to cost and size. Accordingly Agilent Technologies has developed a bench top instrument that can quickly and easily evaluate Qg in an office environment.

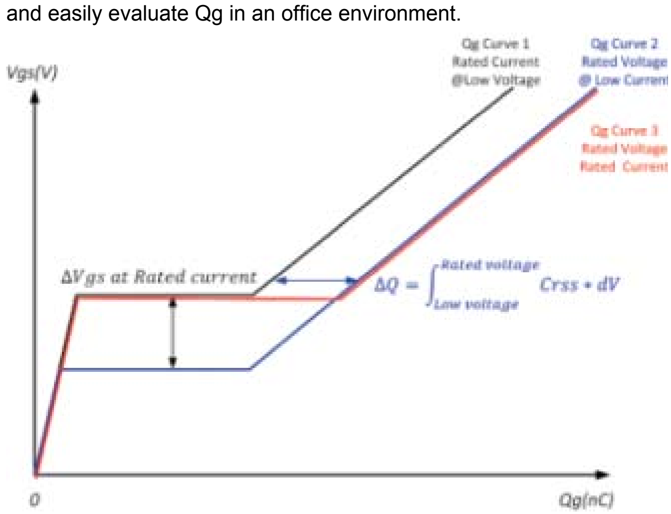


Figure 10: New Qg measurement technique

A new and innovative Qg test technique

Agilent Technologies has developed a new method to derive complete Qg curves (Fig.10 Qg curve 3). This composite curve is fashioned from two different Qg curves. The first, (Qg curve 1) is measured with a high current low voltage test instrument while the second, (Qg curve 2) is measured with a high voltage low current test instrument.

A high current low voltage instrument delivers the Qg curve during device turn-on while a high voltage low current instrument provides the Qg curve displaying the device Crss dependency. This technique eliminates the need for a huge power supply which is otherwise mandatory for high voltage and high current devices.

Accordingly, Agilent Technologies has developed a test system with a constant current source gate driver. This is used in combination with a high current but low voltage and high voltage but low current drain (collector) supply with simultaneous voltage and current sampling capability. This unique combination enables complete gate charge measurement, switching time and the resultant loss calculation.

The following table 1 shows an example IGBT and super junction MOSFET characterization by measuring Ron/Qg/Rg/Crss characteristics. The super junction MOSFET has switching loss advantages over the IGBT for frequencies in excess of 20 kHz of switching frequency for measurements performed under similar conditions.

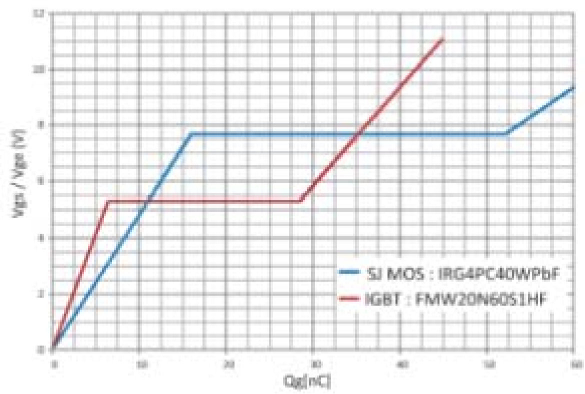


Figure 11: Gate Charge Characteristics of IGBT and Super Junction MOSFET

Conditions		
VDS	480V	
ID	20A	
Vgs	0 to 10V	
Switching Frequency	10kHz / 20kHz	
Ton Duty Cycle	10%	
Gate Series Resistance	27Ω	
Device Type	IGBT	Super Junction MOS FET
	IRG4PC40WPBF	FMW20N60S1HF
Measured		
Qg	63 nC	42 nC
Qgd	36 nC	22 nC
Qsw (=Qgd1)	12.2 nC	10.0 nC
Rg	0.7 Ω	3.5 Ω
Vce_sat/ Rds_on @ 20A	1.95 V	183 mΩ
Calculated		
Td(on)	39 ns	15 ns
Tr	47 ns	28 ns
Tf	28 ns	36 ns
Td(off)	162 ns	170 ns
P(driving loss)	6.3 mW	4.2 mW
P(Switching loss) @L load	9.0 W /18.1 W	5.8 W /11.5 W
P(conduction loss)	3.9 W	7.3 W
Total Power loss	12.9 W /22.0 W	13.1 W /18.8 W

Table1: Comparison table of IGBT/MOS's switching loss

Device evaluation by Agilent Technologies B1506A

The B1506A Power Device Analyzer for Circuit Design is an industry first bench top instrument that has Qg curve test capability up to 1500 A / 3 kV. It can generate complete Qg curves from 1 nC to 100 µC using a new and innovative method using a sophisticated gate driver with sensitive current control in combination with high current/low voltage source/sampling and high voltage/low current source/sampling capabilities.

Measure/Control parameter	Range	Minimum resolution
Qg	1 nC to 100 µC	10 pC
Vdd	+/- 0 V to 3000 V	100 µV
Id Limit	+/- 1 A to 1100 A	2mA
Ig	+/- 1 nA to 1 A	10 pA
Vg	+/- 30V	40 µV
On Time	50 µs – 950 µs	2 µs
Driver Vg for Current load	+/- 30 V	40 µV

Table 2: B1506A Qg curve measurement range.

In addition to IV characteristics the B1506A can also measure device parasitic parameters: Rg, Ciss, Crss, Coss, Cgs, Cds. Accordingly, it can validate a power device from two different perspectives. Additionally, it also can calculate switching time (td, tr, tf), power losses (driving, switching and conduction) from Qg curves and other measured parameters. Finally, temperature dependency characteristics from -50°C to +250°C can be measured.

The Agilent Technologies B1506A can evaluate all necessary circuit design parameters over a wide range of operating conditions.

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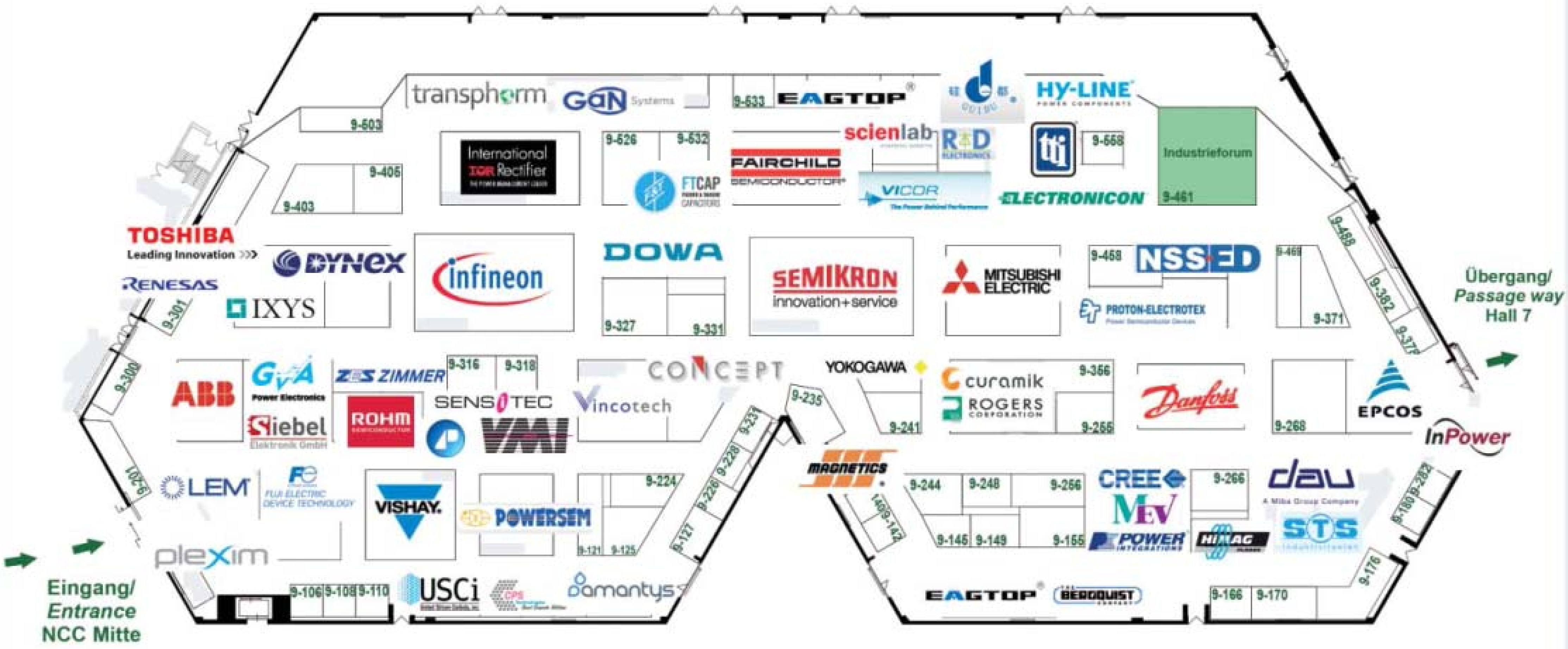

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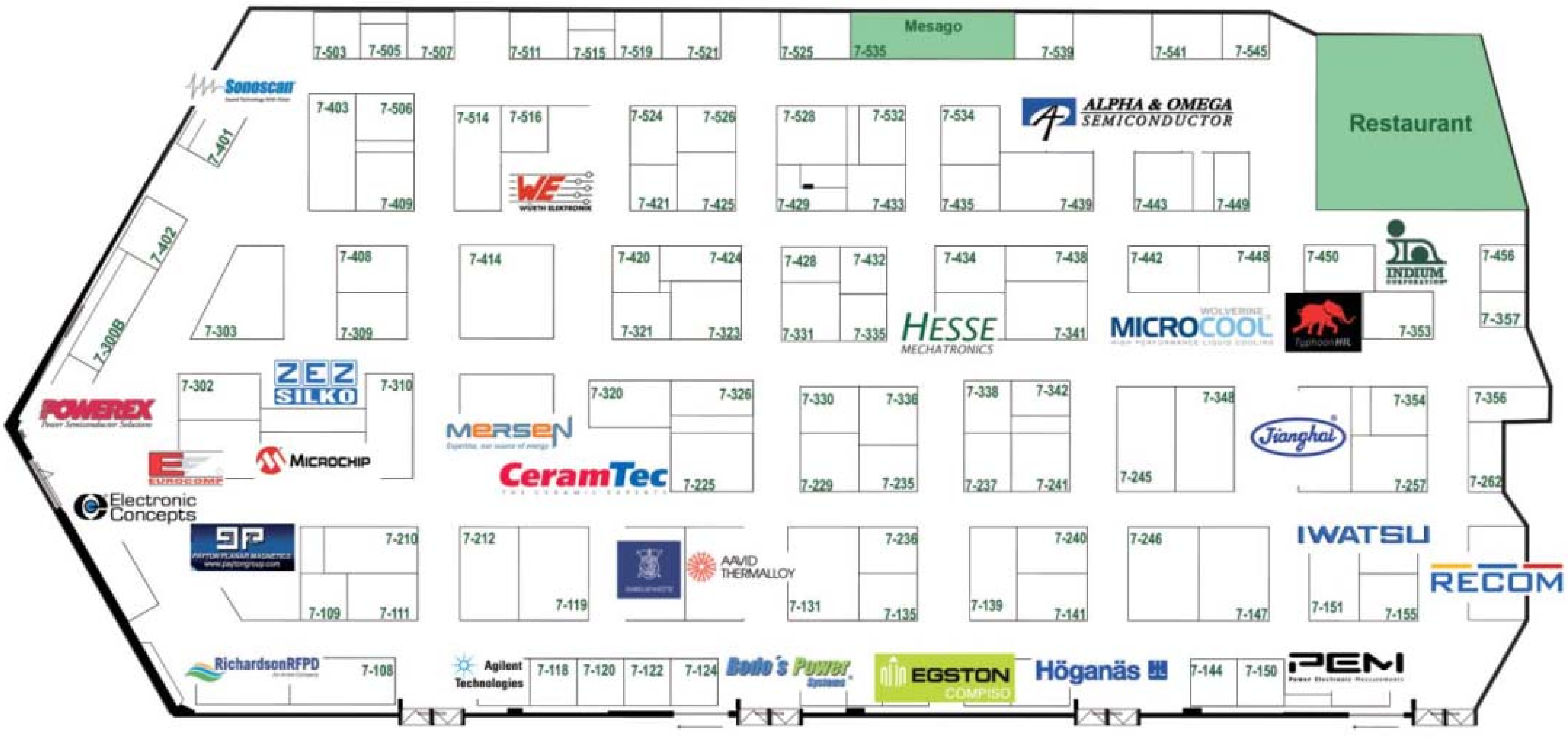

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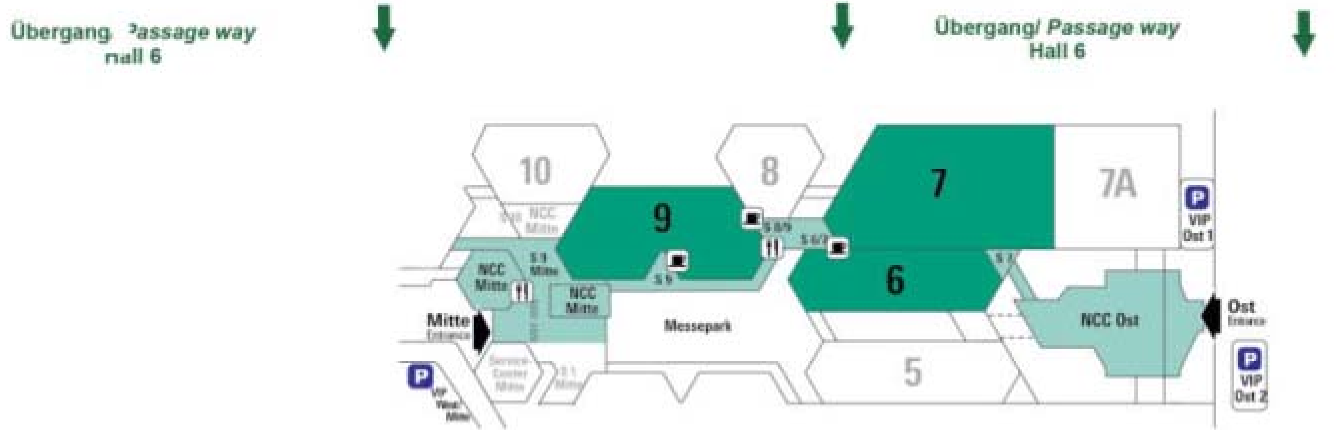

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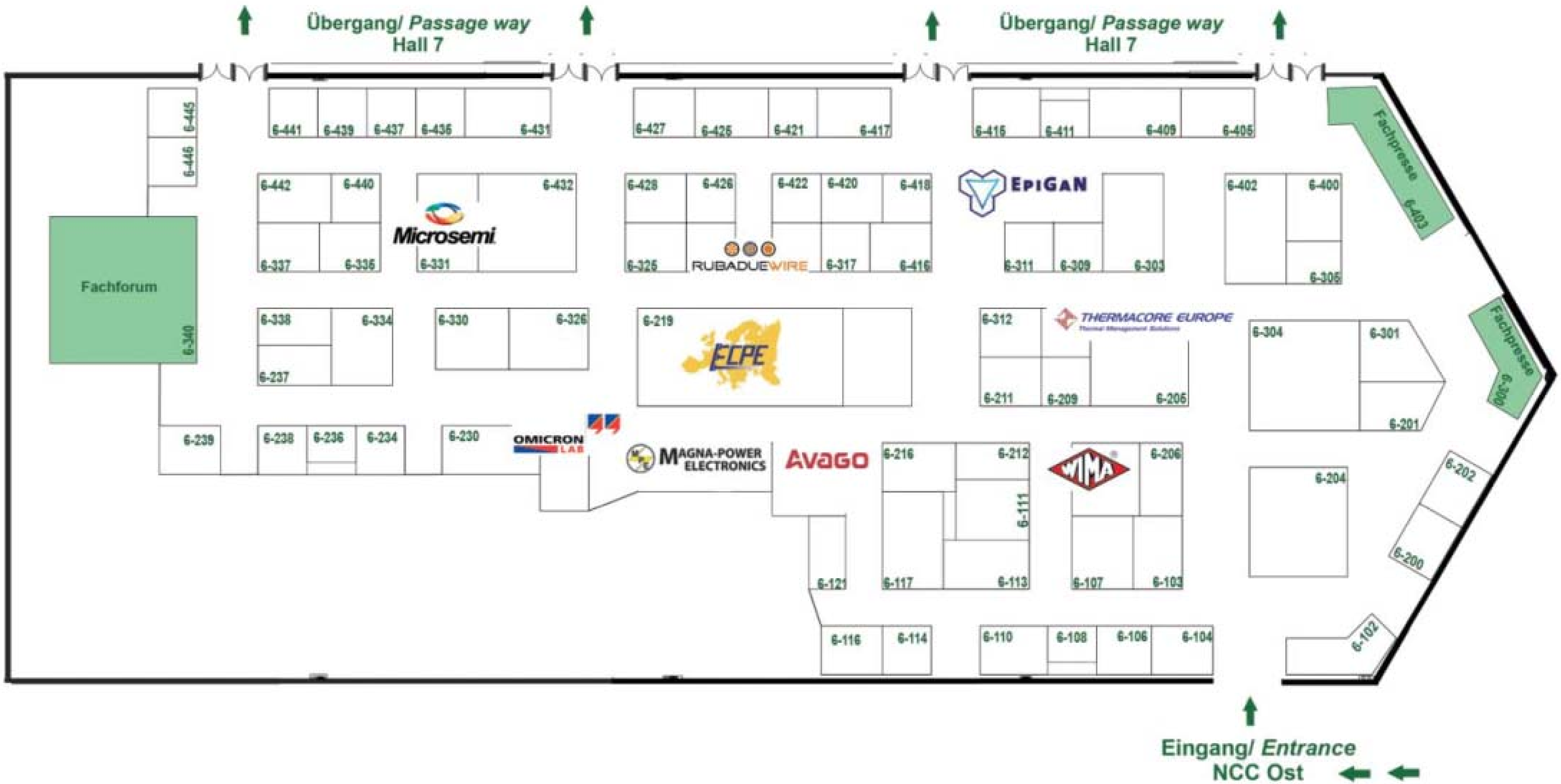

Next-Generation Current Probes for High-Speed and High Power-Density Applications

Clip-on Rogowski current probes provide a convenient and accurate means of measuring alternating currents. The latest wideband probes use an innovative shielding technique to eliminate the effects of high electrostatic field strengths in today's high power-density and high-speed circuits.

By Dr Chris Hewson, Power Electronic Measurements Ltd

Rogowski Probes: The Current State of the Art

Engineers involved in power electronics often use Rogowski current probes for measuring complex current waveforms. The probe comprises a thin, flexible, clip-around coil connected by a low-noise cable to an electronic integrator. The integrator plugs directly into a wide variety of recording devices, most typically an oscilloscope but also data acquisition systems and power, network, or spectrum analysers.

The coil is clipped around the conductor carrying the current to be measured. The coil measures the rate of change of current and the electronic integrator produces a voltage output proportional to the current. Although DC measurements are not possible, because the Rogowski coil measures di/dt, the probe offers many advantages to the power electronics engineer:

- Virtually zero insertion impedance (<10pH)
- The small probe head can be inserted into difficult to reach parts of a circuit thereby saving engineers adding flying leads, which corrupt circuit performance. A typical application is shown in figure 1.
- A wide-bandwidth from a few Hz to 30MHz
- High slew-rate capability of up to 70A/ns
- Isolated measurement
- High peak current ratings from 30A to 6kA (or more), maintaining the same small coil size throughout the current range.
- Measure small AC currents in the presence of large DC current

Figure 1: A CWT Mini coil, insulation voltage 2kV peak, thickness 3.5mm, coil length 100mm, threaded through the legs of a TO-247 semi-conductor package.

New Challenges

Recent developments in power converters and devices present new challenges to the use of Rogowski probes. Power converters such as UPS circuits, SMPS and Variable-Speed Drive (VSD) inverters are becoming smaller for a given power rating. This increase in power density increases the field strength inside the converter, creating a more hostile environment for a current probe. In addition, silicon carbide (SiC) semiconductors, which combine faster switching times and higher blocking voltages than previous devices, are becoming common. Thus Rogowski probes must have a higher bandwidth and better common mode immunity (rejection of external fields) to accurately measure current in these devices.

The latest generation of Rogowski current probes are able to overcome the problem of interference from local dV/dt transients, and yet maintain a small size and 30MHz bandwidth. To understand how this is achieved, it is necessary first to examine the effect of high electrostatic fields on a conventional Rogowski current probe.

Typically, a Rogowski coil comprises a solenoidal copper winding on a flexible plastic core. The output voltage from the coil is proportional to the turns density of the winding, N, and its cross-section area, A. The end of the solenoidal winding may be returned along the axial centre to form a cancelling turn, to prevent unwanted interference from conductors outside the coil loop.

Unlike other current probes using magnetic formers such as Hall-effect sensors or current transformers the Rogowski coil does not concentrate the flux produced by the current-carrying conductor around which the coil is looped. Thus the signal produced by the Rogowski coil is small and more susceptible to interference from external fields. In particular large local voltage transients (dV/dt) can cause interference on the Rogowski measurement through capacitive coupling onto the coil winding.

The schematic in figure 2 shows the essential elements of a Rogowski probe and the mechanism by which local voltage transients cause an error at the output of the probe. The Rogowski coil can be approximated to an inductance L (determined by the winding parameters A and N), a capacitance C (determined by the plastic material of the former and the distance between the axial return conductor and the winding), and the copper winding resistance, R. A disturbance voltage

dVx/dt causes a displacement current Ix which flows onto the coil winding via local stray capacitance C_X. The current Ix and the coil impedance produce an interference voltage at the output of the coil. This voltage is ultimately integrated to produce Verror at the output of the probe.

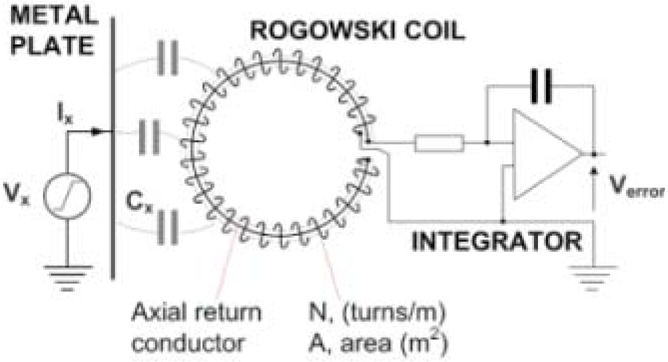

Figure 2: Schematic showing the Rogowski coil with a winding N (turns/m) and cross-section A (m^2). The output is connected to a high gain integrator

Screening the Probe

Fitting a screen (or shield) over the top of the Rogowski coil winding appears to offer a solution by providing a low-impedance path to ground allowing the displacement current to avoid the high-gain electronic integrator, resulting in lower Verror. However this simple solution has a problem, since the coil impedance has an appreciable effect on the high-frequency performance fHF(-3dB) where,

$$f_{HF(-3dB)} \propto {}^{1}/_{\sqrt{LC}}$$

Fitting a screen will significantly increase the overall capacitance as there is additional capacitance between the coil winding and the screen. This will reduce the high-frequency bandwidth fHF(-3dB), compromising the probe's main function, which is to measure fast current waveforms.

Power Electronic Measurements Ltd (PEM UK) has developed an alternative technique for producing a small, screened, wide-band Rogowski probe, which significantly improves its rejection of common-mode interference. Instead of using an axial return conductor, the coil is inverted allowing the return conductor to be implemented as a thin copper screen on the outside of the coil winding. This presents a low-impedance path to ground for Ix significantly attenuating Verror. High-frequency performance is also improved, since any capacitances other than those between coil and screen are eliminated. Fitting another screen tightly over the top of the return conductor only marginally increases coil thickness and has no effect on bandwidth, yet significantly increases electrostatic field rejection.

High-frequency performance is also improved by reducing the winding density and hence the coil inductance, L. Because the inductance of the coil and the coil output voltage are interdependent, the gain of the integrator must be increased to resolve small currents. This has in the past led to an unacceptable SNR at low frequency. However through improvements in integrator design and op-amp performance, using a

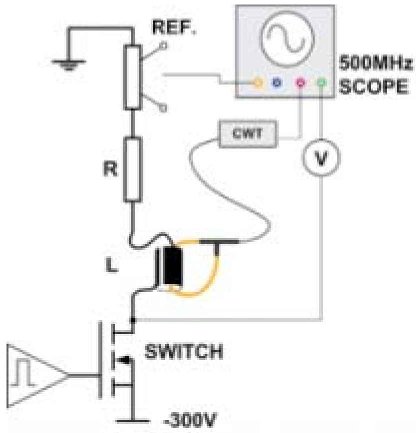

Figure 3a: Switching circuit to test the common-mode rejection of the CWT Mini

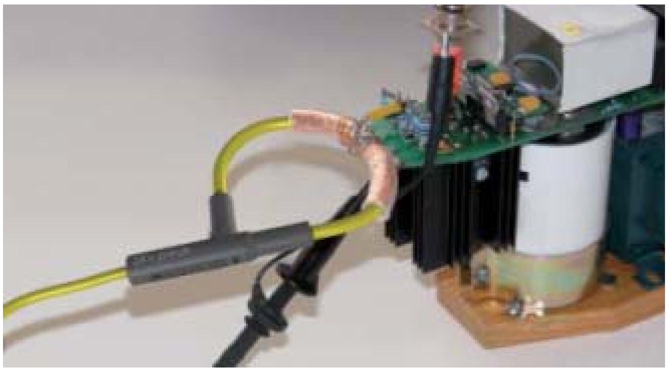

Figure 3b:Actual test circuit showing the coil in the tight fitting copper tube

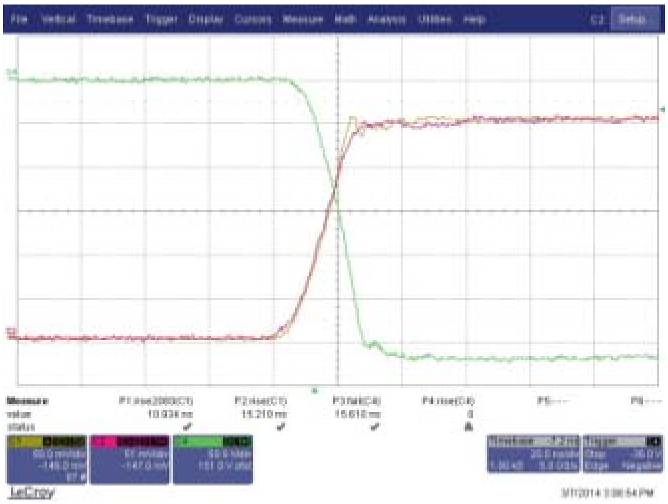

Figure 4: Comparison of reference and Rogowski probe measurements. Time base 20ns/div C2 - CWTMini/03 (Note the waveforms include 16.8ns de-skewing to eliminate the inherent yet predictable delay of the Rogowski current transducer. This delay is the sum of delay in the Rogowski coil, the connecting cable and the integrator)

Sensitivity (V/A) [Peak current (A)]	Noise (mVp-p)	Low frequency (-3dB) (Hz)	High frequency (-3dB) (MHz)
0.1 [60]	15.0	100	30
0.01 [600]	15.0	10	30

Table 1: Example performance of a screened small Rogowski probe

combination of active and passive integration, it is possible to achieve example performance as summarised in table 1.

The ability of the coil to reject local dV/dt transients has been demonstrated using the test circuit shown in figure 3a, which replicates a single inverter leg. The circuit comprises four parallel superjunction MOSFETs with less than 15ns turn on time. The reference measurement is a DC-to-2GHz co-axial shunt. A tight-fitting copper tube, covering at least one third of the coil circumference, is added to increase the capacitive coupling between the coil and the dV/dt transient, so as to make this a ‘worst case’ measurement.

Figure 4 compares the response of the reference shunt and a CWTMini/03/B/1/100M/2 shielded Rogowski probe to a 2.5A, 1.2μs test pulse with a rise-time of 12ns. The waveforms are almost identical, showing that even with a 20V/ns transient close coupled to the Rogowski coil there is no visible interference on the 2.5A current waveform.

The result of the experiment demonstrates the probe’s ability to measure rapidly changing current with high accuracy, which is particularly useful when measuring device switching loss.

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Record performance with IGCTs, cool!

The Integrated Gate-Controlled Thyristor (IGCT) is the semiconductor of choice for demanding high-power applications such as pumped hydro, medium voltage drives, marine drives, co-generation, wind power converters, interties and STATCOMs. IGCTs deliver highest power density and reliability and can easily be optimized to feature a low on-state voltage or low switching losses just as required by the particular application.

By Björn Backlund and Christoph Holtmann,
ABB Switzerland Ltd., Semiconductors

As more and more intermittent wind and solar power generation capacity is added to the electricity grid, demanding high-power applications like energy storage are gaining in importance. Pumped storage power plants, such as those found in the Swiss Alps, are ideal partners for the expanding use of solar and wind. Storage plants behave like huge batteries, ensuring the necessary balance between production and consumption. Therefore, when power is plentiful, water is pumped from a lower altitude lake to replenish a higher altitude lake, where it can remain stored for a long time. When power is needed, water is released, instantly turning turbines as the water falls to rapidly generate electricity. Pumped storage is playing an increased role in grid regulation and assuring the continuity of supply.

ABB has installed the world's most powerful frequency converter for variable speed pumped hydropower application at the Grimsel 2 plant in Switzerland. This plant connects the upper reservoir of the glacier water fed Lake Oberaar (2,303 meters above sea level) to the more than 400 m lower Lake Grimsel (figure 1).

Figure 1: Hydro power site Grimsel in the Swiss Alps.

Until now, the pump operation could only be controlled by regulating the number of pumps in operation. The pumps were running either at full load or not at all.

Today, however, by upgrading one of the four synchronous generator/motor sets from fixed speed to variable speed by means of more than 1,000 IGCTs in ABB's PCS 8000 power converters, the synchronous machine can now operate between 600 and 765 rpm in pump mode. It can thus be controlled more quickly and flexibly according to the surplus energy and uses water more efficiently as a resource for electricity production.

The Grimsel 2 pumped storage power plant is equipped with four synchronous units. Each unit has a separate Francis turbine and pump on the same shaft to either generate electricity or pump water. Including its dedicated transformers, the 100 megavolt amperes (MVA) converter (figure 2) is around 10 meters long and 7 meters wide and is housed on two floors behind an imposing machine hall.

Despite progress with other storage technologies, pumped storage remains the only mature and affordable means of energy storage suitable for grid regulating, and thus has an important role to play in the generation landscape of tomorrow.

Figure 2: More than 1,000 IGCTs enable the pumped storage power plant Grimsel 2 to operate more flexible and efficient.

The record converter for Grimsel is only one example of many where the IGCT is used. Other application fields are medium voltage drives (MVD), marine drives, static compensators, wind turbine converters, co-generation, interties and DC-breakers. With its low on-state voltage drop the IGCT is also an interesting option for high power multi-level converters for various purposes.

Since these applications have quite different needs the devices need to be tuned to have the right trade-off between conduction and turn-off losses for the given use. The basic phenomenon making the tuning possible is that the operation of bipolar power devices, like IGCTs, is based on the injection of charged carriers (electrons and holes) into the base region, where they recombine and annihilate after a certain time called carrier lifetime. This lifetime can be reduced by electron or ion (proton or helium) irradiation. When the processed IGCT wafer leaves the wafer manufacturing it has a long lifetime it in its original state has a low on-state voltage but high turn-off losses. By selecting the irradiation dose (number of impinging electrons or ions per device area and time), the concentration of generated point defects in the silicon bulk can be controlled and the required lifetime is achieved. Higher irradiation doses achieve lower turn-off losses and high ruggedness during fast switching at the price of increased on-state voltage.

Electron irradiation is used to control the carrier lifetime in the whole device volume, because the small electrons can easily penetrate the whole device. Since the protons, about 1,000 times larger, and helium ions easily stop in the bulk silicon, they are used for local lifetime control. The stopping range (irradiation depth) is then adjusted by a carefully designed ion energy usage, typically between 1 and 10 MeV. For the most demanding devices, a combination of ion and electron irradiation is used. ABB was among the first companies to introduce ion irradiation in the production of high power semiconductors.

Figure 3: Asymmetric 4.5 kV IGCT, the device of choice for demanding high-power applications.

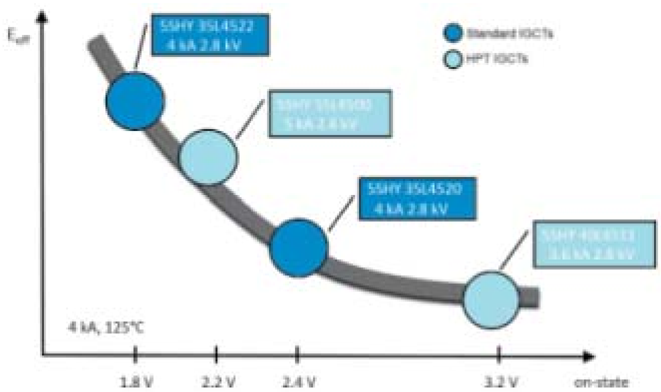

Figure 4: Trade-off curve for ABBs standard 4.5 kV asymmetric IGCTs.

For the commonly used 4.5 kV asymmetric IGCT (figure 3) ABB offers four predefined standard devices. Two with the standard technology and two with the HPT technology featuring an increased turn-off capability. The difference between the two technologies is the improved switching capability for the HPT technology. Each of these devices has its unique irradiation scheme giving four devices with different electrical characteristics making it easy to find the device needed for a specific application. Figure 4 shows the four standard IGCTs in their respective position on the conduction (on-state) versus turn-off (Eoff) losses trade-off curve. For applications with a high switching frequency the 5SHY 40L4511 would normally be the device of choice whereas the 5SHY 35L4522 is tailored for applications with a low switching frequency.

The devices 5SHY 55L4500 and 35L4520 are aiming for the golden mean. In special cases where it would be advantageous to have a device located somewhere in-between the predefined standard devices a customer specific solution can easily be realized to optimize the trade-off for its given application. Adjusting the on-state voltage and turn-off losses impact other parameters, such as surge current, but there are no fundamental differences caused by the irradiation. Due to this it is possible to use the same gate unit for all four standard devices in figure 4 and possible customer specific devices in-between without the need for device dependent adjustments.

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Performance Evaluation of Enhancement-Mode GaN Transistors in Class-D and Class-E Wireless Power Transfer Systems

The popularity of wireless energy transfer has increased over the last few years and in particular for applications targeting portable device charging. In this article, the focus will be on loosely coupled coils, highly-resonant wireless solutions suitable for the A4WP [1] standard operating at either 6.78 MHz or 13.56 MHz unlicensed Industrial, Scientific and Medical (ISM) [2] bands.

By Alex Lidow Ph.D. and Michael De Rooij, Ph.D.; Efficient Power Conversion

Many of the wireless energy transfer solutions have targeted portable device charging that require features such as low profile, high efficiency, robustness to changing operating conditions and, in some cases, light weight. These requirements translate into designs that need to be efficient and able to operate without a bulky heatsink. Furthermore the design must be able to operate over a wide range of coupling and load variations. There are a few amplifier topologies that can be considered such as the voltage mode class-D, current mode class-D and class-E. The class-E has become the choice for many wireless energy solutions as it can operate with very high conversion efficiency.

eGaN® FETs have been previously demonstrated in a wireless energy transfer application using a voltage mode class-D topology [3, 4] and showed superior performance when compared to a system utilizing equivalent MOSFETs by as much as four percentage points higher peak conversion efficiency. At output power levels above 12W, the design required a heatsink to provide additional cooling to the switching devices and gate driver. In addition, the traditional voltage mode class-D topology requires that the resonant coils be operated above resonance to appear inductive to the amplifier. This is needed to allow the amplifier to operate in the ZVS mode and overcome the C_{OSS} of the devices that would otherwise lead to high losses in the devices as opposed to being operated in the ZCS mode. Operating the coils above resonance comes at the cost of coil transfer efficiency and high losses associated with the matching inductor due to the presence of reactive energy.

eGaN FETs have also been demonstrated in a class-E topology by Chen et al [5] with up to 25.6 W power delivered to the load while operating at 13.56 MHz. The wireless energy transfer system was operated with very high load resistance (350 Ω) which ensured a high Q resonance, and the system efficiency was measured at 73.4% including gate power consumption. The shunt capacitor in that example was completely embedded in the EPC1010 device used in the experimental setup, thereby keeping the component count low.

Coil and Load simplification

To facilitate the discussion and design evaluation, the coil set, device side matching, rectifier and load will be reduced to a single reactive element (Z_{load}) as shown in figure 1.

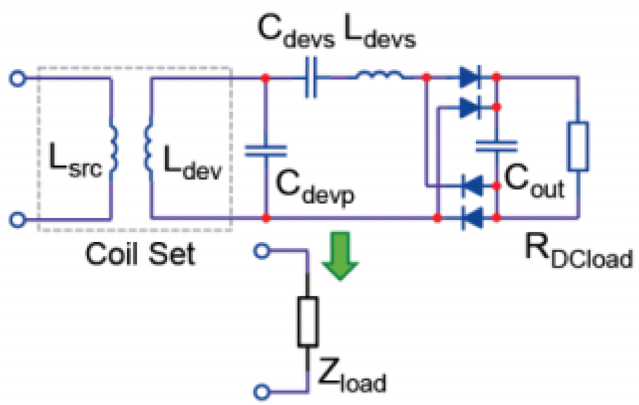

Figure 1: Single element simplification of the entire coil system and DC load.

All subsequent design and discussion will make use of this single element, which allows for equal comparison between various topologies under equivalent load conditions.

Class-E Wireless Energy Transfer

The ideal single ended class-E circuit for a wireless energy transfer system is shown in figure 2. In this setup C_s is used to resonate out the reactive component of Z_{load} to yield only the real portion of the coil circuit to the amplifier.

The design and operation of the class-E amplifier is well documented in [6, 7, and 8]. The matching network is designed for a specific load impedance to establish the necessary conditions for zero voltage and current switching.

Adopting the class-E topology for wireless energy transfer requires detailed knowledge of the coils and how the load affects the impedance seen by the amplifier. The design is further complicated by variations in load power demand and coupling between the source and device coils. This can introduce variations in the impedance seen by the amplifier that are not typically present in communication based designs. These variations and impact on the performance of the amplifier need to be considered in the design of the class-E, which is particularly prone to high device losses if the variations fall outside specific parameters. Changes in DC load resistance can shift the tuned reactance of Z_{load} to be either capacitive or inductive depending on what DC load resistance value was used to tune the coil set.

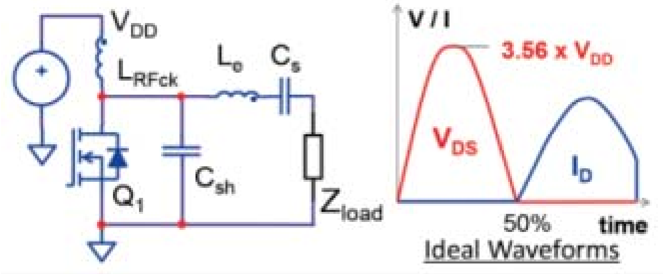

Figure 2: Class-E amplifier with ideal waveforms

Design of the class-E amplifier

A wireless class-E amplifier was designed based on a Q_L factor of infinity [9]. The coil spacing and load was fixed to eliminate source impedance variation. The design was made to deliver 30 W into the following coil: Coil impedance Z_{load} for a 20.2 Ω DC load = 14.7 Ω and in series with a 3.1 µH. The coil was tuned to 6.78 MHz using a series capacitor (C_s) of 178 pF which results in only the real 14.7 Ω being presented to the amplifier.

To deliver 30 W into 14.7 Ω, the class-E amplifier needs to operate from a supply of 31 V, with a peak voltage across the shunt capacitor (C_{sh}) and the drain-to-source (V_{DS}) of the device of 110 V. A shunt capacitance of 293 pF was needed for this design, and any device selected must have a charge equivalent C_{OSSQ} that is equal to, or lower in value. The charge equivalent capacitance of C_{OSSQ} must be determined from two parameters; (1) the C_{OSS} as function of drain-to-source voltage of the device selected and (2) the RMS voltage to which the device will be exposed. For this design the RMS voltage was 78 V. Selecting the EPC2012 [10], with V_{DS} rating of 200 V, the charge equivalent C_{OSS} at 78 V was 126 pF, thus an additional capacitance was required to complete the design of 167 pF which will be C_{sh}. Finally, the extra inductance L_e calculates to 390 nH.

The choice of RF choke is based on the required ripple specification and minimal impedance impact to the circuit. In this design example a value of 150 µH was chosen and a smaller value can also be used without degradation in performance.

To summarize the Class-E design:
C_s = 178 pF
L_e = 390 nH
C_{sh} = 167 pF
L_{RFck} = 150 µH
Q1 = EPC2012

An analysis of the design predicts device losses to be around 250mW under full load conditions. This is low enough to operate without the need for a heatsink.

Experimental performance of the Class-E System

An experimental class-E amplifier was built that connects to the WiTricity coil set [11] and rectifier with load board set to R_{DCload} = 20.2 Ω. The amplifier board is shown in figure 3 (without the coil set). An adapter board was designed to interface the extra inductance (L_e) with the coil set. This allowed the same coil set to be used with other amplifiers without the need to retune and is also shown in figure 3.

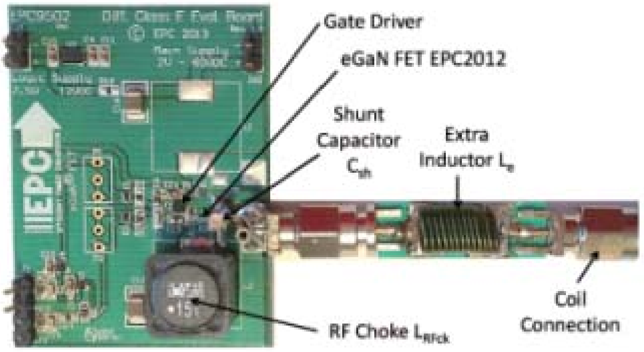

Figure 3: Class-E eGaN FET experimental setup

To properly evaluate the performance of the class-E amplifier, given that the C_{OSS} of the device was used in the matching circuit, the power required for the gate must also be included in the performance evaluation. This further allows for a fair comparison against a MOSFET version of the amplifier.

The eGaN FET experimental board efficiency was measured as function of output power by varying the input voltage to the amplifier and is shown in figure 4. The board was operated at 6.78 MHz during this test.

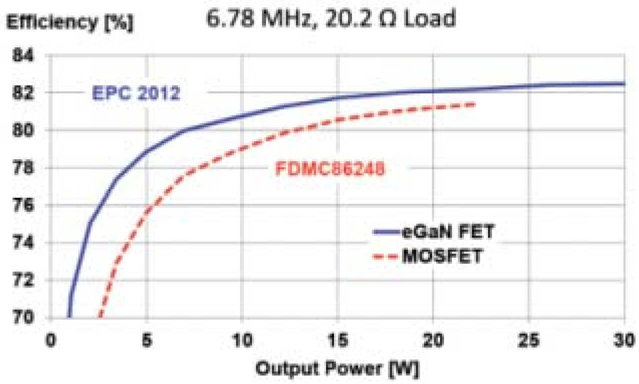

Figure 4: Class-E efficiency results

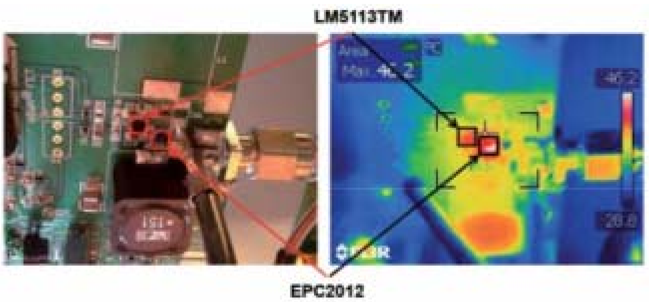

Figure 5: Class-E Thermal performance with R_{DCload} = 20.2 Ω, V_{in} = 28 V, P_{out} = 30 W.

Figure 5 shows the thermal performance of the eGaN FETs operating in the experimental circuit delivering 30 W into a 20.2 Ω load.

Both the gate driver and eGaN FET temperature remain well below 50°C when operating in an ambient temperature of 25°C. No heatsink or forced air cooling was used for this test.

There have been many questions about how to compare the performance between a class-E amplifier utilizing an eGaN FET or MOSFET, given that C_{OSS} is included in the matching network. The first step to answer that question is to look at the soft switching figure of merit (FoM_{SS}) [12]. Figure 6 shows the soft switching figure of merit comparison between an EPC2012 [10] eGaN FET and FDMC86248 [13] MOSFET. The comparison is made for two gate voltage operating conditions for the MOSFET, 6 V and 10 V. This allows a comparison in performance for a circuit that uses the same gate driver for both the eGaN FET and MOSFET. From figure 6 is can be seen that the gate charge is significantly lower for the eGaN FET, which is an important consideration for low power converters as gate power is a significant portion of the total power processed by the amplifier.

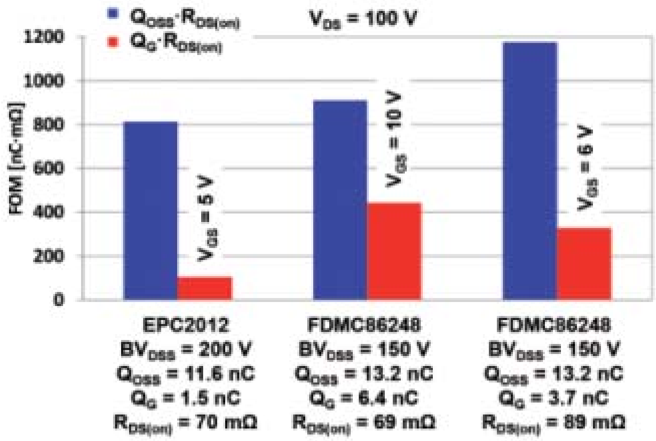

Figure 6: Soft Switching Figure of Merit comparison for the class-E Amplifier

Comparing the output charge, the difference is smaller. However, the eGaN FET is still lower for the same $R_{DS(on)}$ and has a higher voltage rating than the MOSFET. This allows the class-E amplifier to be operated at a higher voltage than the MOSFET, with resulting higher output power. Operating the MOSFET based amplifier with a gate voltage of 6 V yields lower performance than at 10 V gate despite the halving of the gate charge figure of merit. Figure 4 shows the performance of the MOSFET based class-E amplifier operating with a 10 V gate.

Class-E sensitivity to load variation

Loosely coupled wireless energy transfer systems operate with large load variations as load power demand fluctuates and coupling varies between the source and device units. These variations introduce changes in the coil impedance (Z_{load}) as seen by the amplifier, which when tuned at a specific load condition can shift from inductive to capacitive in addition to introducing large changes in the resistance component of Z_{load}. These changes must be understood and accounted for when designing wireless power systems. Most important is the impact these changes have on the power dissipation of the devices.

The full power circuit of class-E system was simulated in LTspice and the DC load resistance (R_{DCload}) was varied while maintaining a fixed supply voltage to the amplifier. The simulation results were first compared with the experimental results and found to correlate well.

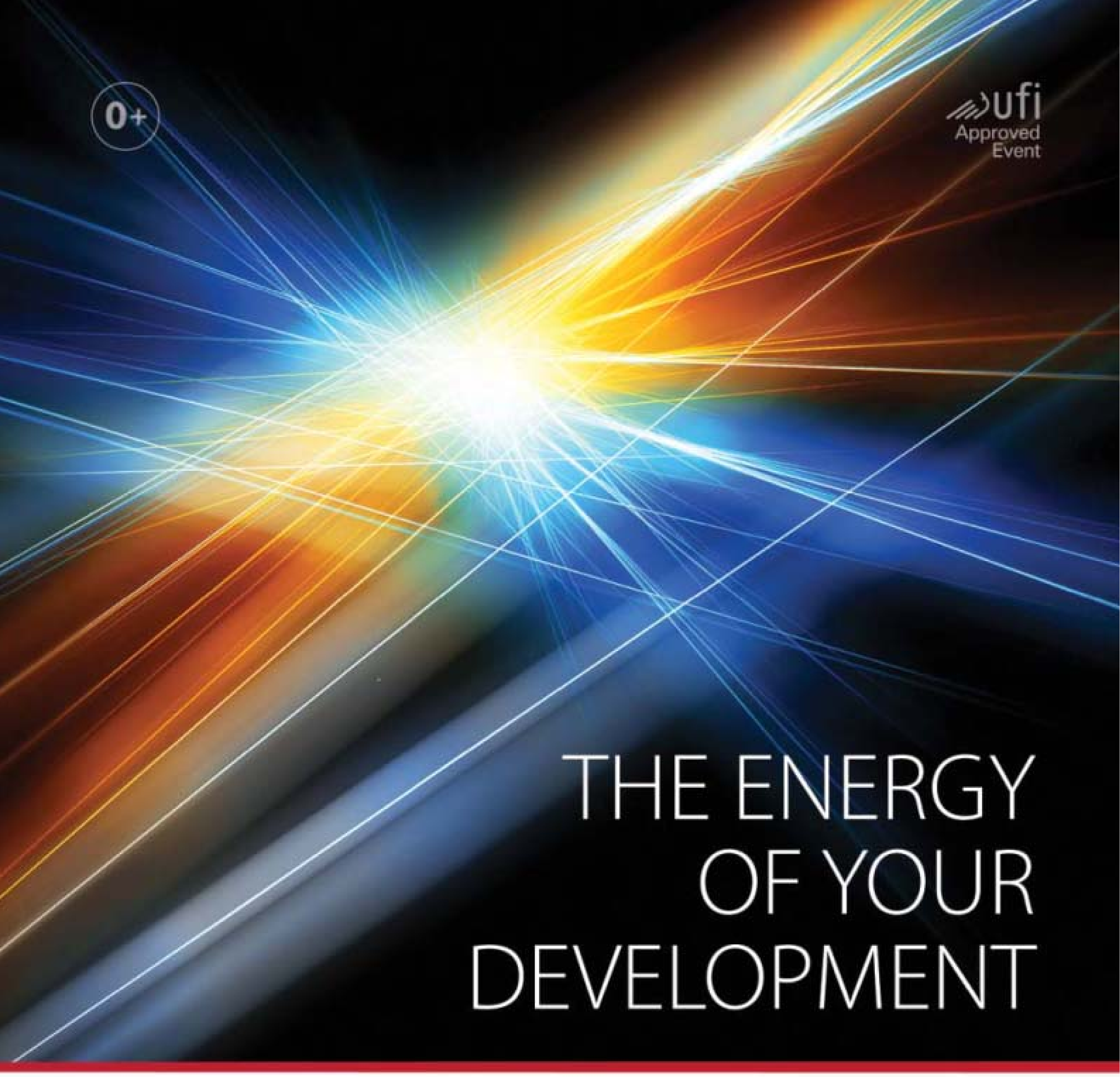
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Figure 7 shows the simulation results for the losses in the eGaN FET as function of the DC load resistance. It can be seen that below the design point (20.2 Ω for this example), the losses in the FET increase rapidly with decreasing load resistance. This condition equates to an increase in load current demand by the device. Also shown in figure 7 is the corresponding output power as function of DC load resistance.

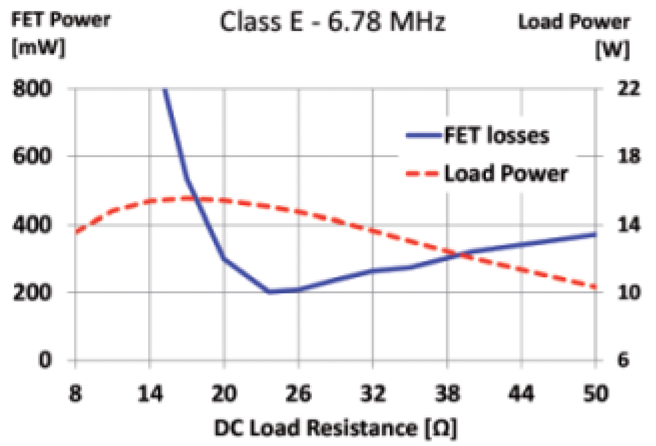

Figure 7: Simulated FET power losses and load power as function of DC load resistance.

ZVS Voltage Mode Class-D Wireless Energy Transfer

In this section we introduce a zero voltage switching (ZVS) variation of the traditional voltage mode class-D. The ideal voltage mode class-D amplifier comprises a half bridge topology that drives the load Z_{load}. Since the load must be tuned by C_s, this capacitor also serves to block the average DC voltage present on the output of the amplifier. The voltage mode class-D incurs high losses due to the output capacitances of the devices and therefore must be operated with the load tuned to be slightly inductive. The output inductance then serves to self-commutate the output voltage, providing the conditions necessary for zero voltage switching. However, tuning the load to appear inductive causes the coil set resonant frequency to shift with a drop in coil transmission efficiency due to the increase in circulating energy between the coil and the amplifier. A ZVS variation to the traditional voltage mode class-D amplifier is shown in figure 8. In this configuration a ZVS tank circuit is added to the output of the amplifier which operates as a no-load buck converter.

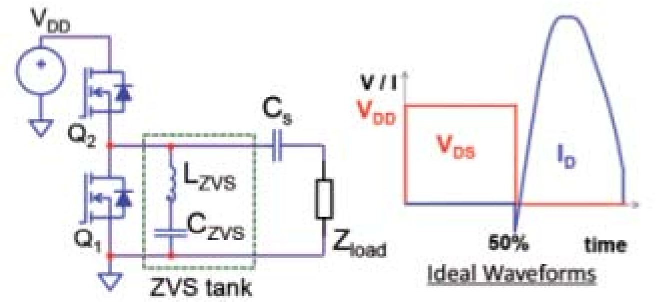

Figure 8: ZVS Class-D amplifier with ideal waveforms

The ZVS tank circuit is not operated at resonance, and only provides the necessary negative device current for self-commutation of the output voltage at turn off. The capacitance C_{ZVS} is chosen to have a very small ripple voltage component and is typically around 1 µF for many wireless energy transfer applications. The value of the inductance L_{ZVS} depends on the operating voltage V_{DD}, C_{OSS} of the devices, the transition voltage slew rate, and the immunity required for shifts in the tuned load ($C_s + Z_{load}$) impedance and can be calculated using the following equation:

$$L_{ZVS} = \frac{\Delta t_{vt}}{8 \cdot f_{sw} \cdot C_{OSSQ}} \qquad (1)$$

Where:

Δt_{vt} = voltage transition time [s]
f_{sw} = Operating frequency [Hz]
C_{OSSQ} = Charge equivalent device output capacitance [F]

Note that the supply voltage V_{DD} is not present in the equation as it is already accounted for by the voltage transition time, as the voltage doubles so does the transition time. To add immunity margin for shifts in load impedance, the value of L_{ZVS} can be decreased to increase the current at turn off of the devices. Typical voltage transition times range from 2 ns through 15 ns, and are application dependent. The transition time should also be kept as low as possible to ensure sufficient voltage for the load.

Design of the ZVS voltage mode class-D amplifier

A ZVS voltage mode class-D wireless amplifier was designed for the same coil set as for the class-E example. The design was made to deliver 30 W into the following coil: Coil impedance Z_{load} for a 23.6 Ω DC load = 12.6 Ω, and is in series with a 3.1 µH. The coil is tuned to 6.78 MHz using a series capacitor (C_s) of 176 pF which results in only the real 12.6 Ω being presented to the amplifier.

To deliver 30 W into 12.6 Ω, the ZVS class-D amplifier needs to operate from a supply of 40 V. The switching devices need to have a drain-to-source (V_{DS}) voltage rating, with margin, of at least 50 V. The charge equivalent capacitance of C_{OSSQ} must be determined from two parameters; (1) the C_{OSS} as function of drain-to-source voltage of the device selected, and (2) the supply voltage to which the device will be exposed. For this demonstration design, the EPC2007 [15], with V_{DS} rating of 100 V was selected, with charge equivalent C_{OSSQ} at 40 V of 223 pF. To correctly calculate the inductance, the output device capacitances of both devices need to be added together. For a transition time around 7.3 ns, and using equation 1, an inductance of 300 nH for the ZVS tank circuit was calculated.

To summarize the ZVS Class-D design:

C_s = 176 pF
L_{ZVS} = 300 nH
C_{ZVS} = 1 µF
Q1, Q2 = EPC2007

An analysis of the design predicts device loss to be around 170 mW per device under full load conditions, which is low enough to operate without the need for a heat-sink.

Experimental performance of the ZVS Class-D System

An experimental ZVS class-D amplifier was built that connects to the same coil, rectifier with load board as used in the class-E example and was set to R_{DCload} = 23.6 Ω. The amplifier board is shown in figure 9 (without the coil set).

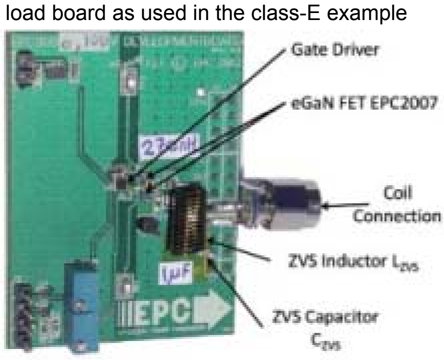

Figure 9: ZVS Class-D experimental setup

The eGaN FET experimental board efficiency was measured as a function of output power by varying the input voltage to the amplifier, and is shown in figure 10.

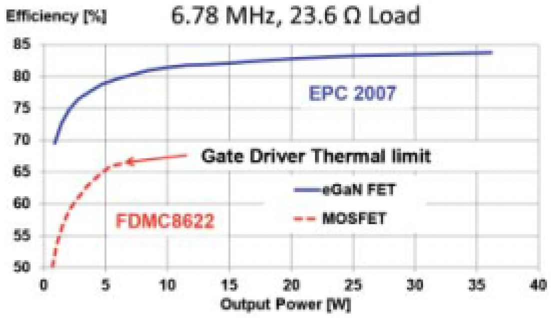

Figure 10: ZVS Class-D results

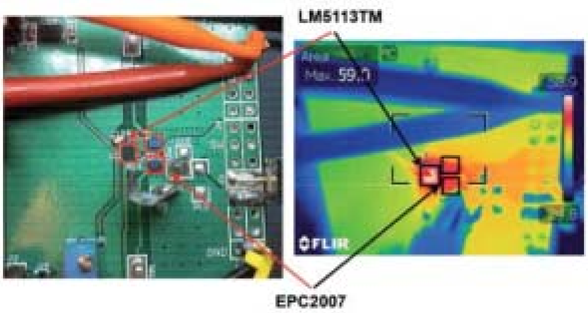

Figure 11: ZVS Class-D thermal performance with R_{DCload} = 35 Ω, V_{in} = 42 V, P_{out} = 35 W.

Figure 11 shows the thermal performance of the eGaN FETs operating in the experimental circuit delivering 35 W into a 35 Ω load.

Both the gate driver and FET temperature are below 60°C when operating in an ambient temperature of 25°C. No heatsink or forced air cooling was used for this test. It is notable that the gate driver IC is the hottest component, which is in part due to the reverse recovery of the internal bootstrap circuit diode and the parasitic capacitance between the switch-node and ground within the gate driver [14]. These factors introduce additional losses and can be mitigated by design or improvements in future gate drivers that are designed to operate at higher frequencies.

Again we compare the performance between an eGaN FET and MOSFET, this time in the ZVS class-D amplifier. In this example it was important to closely match the Q_{OSS} rather than the $R_{DS(on)}$ as it affects the voltage transition time and hence the RMS voltage applied to the coil set. Again we turn to the soft switching figure of merit, as shown in Figure 12, for a comparison between an EPC2007 [15] eGaN FET and the FDMC8622 [16] MOSFET. The comparison is made for two MOSFET gate voltages; 6 V and 10 V. This allows a comparison in performance for a circuit that uses the same gate driver for both the eGaN FET and MOSFET. From figure 12 is can be seen that the gate charge is again significantly lower for the eGaN FET than it is for the MOSFET.

Comparing the output charge, the difference is smaller. Operating the MOSFET based amplifier with a gate voltage of 6 V yields lower performance than at 10 volts on the gate despite nearly halving of the gate charge on-resistance product. Figure 10 shows the performance of the MOSFET based ZVS class-D amplifier operating with a 5 V gate. The experimental setup was unable to exceed 6.4 W output power as the gate driver had exceeded the thermal limit of 85°C despite force air cooling. The measured gate power for the eGaN FET amplifier was 26 mW, versus 232 mW for the MOSFET, an almost 10 times difference. Using a gate driver with higher power capability will no doubt enable the MOSFET based amplifier to increase its power output, but it will be unable to improve the total system efficiency. Furthermore, operation at 13.56 MHz for a MOSFET based converter may not even be possible due to the more than doubling in gate driver losses, rendering the system efficiency to drop well below 50%.

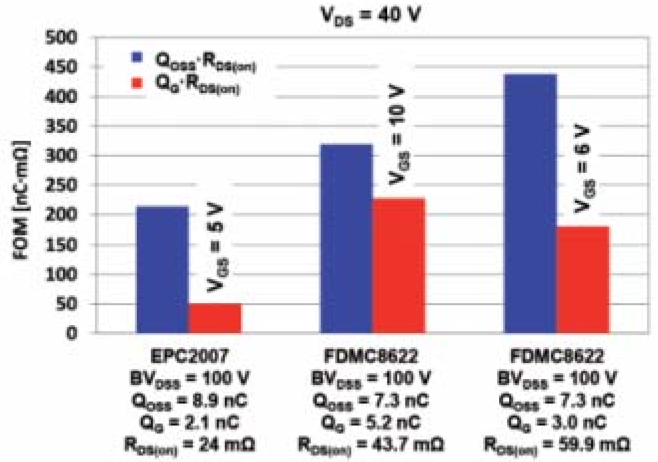

Figure 12: Soft Switching Figure of Merit comparison for the ZVS class-D amplifier

ZVS Class-D sensitivity to load variation

As for the class-E topology we again look at the sensitivity of load variation on the performance of the ZVS class-D amplifier. The full power circuit of ZVS class-D system was simulated in LTspice and the DC load resistance (R_{DCload}) was varied while maintaining a fixed supply voltage to the amplifier. The simulation results were first compared with the experimental results and found to correlate well. Figure 13 shows the simulation results for the losses in the eGaN FET as function of the DC load resistance using the same scale as in figure 7. In this case it can be seen that output power is a strong function of DC load resistance and output power increases as DC load resistance increases, also shown in figure 13. This is due to the increase in the Q-factor of the coil set with increase load resistance.

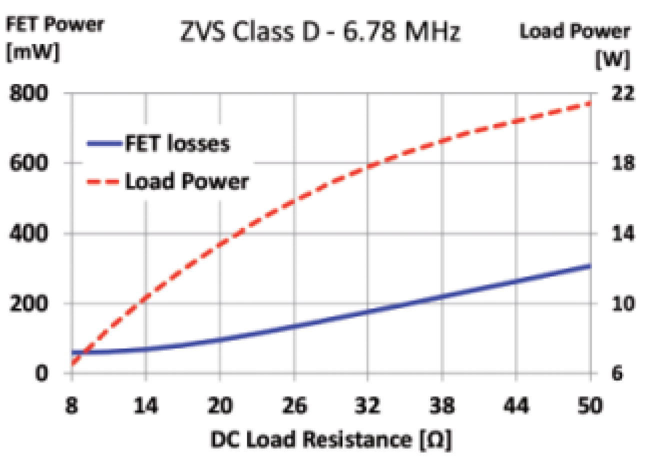

Figure 13: Simulated FET power losses and load power as function of DC load resistance.

Conclusions

The class-E topology has shown promise as a simple and efficient wireless energy transfer converter that is further enhanced when using eGaN FETs. This is despite the inclusion of C_{OSS} into the matching network, and is primarily due to two factors; the significantly lower gate charge of the eGaN FET and the lower $R_{DS(on)}$ for equivalent Q_{OSS}. In the example presented the voltage rating of the eGaN FET was also 33% higher than the MOSFET, further extending the available output power range.

The ZVS class-D showed higher system efficiency than the class-E when operated under the same load conditions. This is mainly due to ZVS switching and the elimination of matching inductors in the main current path. The use of eGaN FETs further enables this topology due to the low gate charge requirement, and the difficulty of driving the upper device using a simple bootstrap supply when using MOSFETs. At 13.56 MHz it may not be possible to drive the upper device without the use of an expensive fully-isolated power supply. The ZVS class-D topology has further been demonstrated to be less sensitive to load variations that causes the coil set impedance to shift, and can even tolerate a small amount of capacitive loading given sufficient current is established in the ZVS tank circuit.

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Opening Doors

An explanation of how to complete a low-cost design and analysis using a single-phase AC induction motors and an 8bit microcontroller in a garage door application

By Justin Bauer, Microchip

Small AC induction motors, say for opening garage doors, can have speed control and soft start added with little cost using a three-phase inverter circuit. These permanent split capacitor (PSC) motors are among the simplest and widest used for this type of application. They have low starting torque and current, but can be inefficient due to the non-polarised run capacitor, which often fails before the rest of the motor.

These single-phase motors are often referred to as two-phase motors because they cannot run without sufficient phase shift between the two windings. The capacitor is placed between the input signal and winding to produce an approximate 90˚ phase shift.

The switch is often replaced with a relay that can control the direction by swapping which phase leads or lags the other. The value of the capacitor is typically specified by the motor manufacturer and is sometimes in the range of 5 to 50µF for motors that are less than 0.75kW, of the type being looked at here. The capacitor should be carefully chosen to correct the power factor for maximum power efficiency. Figure 1 shows the topology of a traditional AC induction motor.

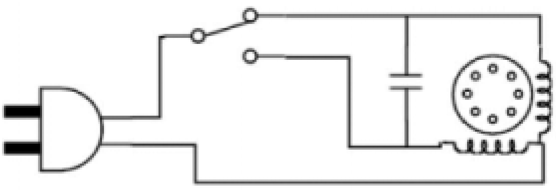

Figure 1: Topology of a traditional AC induction motor; the capacitor provides the necessary phase shift to produce a rotating magnetic field

The voltage rating is typically high at around 220 to 450V, depending on the input voltage. The capacitor must not be polarised, since it is across an alternating voltage. If this capacitor fails, the motor will cease to turn. The importance of selecting the correct capacitor is therefore critical.

A practical capacitor has resistance and radiates heat as it consumes the RMS AC ripple current within its equivalent series resistance. The permanently installed capacitor trades off starting torque capability at standstill with ripple torque reduction at running speed. Because of the high VA rating of the capacitor, it is often selected to meet the minimum starting performance requirements, resulting in poor running efficiency.

For motors that do not have identical windings, it is necessary to feed the two phases with different voltages. This asymmetry is due to the presence of the capacitor, which forms a resonant circuit with the motor's inductance. Consequently, this raises the voltage across one of the windings and causes uneven current flow.

However, a three-phase inverter can be used to replace the permanent capacitor, as shown in Figure 2. This allows the speed of the motor to be adjusted with the appropriate amount of voltage applied to each winding so that weaker windings are not overdriven.

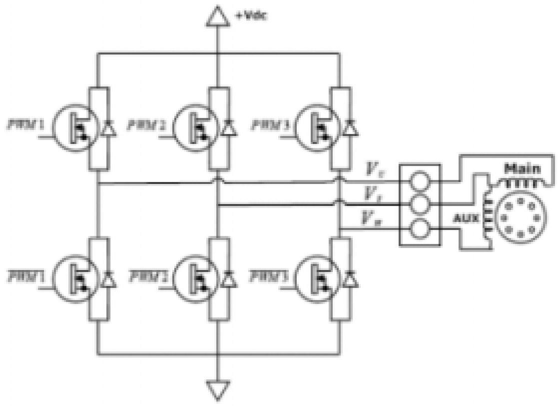

Figure 2: Single-phase inverter with three half bridges; six PWM signals are used to drive the connected squirrel-cage PSC motor

The motor will still spin without the capacitor if the coils are driven out of phase from one another. This can be achieved by creating three phases in software. These three-phase voltages can then be referenced from one another to create two resultant waveforms across the two motor windings. One of the phases is taken as the reference, or neutral, to create the two waveforms. The three phases can be created in software using PWM techniques.

Comparison

Three tests can be run to compare the PSC run method with the inverter method with no run capacitor. These are: torque to characterise the effects of variable frequency drive on the motor; acceleration and speed to identify which method turns the motor shaft the fastest and how quickly the load will accelerate; and efficiency to compare the real component of the output power to the input power and to measure the power factor and other inefficiencies.

These three tests cover the largest design considerations in motor control. None of the tests require a special setup from the other tests. Each analysis in the three separate tests can use the same subset of data. The test set up is shown in Figure 3.

This test used a 0.19kW single-phase motor with a balanced wiring configuration. Both windings had identical resistance and inductance. A Hall-effect sensor was used to measure the shaft speed. The input was a single-phase, two-wire 220V at 60Hz. The output was fed into the two terminals on the inverter.

The PC interface ran Magtrol's M-Test 7 software. The programmable controller applied the test set-up from this software to the dynamometer and read the applied torque. The power analyser performed and logged all the other readings.

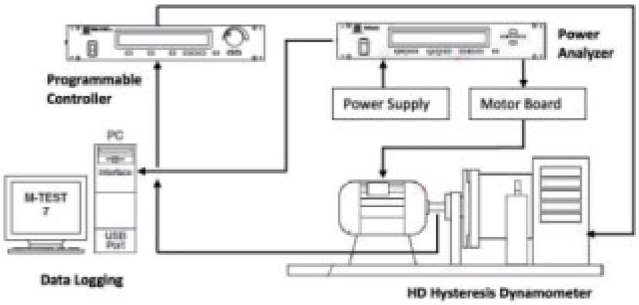

Figure 3: Test set-up on the dynamometer

Starting with the torque test, it was apparent that the motor had the highest starting torque of around 0.75Nm between 50 and 60Hz in line with the motor design. Frequencies above and below 60Hz had lower torque profiles. However, the low frequency readings did not produce a constant torque curve. Frequencies lower than 60Hz required a fine tuning of the voltage-frequency ratio because of losses in the motor and inaccuracies in the motor drive. Frequencies below 60Hz were kept at maximum voltage.

A low frequency causes a decrease in an inductor's impedance. The high voltage applied to this lowered impedance raises the current in the stator, which produces higher torque. The fine tuning is needed to make the torque curve linear.

The shapes of the curves between the two methods differ greatly. The capacitor method shows a slightly larger starting torque and will accelerate faster than the inverter board at 60Hz. The inverter board produces a curve similar to that of a class D design motor, while the PSC run topology produces a similar class A torque curve. An unequal voltage magnitude caused by the permanent capacitor creates an

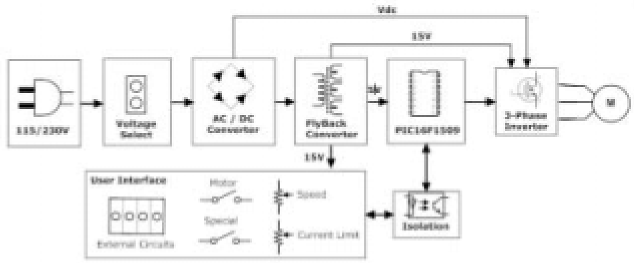

Figure 4: Top level overview of the overall system

unequal magnitude of magnetising flux within the stator. The inverter board attempts to create an equal amount of current in each winding, since this particular motor has identical impedance in each. The shape of the torque curves are not similar because of these discrepancies in the driving topologies.

Looking at the starting torque when the rotor is locked, the inverter would be unable to lift the same-sized load as the PSC method if the inverter were programmed to simply turn the motor at a 60Hz modulation frequency. However, the inverter board can use variable frequency drive to lift an even larger-sized load. The designer must also take into consideration the trade-offs of large starting torque versus efficiency and speed.

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The most obvious benefit of controlling the voltage and frequency is that the designer can control the speed at which the motor shaft spins. The faster it spins, the sooner the load can be pushed or pulled to its destination. This can be a critical design win in a garage door or gating system application.

Inverter board

So, the inverter board allows the motor to out-pace a replica motor that is driven by the PSC method. The PSC method can only be driven at one frequency and, hence, it cannot exceed its synchronous speed.

The inverter board can be constructed as an application-specific platform rather than a general-purpose demo board. However, it does provide numerous inputs and outputs (I/O) for the user to interact with and modify. The inverter is engineered to drive a single-phase or three-phase AC induction motor. An overview of the board is shown in Figure 4 using a PIC16F1509 microcontroller from Microchip.

The board was designed with flexibility in mind, so some of its features can be used or not to achieve optimisation. Most of the I/O are used by the default code but there is still plenty of space for the developer to use custom modifications. The I2C lines are also free for any added slave devices.

Some of the I/O are multiplexed onto one pin to increase the number of I/O that can be used. All user interface requirements are isolated via two four-channel optocouplers and a one-channel optocoupler.

The board provides two switch buttons and two potentiometers. There are also headers that provide connections for external I/O, such as garage door trip sensors. The two potentiometers have their transistor in the optocoupler circuitry biased in its amplifying region. The output is therefore approximately linear, since the optocoupler LED does not have a linear I-V curve. Large currents in the 30mA range are consumed for each potentiometer.

The digital push buttons and auxiliary inputs are biased to cause an interrupt-on-change (IoC) when either is used. This alleviates the CPU from constantly checking the voltage level on the pins. Whenever an IoC is detected, an ADC reading must be taken to determine which input caused the interrupt.

Operation

The motor is in its idle state when the PIC16F1509 microcontroller initialises pins and stops the motor. When the start button is pressed, the motor starts using a soft-start method where the frequency and voltage are adjusted in a linear fashion to bring the motor up slowly to its operating speed. The motor then moves to its on state when the soft-start operation is completed.

The motor speed and current trip points are constantly polled in the main loop. If an over-current is detected, the motor is stopped and the status LEDs blink to indicate a fault. The motor is normally stopped by push-button using braking or soft-stop to return it to its idle state.

Conclusion

AC induction motors such as used in garage door applications can be driven using an inverter board rather than a traditional capacitor. This allows speed control and soft-start capabilities to be added to the motor at relatively low cost. The inverter board is based around a PIC16F1509 8bit microcontroller from Microchip.

www.microchip.com

Power Cycling Community 1995-2014

An overview of test results over the last 20 years

Semiconductor lifetime is a key factor for economical and sustainable use of power electronics. To assess the lifetime of power electronic modules, active power cycling tests are a state-of-the-art procedure. This article shows the results of 110 publications from the last 20 years related to samples per test run, temperature swing, coolant temperature and cycling time.

By Aaron Hutzler, Felix Zeyss, Stephan Vater, Adam Tokarski, Andreas Schletz and Martin März, Fraunhofer Institute of Integrated Systems and Device Technology, Nuremberg, Germany

Manufacturers of power semiconductors and modules invest much money and effort into the optimization of their products' reliability. This includes predicting in-application lifetime through active power cycling tests. To distinguish various products and technologies, these tests have to be comparable in terms of parameters, conditions and results.

This study analyzed correlations and mismatches between 110 publications of the power cycling community. Due to the lack of a complete description of boundary conditions, test strategy, and end of life criteria, only 59 papers were usable for the comparison. However, the remaining papers nevertheless exhibited a huge variety.

Active Power Cycling Tests

Active power cycling determines lifetime of power modules under working conditions. The modules are mounted on a heat sink (cooling with air or liquid) and a voltage is applied in forward direction to reach a defined current. This current through the Device Under Test leads to power loss and results in an increase of the semiconductor temperature. When the current is periodically switched on and off the temperature of the semiconductor rises and falls due to alternating heating and cooling. One power cycle is defined as the full period of heating up the junction from minimum temperature $T_{j,Min}$ to maximum $T_{j,Max}$ and cooling it down. In most test setups, the temperature and electrical data are monitored during each cycle. If these values changed more than a previously determined amount (e.g. 20 %), the end-of-life criteria is fulfilled [52].

The number of cycles to failure (N_f) is mostly influenced by the temperature swing at the junction (ΔT_j), the minimum temperature ($T_{j,Min}$), the heating time (t_{on}), and the current (I_{Heat}) [13; 63]. Besides these obvious influences, the mounting of the device on the heat sink (i.e. thermal resistance and thermal impedance) also influences power cycling results. Another factor is the size and type of the semiconductor device, which has to be considered when separating different product families and generations.

In conclusion, power cycling tests can lead to a lifetime approximation which is close to the application when performed under realistic conditions. Power cycling can be distinguished from the passive temperature cycling test in terms of heating source (active vs. passive). Furthermore, the commonly used cycle times are about ten to hundred times shorter at power cycling than at temperature cycling (seconds vs. minutes).

Reviewed Papers

This study analyzed publications from 1995 to February 2014, which dealt with the topic active power cycling and/or semiconductor lifetime in general. Originally, 110 papers built the database. In the end, 59 of those papers contained usable information in terms of a complete listing of test conditions, as well as using a standardized test procedure (cooling method and cycle times). Yet, only a few papers stated the basic conditions. For example, the number of samples was missing quite often. Figure 1 shows the distribution of the devices per test run.

For any paper with no given number of devices, the sample size was assumed to be one. In order to recognize significant effects between different power cycling tests, the statistical power has to be known. This can only be achieved with an analysis, which requires a minimum of 10-15 samples per test. As there are minor deviations in the production parameters, the result for every sample can differ.

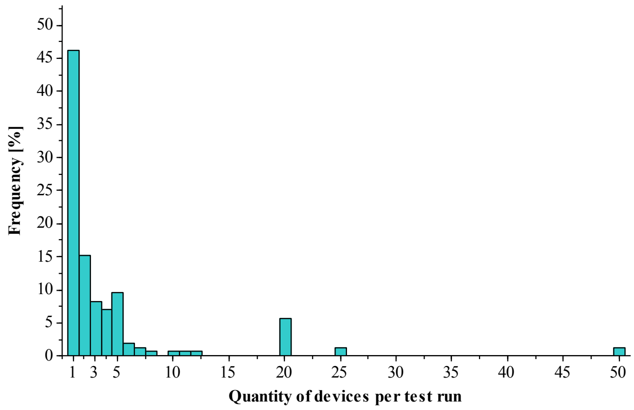

Figure 1: Histogram of samples per test run [1–65]

Regarding the test conditions, the analyzed papers showed a variety in terms of test setup, monitoring, and power-cycling parameters. This variety might be due to the fact that an international standard for power cycling tests does not exist. In fact, there are several standards that differ in regards to the main focus of the test [60–62].

Figure 2 illustrates the essential test parameters that could be extracted from the papers. The minimum junction temperature per test run is drawn versus the temperature swing of the device. The diagram shows that the majority of the tests took place in the temperature

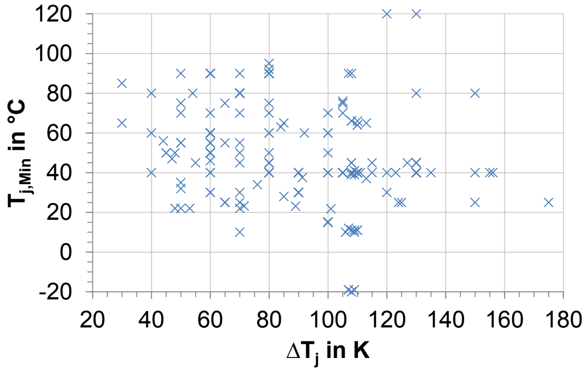

Figure 2: Minimum temperature versus temperature swing [1–3; 5; 7–15; 17; 18; 20–22; 24–40; 42–55; 57–59; 64]

Power Cycling Test Results

To see any influences of the test parameters on the lifetime, the results of the individual test runs have to be taken into account. This analysis is limited by the fact that many different devices' test results had been published and no common test standard was given. Furthermore, the observable dependence of the lifetime on any factor is influenced by the variation of other factors.

An exemplary dependency analysis can be seen in Figure 3. It shows the cycle count to failure versus the temperature swing of the device.

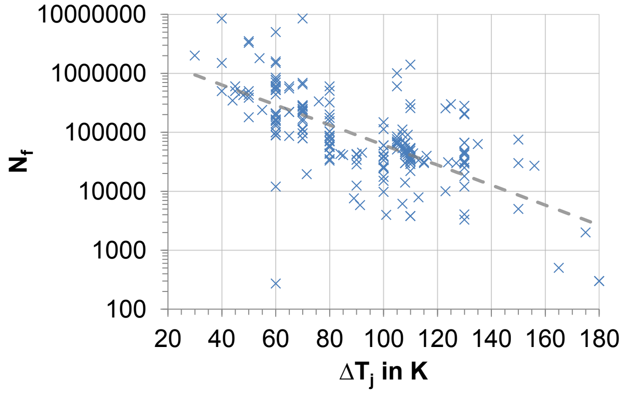

Figure 3: Number of cycles versus temperature swing [1; 3–5; 8–11; 13–25; 27; 29–34; 36; 37; 40; 43–45; 47–59; 64]

influence on lifetime than the temperature swing.

In the previously mentioned lifetime models, the influence of the coolant temperature is given by an Arrhenius-term:

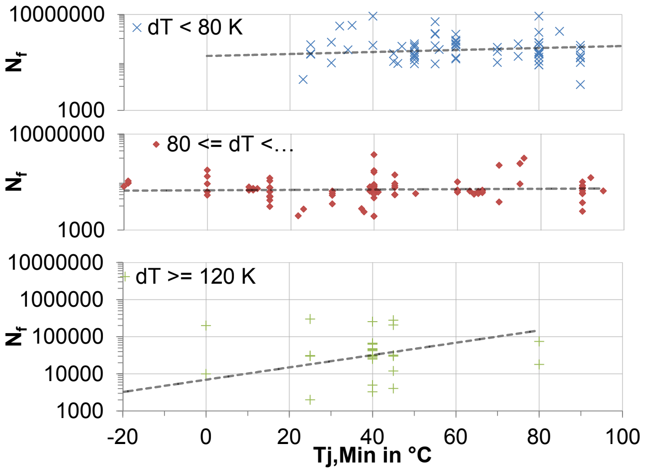

Figure 4: Number of cycles versus minimum temperature [1; 3; 5; 8–11; 13–15; 17; 18; 20–22; 24; 27; 29–34; 36; 37; 40; 43–45; 47–55; 57–59; 64]

$N_f \propto \exp\left(\frac{\beta_2}{T_{j,Min} + 273}\right)$ [13; 36; 63].

In this case, empirical lifetime curves predict a lower lifetime at increased temperatures, which did not correspond with the analyzed data.

Another factor that is supposed to influence the number of power cycles is the timespan in which the device is powered on and conducts current. Figure 5 shows the achieved power cycles per test versus the used on-time.

The cycle time seemed to influence the lifetime, but the data set was quite low compared to the last diagrams, which meant that the result was less reliable. This comes from the fact that the value of the heating time ton was missing quite often. However, most papers did state the cycle time without mentioning the ratio of on- and off-time (symmetrical $t_{on} = t_{off}$ or asymmetrical $t_{on} \neq t_{off}$.). It should be stated that the heating time has a too high influence to neglect.

Conclusion and Outlook

The study showed that an international standard for active power cycling tests is needed. The lack of complete data regarding the test strategy, conditions, number of devices, and sample setup makes most results not reproducible at all. Almost every institution that deals with semiconductor reliability has developed its own internal procedures.

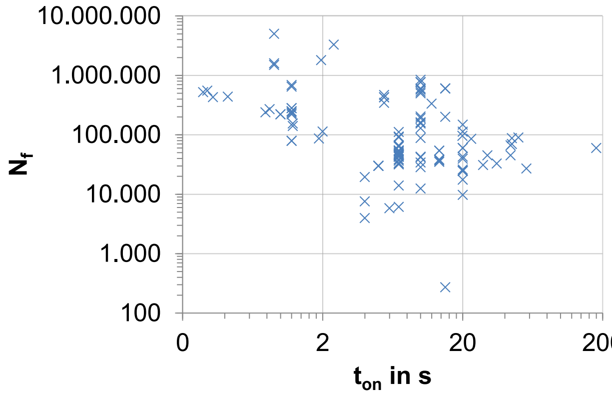

Figure 5: Number of cycles versus heating time (IGBT only) [1; 4; 5; 8; 10; 11; 13–18; 20–22; 24; 27; 29–34; 36; 37; 40; 43–45; 47; 49–59]

A suggestion could be the harmonization of the cooling method or the mounting of the samples. Furthermore, a detailed list of essential test variables has to be stated in the conclusion. To end this diversification in test procedures, a newly revised and internationally accepted standard is inevitable. Otherwise the published data will remain worthy for marketing purposes only for all future.

Note: This study makes no claim to be complete. The shown overview will be continuous improved and new or not included papers are welcome.

References are listed at Fraunhofer

www.iisb.fraunhofer.de/pct

Reliable When it's Hot and Humid

Power utilities around the world are rolling out smart meters in order to enable automated meter reading and optimized energy management. The X2 capacitors from the EPCOS B3293 heavy duty series of film capacitors are well suited for these meters because they operate reliably over a long service life under extreme environmental conditions.*

By Martina Auer,
Director Product Marketing Film DC, TDK

Smart meters are continuing to enjoy strong growth rates as more and more power utilities implement automated meter reading (AMR) to save the expense of periodic trips to each physical location to read a meter. Moreover, information based on near real-time consumption can help both utilities and their customers better control the use and production of energy.

An estimated 40 percent of all power meters are installed outdoors, where they are exposed to high humidity, as well as extreme and rapidly changing temperatures. While outdoor mounting poses no serious problem for conventional meters with relatively simple electromechanical designs, the challenge is much greater for electronic smart meters. Smart meters typically employ a capacitive power supply where the key component, the AC capacitor, is permanently connected in series to the power line. This, combined with high humidity and temperatures, can significantly reduce the capacitance of conventional capacitors and thus severely limit their useful life in smart meters.

Historically, standard EMI suppression capacitors have been selected for this particular circuit position because of their safety approval (UL, ENEC). These capacitors, however, are not designed specifically to satisfy the long-term operation requirements of the power meter.

New heavy duty series

The challenge for the component manufacturer was to develop a capacitor that offers extremely stable capacitance values over a period of decades, regardless of the climatic conditions. These requirements defined the development targets for the EPCOS B3293* heavy duty series of AC film capacitors. They combine the high capacitance stability under AC load and severe environmental conditions within relatively small dimensions and maintain the safety certification for an X2 rating.

While there is no specific requirement for safety-certified capacitors, X2 capacitors are normally preferred by customers as they are approved to IEC 60384-14 and UL 60384-14. X2 capacitors, however, are designed specifically to operate in parallel with the power line for EMI suppression. In capacitive power supplies, however, the capacitor is connected in series with the load (Figure 1).

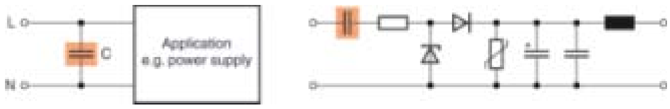

Figure 1: Use of X2 capacitors

Exposure to aggressive environments with high humidity levels and/or relatively high temperatures in combination with AC voltage can start a destructive process, causing the metallization edges of the electrodes to degrade, and resulting in a drop in capacitance (Figure 2).

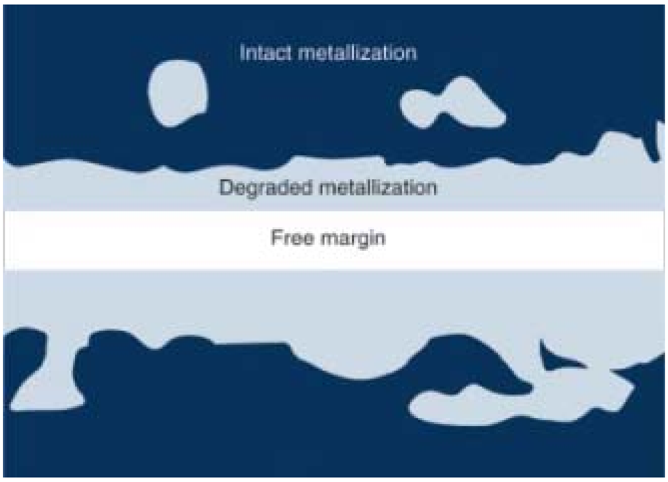

Figure 2: Plastic film with degraded metallization edges

Threefold threat to capacitors in smart meters

In smart meters the capacitors are exposed to a threefold threat:
- Permanent high AC voltage
- High temperature
- High humidity

The design challenge for the B3293* heavy duty series of film capacitors was, therefore, to offer high durability and very low capacitance drift under these conditions, which are lethal for conventional capacitors.

Designed to withstand high AC voltages and temperatures
In order to avoid the degradation of the electrodes due to high AC voltage, the B3293* series was designed with an alternating metallization pattern that in effect creates two capacitor circuits in series and thus reduces the AC voltage for each capacitor circuit by half (Figure 3). This effect is of high importance because it significantly reduces the speed of degradation. A further advantage of this design is the added safety: In the event of a short in one capacitor circuit, the other is not affected and the power supply can continue to function.

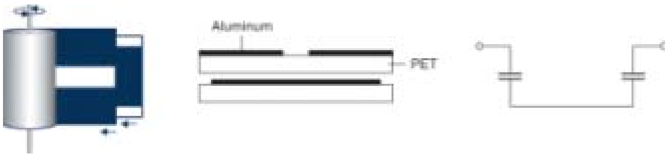

Figure 3: Film metallization pattern for the new EPCOS B3293 heavy duty series*

Metallized film capacitors are a very safe technology due to their self-healing property, which allows weak dielectric areas to be burned out when overvoltages appear. These capacitors represent the only suitable alternative for high capacitance values, high peak voltages, high temperature levels (105 °C), and X2 safety levels (the capability to withstand overvoltages of up to 1000 V). Thanks to their high dielectric strength, the B3293* heavy duty series thus eliminates the need to overdimension the capacitor in the circuit.

Polypropylene (PP) film is typically used for the majority of X2 class EMI capacitors used today. The B3293* series is based on polyester (PET) film, a dielectric material whose dielectric constant of 3.3 is 50 percent higher than that of PP film. PET also offers better resistance to high temperatures, enabling capacitors that are suitable for higher operating temperatures of up to even 125 °C.

Immune to high humidity
A further key requirement is to increase the capacitor's resistance to humidity. In order to prevent moisture from entering the component, the B3293* series employs specially designed materials for the box, the resin filling, and the metallic spray for connecting the leads. The most important improvement, however, was gained by using a plastic film that is not metallized with zinc. This material, commonly used in X2 and AC capacitors, is very sensitive to humidity and, as a result, corrodes very easily when exposed to the severe conditions commonly encountered with outdoor meter installations. Moreover, the film metallization profiles of B3293* series have been optimized to be even more robust against humidity.

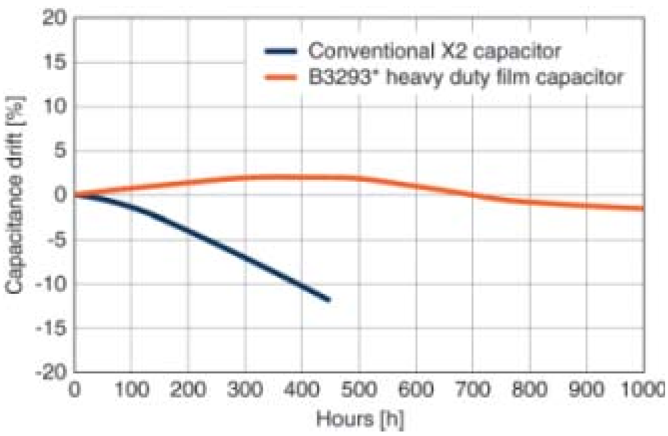

Figure 4: Capacitance drift of the EPCOS B3293 heavy duty series in comparison with conventional X2 capacitors*

As a result of these design measures, the B3293* series of capacitors offers a very high capacitance stability under the most severe conditions and complies with the extremely high safety requirements that every X2 capacitor must meet.

Long-term reliability proven with demanding tests
Under standard testing conditions (85 °C, 85 percent relative humidity, 275 V AC), the B3293* heavy duty series exhibits a capacitance drift of less than 2 percent after 1000 h compared to a drift in excess of 10 percent after only 500 h for conventional X2 capacitors (Figure 4), confirming the significant improvement in performance. Indeed, tests under these same conditions confirm that capacitance drift remains below 2 percent even after 2000 h.

The reliability of the series has also been proven in long-term endurance tests according to the rigorous requirements of the IEC 60384-14 standard and based on the demands of smart meters. IEC 60384-14 standard specifies a maximum capacitance drift of 10 percent after 1000 h at the maximum temperature for the climatic category and at 1.25 times the rated voltage. Under these extreme conditions, a 2.2 µF capacitor from the B3293* heavy duty series exhibits a capacitance drift that is well within the permissible 10 percent tolerance range (Figure 5).

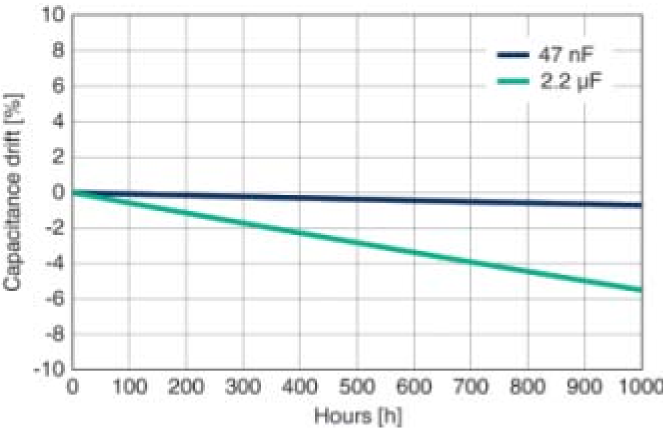

Figure 5: Durability results for the EPCOS B3293 heavy duty series under extreme conditions*

With the B3293* heavy duty series, a new range of AC film capacitors is now available for a rated voltage of 305 V AC and temperatures up to 105 °C with capacitance values ranging from 47 nF to 2.2 µF. Up to this capacitance, they more than fulfill the IEC60384-14 requirements for safety certification as X2 capacitors. Moreover, the EPCOS capacitors will be the first to be approved to the new UL standard 60384-14. Thanks to their reliable performance at high humidity, these capacitors are well suited for use in the growing number of smart meters. Other typical applications for the B3293* series include motion sensors, household appliances, rolling shutters, and other products that require a low current and cost-effective capacitive power supplies.

Technology	MKT wound, internal series connection
Climatic category	40/105/56 (−40 °C/+105 °C/56 days damp heat test)
Passive flammability category	B
Capacitance range [µF]	0.047 to 2.2 µF
Rated voltage [V AC] (IEC 60384-14)	305 (50/60 Hz)
Maximum operating temperature [°C]	105
Lead spacing [mm]	15 to 37.5
Approvals (up to 2.2 µF)	IEC 60384-14 / EN 60384-14 UL 60384-14 (pending)
Damp heat test	
Temperature [°C]	85 ±2
Relative humidity (RH) [%]	85 ±2
Test duration [h]	1000 / 2000
Voltage value [V AC, 50 Hz]	240
Limit values after damp heat test	
Capacitance change (ΔC/C) [%]	≤ 10
Dissipation factor change (Δ tanδ)	$\leq 5.10^{-3}$ (at 1 kHz)
Insulation resistance R_{ins} [%]	≥ 50 of minimum or time constant $\tau = C_R \cdot R_{ins}$

Table 1: Key technical data of the EPCOS B3293 heavy duty series of X2 capacitors*

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The 6th Annual IEEE Energy Conversion Congress and Exposition (ECCE 2014) will be held in Pittsburgh, Pennsylvania, USA on September 14-18, 2014. ECCE has come to be regarded as the ideal environment for industry, academia, and startups to meet, collaborate, motivate, and innovate over global initiatives in research and industrial advancements. With a record number of submitted digests the conference expects to be the largest ECCE to date. An exciting list of events include 1) a plenary session featuring speakers from US national labs and global industry champions, 2) numerous technical sessions on energy conversion systems and technologies as well as components and materials, 3) exposition featuring exhibitors displaying the latest advances in energy conversion technology . Please visit http://2014.ecceconferences.org/ for more information and be a part of this international hotspot on all things related to energy!

High Permeability, High Impedance Mn-Zn Ferrite Material for Wide Frequency EMI Applications

High permeability Mn-Zn ferrite materials are widely used in the field of solving electromagnetic interference (EMI) problems, such as the filters of electronic equipments, the line filters of switch power supply and the common mode chokes of commercial power. The impedance of high permeability Mn-Zn ferrite materials plays an extremely important role reducing EMI. This paper introduces DMEGC's new R10KZ material with high permeability and high impedance over a wide frequency range.

By Chao-Ming Wang, Xin Jin, Yang-Zhong Du and Su-Ping Wang;
Hengdian Group DMEGC Magnetics CO., LTD, Hengdian, Zhejiang 322118, China

The electronic equipments are widely used in the real life and the electro- magnetic interference (EMI) becomes more obvious, what often causes problems fulfilling electromagnetic compatibility (EMC) requests. Therefore, the developed countries and regions paid more attention to the control of EMI which has been brought into the category of management of the state's legal system and environmental protection. All the councils subjected to IEC are designated corresponding standards. Filtering is a technology to deal with electromagnetic noise in a certain frequency range, which can filter out the part of signal that we don't need. However, Mn-Zn ferrites with high permeability are regarded as one of key materials meeting requested EMC standards. Thus, the research on the impedance characteristics at various frequency ranges is highly demanded.1

The ferrite impedance can be divided into two parts, inductance and resistance contributions. In the low frequency range, ferrite impedance are mainly dominated by inductance. It can be expressed as follows:

$$Z = K * jwL \qquad (1)$$

Where K is the constant related with cores and L is the inductance. While operated at intermediate frequency range, both inductance and resistance contribute to the impedance due to the increasing resistance. And the impedance can be expressed as follows:

$$Z = K/(1/R + 1/jwL + jwC) \qquad (2)$$

Where R is the resistance component and C is capacitor component. In the high frequency range, the ferrite impedance is mainly attributed to the resistance contribution for the decreasing inductance and increasing resistance. Therefore, it is necessary to adjust the ferrite compositions and sintering processing in order to satisfy applications' various demands in impedance at different frequency ranges.

Sample preparation and property measurements
The Mn-Zn ferrites, applied in EMI Applications, must have high permeability and high impedance over a wide frequency range. Thus it can eliminate the noise in the circuit. According this request, we optimized the composition and additions of the materials by making series experiments, and improved the sintering technology.

The initial permeability (μi) and Curie temperature (Tc) were measured by HP4284A, the impedance by HP4291B impedance analyzer and the saturation magnetic flux density (Bs) using SY8258. The elemental properties of R10KZ are listed in Table 1.

Property	Conditions	Value	Unit
Initial Permeability	25℃ 10kHz 0.25mT	10000±30%	
Permeability	25℃ 200kHz 0.25mT	9500±30%	
Relative Loss Factor	25℃ 100kHz 0.25mT	≤10	$*10^{-6}$
Saturation Flux Density	25℃ 50Hz 1194A/m	≥380	mT
Curie Temperature	10kHz 0.25V	120	℃

Table 1: The initial permeability, saturation magnetic flux density and Curie temperature of R10KZ

The relationship between the initial permeability and frequency of R10KZ is shown in Figure 1. It shows almost stable permeability of R10KZ below 200 KHz, indicating an excellent frequency characteristic.

Figure 2 shows the impedance of standard R10K and newly developed R10KZ material from 10 kHz to 1MHz. The impedance of R10KZ is remarkable higher as R10K impedance in200 kHz to 1MHz frequency range. The Zmax of R10KZ material increased by 25% compared to R10K material.

The figure 1 and figure 2 exhibit the frequency characteristics of permeability and impedance of R10KZ material of H25*15*12 core. Furthermore, we can also provide other shapes or sizes of high impedance materials, which can meet different needs of customers.

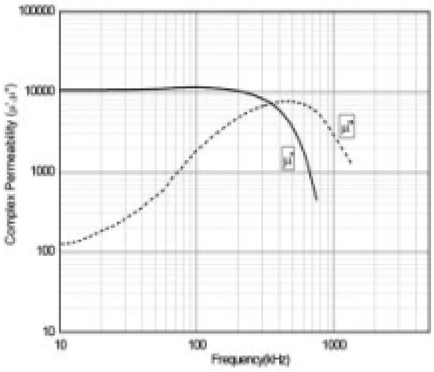

Figure 1: Initial permeability vs. frequency of R10KZ

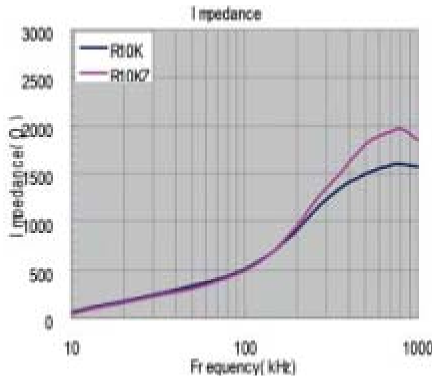

Figure 2: Impedance of standard R10K and R10KZ material

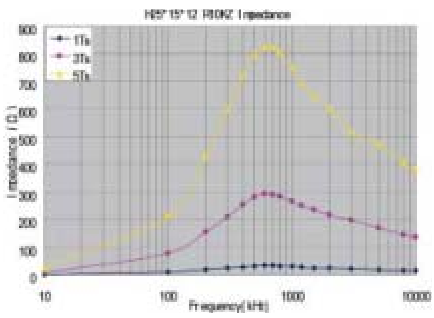

Figure 3: Impedance versus number of turns

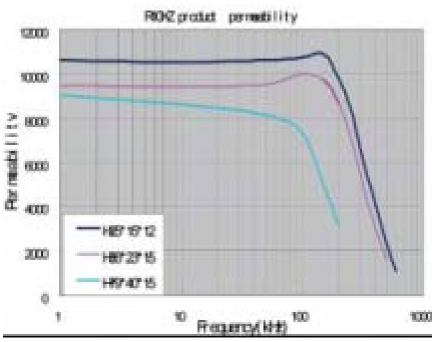

Figure 4: Permeability versus different core size

Figure 3 shows the impedance versus number of turns for H25*15*12 R10KZ core, and Figure 4 shows the permeability of different size core for R10KZ material.

Conclusion

Ferrite material R10KZ means remarkable improvement of weaknesses of high permeability materials and offers opportunity to further technical improvement and cost reduction of various applications.

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Hardware-in-the-Loop testing as a Key Element in the Development of High Performance Battery Emulators

The AVL e-Storage System family is a significant player on the market of dynamic power supplies in automotive industry. To fulfill the growing performance requirements, leading-edge control strategies are introduced in the new generation of AVL products. Hardware-in-the-Loop testing is an important tool for the development team, helping to reduce control algorithm and software verification time and effort.

By Maksym Shkadron, Oliver König and Roland Greul;
BU Electrification and Racing Test Systems; AVL List GmbH

Development targets

The e-Storage System provides multiple usage scenarios as battery tester, battery emulator and e-motor/inverter testing facility. The system has to satisfy such criteria as high dynamics, broad voltage range (typically 8-800 V), low residual ripple and stability despite the variety of possible loads. Variability of possible use cases, automated testing processes and real-time fail-safe operation require usage of specialized microcontrollers for digital control of power electronics system. To fulfill the described requirements, the development team has to be focused simultaneously on three key system elements, which are scalable hardware design, reliable application software and control strategy.

The most challenging task to utilize the dynamic bandwidth of the designed power electronics hardware is designing an advanced controller. Modern approaches allow reducing hardware components size and costs, but have to be thoroughly verified in simulation. On the design stage, software simulation tools allow different parasitic effects and nonlinearities to be factored into. But still, implementation of the control algorithm on respective target MCU/DSP hardware requires an environment where the switching behavior of the control plant is simulated in real-time.

Embedded software development approach using HIL

To ensure prompt verification of the control software, Hardware-in-the-Loop testing approach has been chosen, with Typhoon HIL600 system as core of the testing platform. Relative simple adaptor boards act as an interface between AVL power controller unit (PCU) and Typhoon HIL600 system, making it possible to evaluate the computational power of used microcontroller directly. HIL testing not only provides the closed-loop control verification, but also gives the possibility of application software testing and debugging at early stages of development in the development lab environment (Figure 1 shows the HIL testing setup). The control loop runs side by side with other tasks required by application software (communication, safety supervision, etc.).

Software development with HIL approach fundamentally decreases the typical costs and risks of power electronics development, avoiding the hazard of damaging the system. Simultaneously, the flexible evaluation platform enables software verification under various operating conditions and makes it easier to find appropriate hardware configuration for the desired performance requirements. It is worth mentioning, that measurements obtained from prototype hardware setup, were almost the perfect match with HIL simulation.

Considering the importance of Hardware-in-the-Loop testing in the embedded software development workflow for AVL e-Storage System (which is shown in the Figure 2), it can really be called the key element in it.

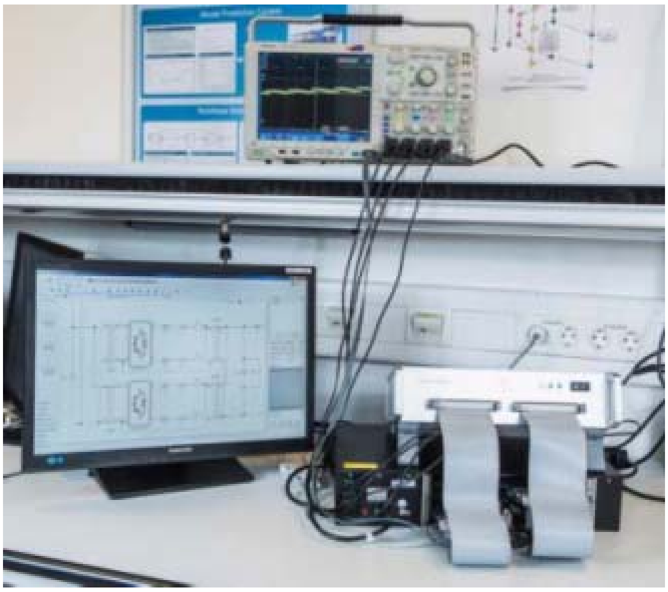

Figure 1 - HIL working environment: AVL power controller unit in a loop with HIL600

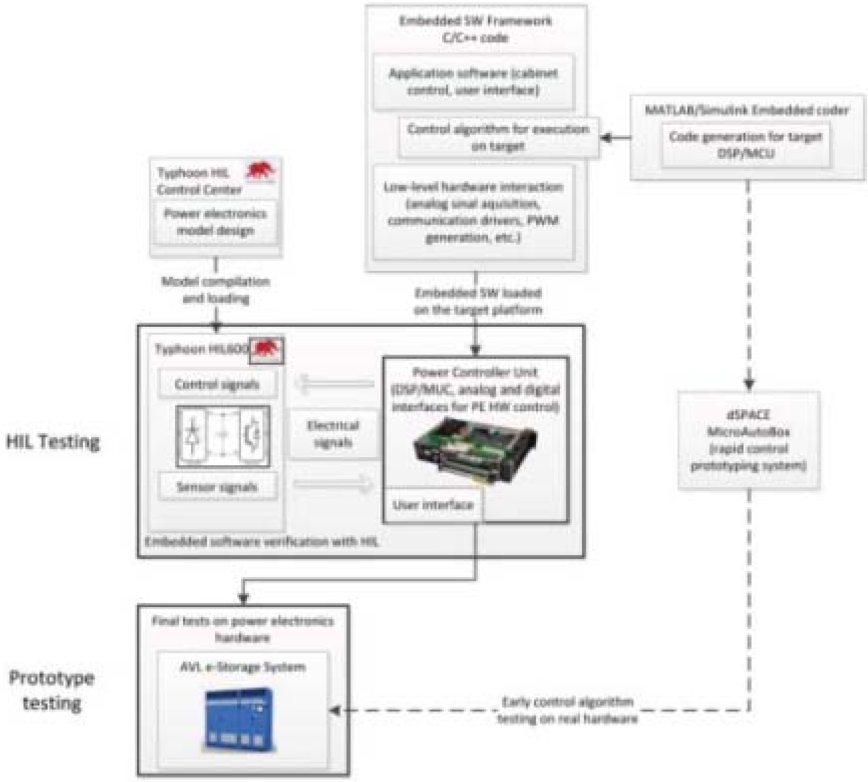

Figure 2 - AVL embedded software development workflow using HIL

Conclusions

The efficiency of the described workflow using Typhoon HIL600 could be leveraged during the development of AVL e-Storage Systems. The classical V-model of system engineering and verification can be improved by using HIL testing on different system maturity levels. In context of power electronics product development, HIL simulation was particularly beneficial because embedded software design was running in parallel to prototype hardware development and assembling. Owing to the fact of early porting of controller algorithm to the real target hardware, a large number of issues, especially in control hardware configuration, can be solved prior to system integration phase. This results in significant development time and cost benefits.

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Contact:
BU Electrification and Racing Test Systems; AVL List GmbH
Hans-List-Platz 1, 8020 Graz, Austria;
maksym.shkadron@avl.com; oliver.koenig@avl.com
roland.greul@avl.com

Rapidly Design, Prototype, and Test your DSP Controller with PSIM and Typhoon HIL

By Ivan Celanovic and Nikola Celanovic Typhoon HIL Inc., USA;
Hua Jin, Powersim, Inc, USA and Simone Castellan, University of Trieste, Italy

The growing complexity of power electronics (PE) systems, intensifying competition, rapidly shrinking product development cycles, and exploding test and quality assurance costs are forcing power electronics industry to accelerate the adoption of advanced tools for design, test, and verification. This trend is particularly evident in power electronics embedded control software whose size, complexity and importance is rapidly increasing. This is only to be expected because power electronics control software:

- Provides large value added to the product via increased functionality and new features;
- Provides an opportunity to quickly develop new products based on existing hardware platforms; (i.e. using solar inverter power hardware for grid storage power hardware)
- Provides the opportunity for newcomers to offer competitive solutions in different verticals thanks to the availability of modularized hardware.

If automotive industry can be taken as an indication of how the power electronics is going to develop, we should brace ourselves for a software dominated power electronics. For example, today's car has between 20 and 70 processors with 100 million lines of embedded code amounting to approximately 1GByte of embedded code [1]. Less than 20 years ago cars had one or no processors. Testing automotive embedded software then was much simpler. Manual testing was acceptable, as it is still the standard practice in most of the power electronics industry today. But times are rapidly changing.

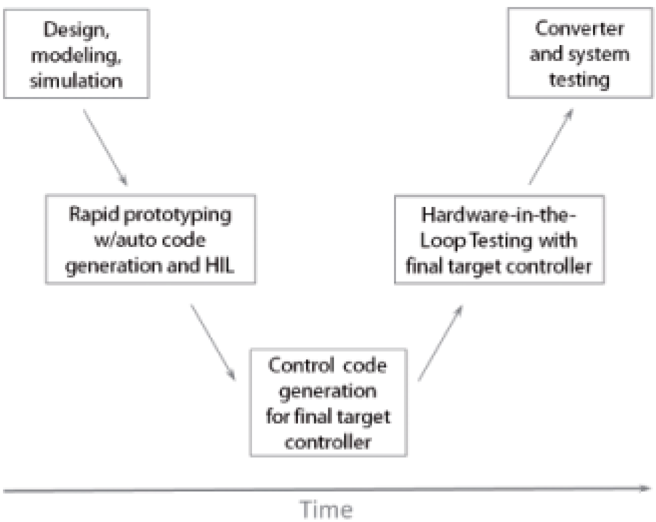

Figure 1: Power electronics model based design process depicted with "V diagram".

In addition, power electronics industry is currently undergoing a power semiconductor revolution with the development of new wide-bandgap semiconductor devices, i.e. SiC, GaN, which are imposing more demanding design requirement specifications for controllers which in turn require a new set of tools for automated design, test, and verification.

Product Development Process

Here we propose a model based process for power electronics embedded controller development - described with "V diagram" - as shown in Figure 1. A new design project starts with high level specification and system level models with high level of abstraction. Once the system level model is simulated and performance is satisfactory, design seamlessly moves on to rapid prototyping (via automatic code generation) to hardware-in-the-loop (HIL) system with the rapid control prototyping hardware. After this step, design moves to control code targeting, production of the final code for the final controller platform - followed with testing of the final controller on the HIL. In the final development stage, controller is interfaced with real converter and tested in the laboratory, only this time in only a limited number of operating points, just what is needed to verify the power and controller hardware. Depending on applications, some converters will be further tested in large system configuration, such as parallel converter configuration, micro-grid configuration or similar. This last step can also be done in both HIL and real hardware setups.

The key in this new, agile control development process is to be able to test after each step, and to test relentlessly. Testing after each step eliminates design problems early on in the process without waiting for the bugs to surface late in the design or deployment stage of

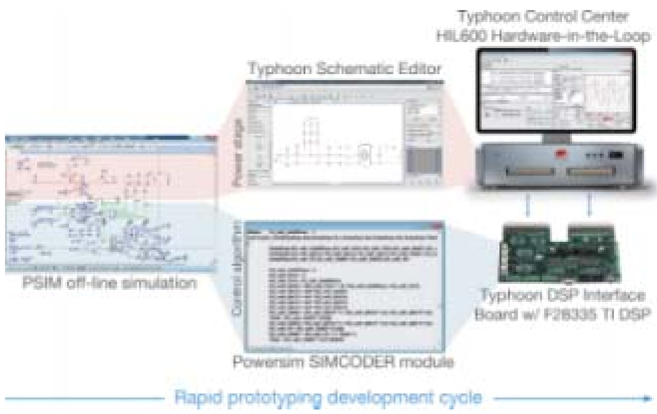

Figure 2: Power electronics model based controller design and testing workflow starts with offline simulation in PSIM, followed by rapid control prototyping with Typhoon's Hardware-in-the-Loop HIL600 real-time simulator and controller prototype (DSP Interface Board). Controller code is generated with PSIM's SimCoder Module.

the product. Indeed, model based design process where we can design and test each step of the way, as shown in Figure 1, shortens the design cycle, improves the controller quality and saves money. Furthermore, unified model based design toolchain will enable streamlined and efficient communication of design specification from the design phase all the way to product deployment across boundaries of the hardware, controls, software, and test departments.

The offline simulator PSIM and the Typhoon Hardware-in-the-Loop (HIL) real-time simulator, with their unique and dedicated focus on power electronics applications, provide the ideal toolset for the model based design process.

Design and Simulation

The key for shortening the design cycle (narrowing the “V” curve) in model based design is to begin with the embedded controller code development as early in the design cycle as possible and to start testing it as early as possible. The PSIM offline simulator enables engineers to simulate the power stage and the controller independent from the power and control hardware [2]. Another advantage of model based design is the code reuse and model reuse from previous designs. In addition, PSIM offers a variety of control design tools to help designers quickly evaluate and tune control algorithm. One example is the frequency response analysis to measure transfer functions of open loop or closed loop systems. This enables design engineers to evaluate performance, test the robustness, and check the feasibility of requirement specification early in the design phase.

Rapid prototyping: Typhoon HIL + DSP Interface Board + PSIM Auto Coder

After the design was simulated against various operating scenarios and the control algorithm optimized and fine tuned to meet the design specification, the control model is ready for rapid prototyping on a platform that interfaces with the real-time hardware-in-the-loop simulator.

Figure 2 shows the workflow of the rapid prototyping process. From the PSIM graphical representation of the control algorithm the control code is generated automatically and downloaded to the DSP located on the TI Controller Card which resides on the Typhoon HIL DSP Interface Board which is then connected to the HIL machine. The power stage is then compiled in the Typhoon HIL compiler to run on the HIL machine in real time. The result is rapid development of the executable specification of controller and power hardware, independent from the control and power hardware.

Automated HIL Testing

Owing to its ultra-high fidelity, and test automation features, Typhoon HIL system enables excellent test coverage, including fault conditions, of the final control software that is fast, affordable and repeatable [3].

Ultra-high fidelity of the Typhoon HIL system enables the most realistic controller testing environment short of real converter setup. Such testing allows unsupervised verification of the controller performance in all operating points (including hardware faults), at a rate that is at least three orders of magnitude higher than what can be achieved by manual testing.

User Case: Grid-Connected Inverter Design
The model based design process was demonstrated in a user case study. In a project by University of Padova and University of Trieste, Italy, a team of researchers were to develop controller for a battery charger that can also supply grid with reactive power.

Figure 3: Full design, simulation, prototyping, testing, and verification of the controller is done from the comfort of the engineer´s desk. Grid-connected inverter is running in real-time in HIL configuration, controlled with automatically generated code from PSIM.

The basic control concept was first developed and implemented in PSIM. Using PSIM's SimCoder Module and F2833x Target, DSP related elements, such as ADC and PWM, were added to the schematic. After the system is fully tested and simulated, DSP code was automatically generated and loaded to the TI DSP connected to Typhoon HIL600 emulator via the Typhoon HIL DSP Interface Board. The power stage of the system was created in Typhoon's schematic editor, and a model for the power stage was compiled and uploaded to HIL600. A PSIM and Typhoon HIL setup, shown in Figure 3, depicts the computer that runs both PSIM and the Typhoon HIL software and is connected to both the DSP Interface Board and the Typhoon HIL600 emulator.

In a very short time, all the voltage and current loops were closed, and the control code was running with the power stage emulated in real-time in the hardware-in-the-loop setup.The team was able to focus on test scenarios that are very difficult to do in the real laboratory such as the investigation of the operation in the presence of grid voltage harmonics, unbalanced grid voltage, and load unbalance. The ease with which one can generate various grid conditions in the HIL and the write scripts to automate such tests is starting a new chapter in the history of power electronics controller software development and quality assurance.

Figure 4 shows the schematic diagram of the grid connected inverter power stage in Typhoon HIL Schematic Editor and HIL real-time waveforms . Waveforms show that, even with grid voltage unbalance

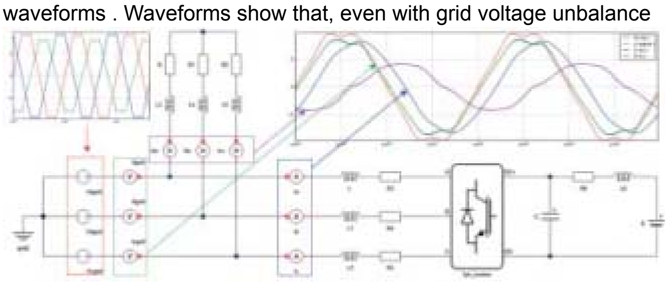

Figure 4: Schematic diagram of reactive power compensator simulated in real-time with 1μs time step in Typhoon HIL600 and controlled with Typhoon HIL DSP Interface board with TI DSP F28335 running the PSIM generated control code. Traces show grid voltage with harmonics (red), grid current (green trace) and load current (magenta trace).

and harmonics, the proposed controller can keep the grid voltage and current in phase, achieving reactive power compensation.

New Control Design Paradigm
The combination of the offline simulator PSIM and its auto code generation capability, coupled with the Typhoon HIL real-time emulator, offers a significant advantage in the design, analysis, and testing of the overall power electronics system. It allows the control algorithm, control hardware, and power stage to be developed independently of each other.
There is no doubt that the field of power electronics need both hardware verification and at the same time good coverage of operating points. Because the hardware used to be demanding enough in its own right, typically the software received reduced attention which resulted in high quality cost and field problems. Fortunately, there is now the PSIM-Typhoon toolset available that makes it possible to design, test, and verify power electronics control software in a systematic, process driven and repeatable way laying the foundation for rapid development of new and improved power electronics solutions.

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Fast Compensator Design and Optimization for Power Converters based on Graphical Visualization

Shaping the control-to-output frequency response is a widely used technique for compensator design. The most important factors of the design process are phase margin (PM) and cross-over frequency (fc). Are all combinations of phase margin and cross-over frequency feasible? Can a high cross-over frequency and a phase margin of 45° always be achieved? Under uncertainties, is slow dominant-pole compensation the best solution?

By Antonio Lazaro and Andres Barrado, Carlos III University of Madrid; Hua Jin, Powersim Inc.

The proper selection of the phase margin and the cross-over frequency will enable the compensator synthesis and achieve good dynamical performance of the control loop. Bode plots are very useful. However, the complete loop performance analysis and PM–fc viability requires Nyquist plots and transient/steady state response plots. SmartCtrl, a CAD tool for analog and digital compensator design, shows that by means of interactive plots, all the information can be used effectively to carry out and optimize the compensator design.

Design Challenges

Each power converter presents a unique challenge in compensator design, depending on the topology type and the mode of operation (i.e. continuous conduction mode vs. discontinuous conduction mode). Designing the compensator of a Buck or Buck–derived converter (Forward, inverters, etc.), for example, is quite different and easier than designing the compensator for Boost or Flyback converter families.

Designers also face a series of design choices and tradeoffs. Which type of compensators is the most suitable: PI, PID, or something else? What is the right combination of the phase margin and cross-over frequency for the best stability and dynamic performance? Is one tenth of the switching frequency in voltage mode control the limit, and can it be pushed higher? Often, a PI or single pole compensator is placed below the resonance frequency. This is a slow, but stable solution. But does it always present a smooth transient-response?

PM-fc Constraints

Selecting the right phase margin and cross-over frequency combination is a particularly critical design consideration. Synthetizing a PI compensator to have the fc value below the resonance frequency, for example, may result in the loop response crossing the 0 dB line several times and the actual fc below the one expected. Bode Plots are required to check this problem.
Most of the time, an analog compensator is made by means of an inverting amplifier. If fc is placed below the resonance frequency, the inverting amplifier compensator introduces an additional zero in the reference-to-output transfer function, causing a highly underdamped response. In this case, it is necessary to check time-domain transient response.
If the phase margin and cross-over frequency combination is selected in such a way that the phase of the control-to-output transfer function crosses below -180° for frequencies lower than fc, the control loop is only conditionally stable. This could cause a problem during start-up or at certain operating points of the converter. Again, Bode Plots visualization is an efficient way to anticipate this problem.
An additional constraint arises when a designer pushes for a high bandwidth. With a higher cross-over frequency, the output voltage ripple may not be attenuated sufficiently, and as a result, a higher ripple level could appear at the output voltage of the compensator. Since this voltage is expected to be close to a dc quantity, the ac component can cause fast scale instability or subharmonic oscillations when it is compared with carrier signal in the PWM modulator.

In this case visualization of time-domain waveform of the voltage at the compensator output helps greatly to avoid this problem.

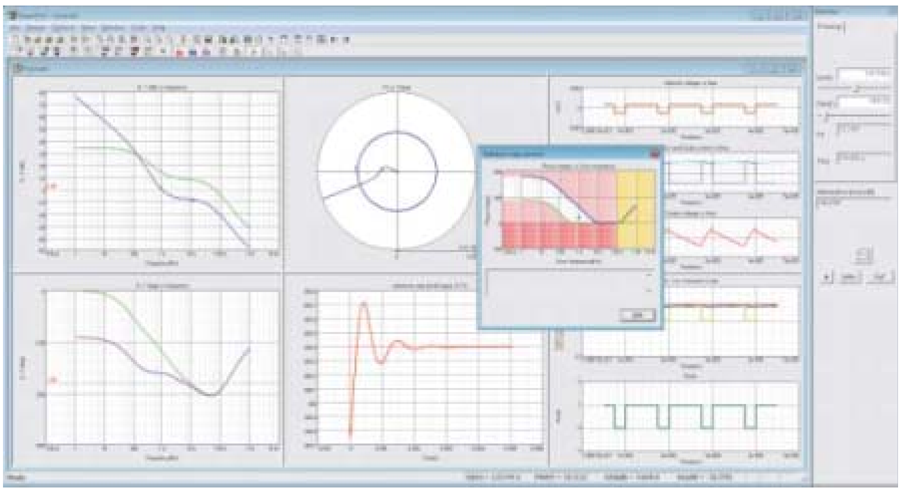


Figure 1: Interface of SmartCtrl

Solution

To address the design challenges of the compensator design, a graphical tool called SmartCtrl is developed to visualize interactively and conveniently all key plots (Bode Plot and Nyquist plots) and waveforms (including transient response, steady state response, compensator output, etc.) in one environment. In particular, to address the phase margin and cross-over frequency constraints, a Solution Map is provided to show a valid design region within which a stable design can be achieved. Also, when a design parameter is changed, all the plots and waveforms are updated instantaneously with all the aforementioned constraints taken into account. Figure 1 shows the interface of SmartCtrl.

Sensitivity analysis of any parameter of the converter or the compensator can also be performed, including digital control effects such as digital delay and rounding effects.

With the visualization of all vital information and the capability to carry out sensitivity analysis, designers can perform compensator design and optimization effectively and with confidence.

As the output, SmartCtrl provides the R-C values and coefficients of s-domain or z-domain transfer function blocks for analog and digital controllers. Finally, SmartCtrl is seamlessly integrated with the simulation software PSIM to validate the large signal performance, closing the complete design cycle.

For more information or to obtain a free demo of SmartCtrl, please visit Powersim's website at:

www.powersimtech.com/SmartCtrl-B

Novel fourth generation digital PWM controller eliminates external loop compensation, yet offers inherent stability

Achieving a stable power supply capable of providing optimum performance over a wide range of operating conditions has always been challenging. The world of power has seen several major shifts in the last two decades as it attempts to deal with this problem.

By Chance Dunlap – Senior Marketing Manager, Intersil

One of the recent innovations in this area is with digital control. To date, several vendors have been successful in applying digital control to power supplies and are beginning to see broad adoption in select markets owing to falling costs and improving performance. This article discusses the latest capabilities of digital control with a new part from Intersil, the ZL8800, a dual step-down PWM controller.

The key reason why digital power is often selected is for the need of telemetry (system monitoring) and control flexibility, whereby one design can support a range of applications. The ZL8800 adds to this capability, through implementation of digital control for stability, giving designers extra degrees of freedom by enabling designs without the considerations of component aging, variation and thermal stress.

The Standard Route to a Stable Power Supply

When designing a supply in a complex system such as might be found in data centers or cellular base stations, the standard power distribution strategy is to provide a dc power bus with local point of load (POL) units supplying the needs of an individual board. This aids system modularity and helps infrastructure operators, who are focused on system up time, and power efficiency.

The traditional design route has been to use an analog fixed frequency switching approach with voltage or current mode feedback. Selecting a fixed switching frequency leads to predictable currents in the passive energy storage components (the inductors and capacitors) easing their selection. These components are then sized based on the needs of the output: load current, output voltage ripple, etc. The challenge for the power designer is stabilizing the loop once the power train components are set. A problem that is compounded when variations and worse case analysis (including environmental) must be taken into account. The end result is often a design that sacrifices performance and bandwidth to satisfy the stability requirements of the system over its entire operating conditions.

Consider the problem of component tolerances with the selection of the inductor. These non-linear components have variances based on current, temperature, switching frequency and time. Non-ferrite inductors are widely used, yet these devices, over their rated current range, may vary by as much as 50%, representing a real optimization challenge. Output capacitors equally exhibit the same variation when you account for temperature, DC bias, and aging. As a result, the only option left for the designer attempting to create a stable loop is to dramatically reduce system bandwidth. Transient performance is only then met through over-sizing the output capacitors to balance the sluggish loop performance, burdening the design with a large footprint and increased bill of materials.

The Digital Way

Digital control can remove this trade off and Intersil, through its acquisition of Zilker Labs, has been at the heart of the digital power revolution since 2003. Now, with the introduction of its latest ZL8800 controller, Intersil has the first product of its type, able to offer a compensation free digital solution. This dual-channel, step-down PWM controller eliminates the need to compensate the loop for stability without compromising system bandwidth. With onboard memory allowing the device to be set up for any application, high power density circuits can be designed with minimal external components (see figure 1).

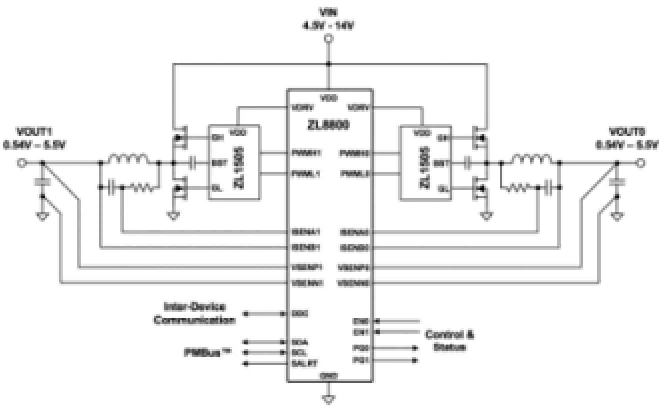


Figure 1: Typical application of Intersil's ZL8800 dual PWM digital controller

A key feature of the ZL8800 is the proprietary control loop known as ChargeMode™ control. This high-speed loop allows precise replenishment of any charge loss from the output capacitor during a transient event in a minimal amount of time. Control is performed rapidly on a cycle-by-cycle basis as the digital loop over-samples the output voltage. Ingeniously, the ZL8800 does not need to know the actual output capacitor value, relying on digital control algorithms to make the correct adjustment, even for stability. The result is the reduction in the amount of capacitance needed to support a specific application, while providing a compensation free design. The controller's response ensures that any transient conditions are met while preserving stability and minimizing any ringing or over-shoot.

The system level benefits derived from this approach are that designers are now no longer tied to a few power component choices. Components can be selected to achieve optimum performance, safe in the knowledge that the controller enforces inherent stability. Furthermore, the controller eliminates the effects of component aging or environmental variations since the digital loop is constantly monitoring and accounting for the change.

The high bandwidth control is enabled through various internal subsystems: a high speed over-sampling ADC gives the control loop its transient responsiveness, while a dual-edge modulator allows the ZL8800 to maintain fixed frequency switching while minimizing any delay through the loop. To provide designers a trade-off in loop bandwidth and gain the ZL8800 provides an optimization setting via a programmable gain control, allowing precise setting of control loop response.

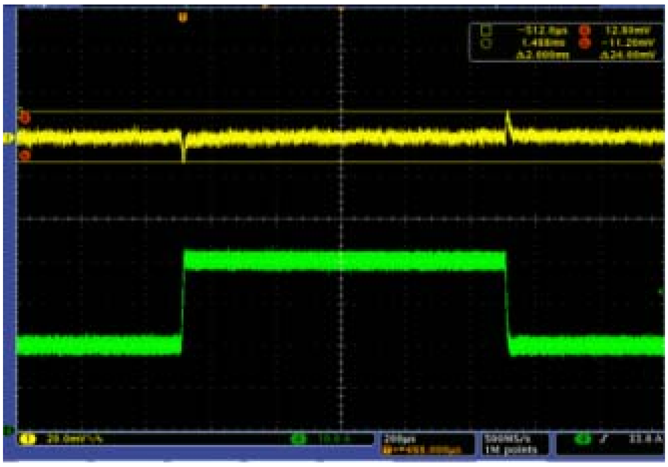


Figure 2: Transient response of ZL8800

Figure 2 illustrates the performance of the ZL8800 in a typical application. Configured as a dual phase, single output running at 550 kHz, the ZL8800 is designed to provide a total of 60A output with less than 2,700uF of output capacitance. In the scope shot below, the application is setup with Vin=12V, Vout=1.2V and a 20A load step applied (20A loading and 20A unloading), with only a total output deviation of 24mV observed (+/-1% of the output).

Additional features of the ZL8800

The ZL8800 operates with input voltages of 4.5 to 14 V and can be programmed to provide an output in the range 0.54 to 5.5 V. It is designed to switch at a frequency between 200 kHz and 1.33 MHz, either through internal selection or accepting an external clock. The device can be configured with dual outputs or be operated in a two-phase mode to support high output current applications. Digital communication with this controller is via PMBus, however, a unique single wire DDC (Digital DC) interface is also included allowing communication between a number of Intersil devices, enabling the construction of complex power architectures. Amongst other features the DDC bus allows complex sequencing and fault management across multiple devices.

In support of telemetry, the ZL8800 provides a parametric snapshot capability, which captures the operational data at the occurrence of a fault event, while on-board non-volatile memory offers local storage of data and user settings. With the release of the ZL8800, Intersil has taken the opportunity to update its PowerNavigator controller interface (GUI), which provides access to all the ZL8800 features via an intuitive programming environment without ever needing to write a single line of code. Two evaluation boards are available: a dual output (30A per output) and a high current 60A 2-phase system.

In conclusion, there seems little doubt that with its fourth generation ZL8800 design, Intersil shows leadership in a strongly growing market.

www.intersil.com

Class D Audio Chipset Featuring the IRS20965 Driver IC with Protected PWM Switching

International Rectifier has introduced a Class D audio chipset comprising the IRS20965 digital audio driver IC with protected Pulse Width Modulation (PWM) switching and a full complement of audio MOSFETs optimized for high performance Class D audio amplifier applications.

The IRS20965 features high-side and low-side independent floating PWM input to allow deadtime control from an external PWM controller. Shoot-through prevention logic provides additional safety in the event of PWM controller failure. The new IC also features over-current sensing output and 2A gate drive output capability.

The new chipset featuring the IRS20965 brings the additional flexibility of an external controller which programs performance and protection features. For example, it allows non-shutdown overload protection while maintaining high audio performance.

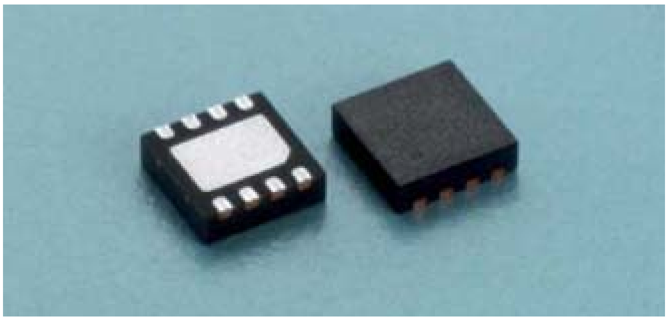
Operating up to 800kHz, other key features of the IRS20965 include programmable bidirectional over-current detection with self-reset function, high noise immunity, ±100 V ratings to deliver up to 500W in output power and 3.3 V / 5 V logic compatible input.

Production orders are available immediately and the devices are RoHS compliant and industrial qualified. Prices are subject to change. Datasheets for the devices are available on the International Rectifier website at:

www.irf.com

Load Switch with Controlled Turn-On offers Very Low On-Resistance

Advanced Power Electronics Corp. (USA has recently launched a small load switch with controlled turn on and very low on-resistance. The APE8937-HF-3 load switch contains one N-channel MOSFET that can operate over a wide input voltage range from 0.8V to 5.5V and support a maximum continuous current of up to 4A. On-resistance is very low with only 22mΩ from VIN=1.8V to VIN=5.0V. The switch is controlled by an on/off input, and is capable of interfacing directly with control signals as low as 0.8V.



Additional features include a 300Ω on-chip load resistor for output quick discharge when the switch is turned off. For power-sequencing, the rise time is adjustable by an external ceramic capacitor on the CT pin, which also reduces inrush current.

The APE8937-HF-3 switch is available in an ultra-small, space saving 2mm x 2mm 8-pin DFN package with thermal pad. The device is ideal for use in applications such as telecom systems, industrial systems, set-top boxes, consumer electronics, as well as portable products where selective sub-system power-down can be used to improve efficiency and battery-life. The device is halogen-free and fully RoHS-compliant.

www.a-powerusa.com/docs/APE8937-3.pdf

Industry-First, JEDEC-Qualified 600V GaN-on-Si

Transphorm Inc. announced the industry's first 600V GaN (Gallium Nitride)-based, low-profile PQFN products and the expansion of its product portfolio in the industry-standard TO220 packages. This follows the introduction of its GaN-on-Silicon transistor family at APEC 2013 as the industry's first JEDEC-qualified 600V GaN device platform. Transphorm's 600V GaN HEMTs (high electron mobility transistors) utilize the company's patented, high-performance EZ-GaN™ technology that combines low switching and conduction losses, reducing the overall system energy dissipation up to 50% compared with using conventional silicon-based power conversion designs.

The new PQFN products, TPH3002LD and TPH3002LS, are offered in widely-used, low-profile PQFN88 packages and feature 290 mΩ $R_{DS(on)}$, 29 nC Q_{rr} and low inductance for superior high-frequency switching capability. The PQFN88-packaged "LD" devices also feature a kelvin connection to better isolate the gate circuit from the high-current output circuit to further reduce EMI.

In addition, the TPH3002PD and TPH3002PS TO220-packaged 600 V GaN HEMTs have been released for use in smaller, lower power applications such as adapters and all-in-one computer power supplies. These devices also feature 290 mΩ $R_{DS(on)}$, 29 nC Q_{rr} and high- frequency switching capability.

www.transphormusa.com

600V Super Junction MOSFET DTMOS IV-H Series

Toshiba America Electronic Components, Inc. has introduced a series of high-speed switching type super junction MOSFETs. The new DTMOS IV-H series consists of the TK31N60X, TK39N60X and TK62N60X, and is based on Toshiba's fourth generation 600V super junction MOSFET DTMOS IV series. Using Toshiba's single epitaxial process, the new DTMOS IV-H series of super junction MOSFETs is suited to applications that require high reliability, power efficiency and a compact design, such as high efficiency switching power supplies for servers and telecom base stations; and as power conditioners for photovoltaic inverters. The series achieves a high speed switching performance while keeping the low ON-resistance level of conventional DTMOS IV - all without loss of power. This is accomplished through the reduction of parasitic capacitance between Gate and Drain, which also contributes to improved power efficiency and downsizing of products.

www.toshiba.com

Embedded Motor Control Software IP for Critical Applications

Alizem announced the release of its new Embedded Motor Control Software IP for Critical Applications based on a technology invented and developed at the Canadian Space Agency (CSA). This solution is meant to work with BLDC and PMSM motors operating in applications where energy-efficiency and reliability are critical. It offers significant benefits to inverter-fed electric motor drive system designers:
Optimal management of phase current distribution lowering losses and enhancing maximum achievable torque and speed by 20% leading to lower motor rating, weight, space and cooling requirements
Ripple-free torque leading to reduced mechanical stress, velocity fluctuation, noise and higher reliability and tracking accuracy in servo applications
Automatic fault recovery from a phase winding failure and/or phase voltage/current saturation
Capability to provide critical information regarding motor health to master system (M2M, machine-to-machine)
Easy-to-use application programming interface (API) for quick and safe operation including multiple debug modes for power stage, transducer and system protection verification for early bug detection
This software can be ported and run on any type of electronic device that fits motor control applications and integrated into new or existing electric motor drive systems.

www.alizem.com

www.asc-csa.gc.ca/eng/industry/ipmtt

TE Connectivity

CLOUDSPLITTER Connector System and Cable Assemblies

Single cable solution for devices requiring data and power. Combines Cat5e performance and 250W of power

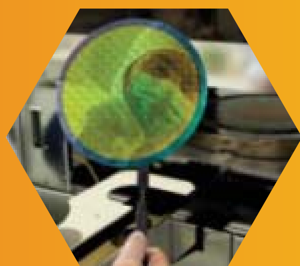
TE Connectivity introduces the new CLOUDSPLITTER connector system and Jack. The CLOUDSPLITTER connector system is a single cable solution for powered devices that delivers Cat5e performance and up to 250 watts of power over a single cable. The 8 position RJ45 jack is surface mountable and includes integrated LED indicator lights. The Jack accepts CLOUDSPLITTER or standard RJ45 shielded plugs and provides DC power at 5A up to 50VDC over two integrated power contacts.

- Achieve both Cat5e and DC power in one shielded or unshielded connection
- SMT jack accepts either standard RJ45 shielded plug or CLOUDSPLITTER plug assembly supporting easy retrofit
- Shielded SMT jack and cable plug
- Pre-terminated cable assemblies in standard lengths for all applications
- Meet market requirements with ROHS/REACH compliant design
- Achieve protection requirements and equipment compliance with regulatory safety certification of UL 1863 and UL444 cable with CM rating

www.ttieurope.com/te-cloudsplitter

CLOUDSPLITTER, TE Connectivity and TE connectivity (logo) are trademarks.

TE connectivity Authorized Distributor



Energy-Conserving Fibre Optic Transmission Modules

Toshiba Electronics Europe (TEE) has announced four new additions to its line-up of TOSLINK™ fibre optic modules. The new TOxX1350-series supports signal transmission from direct current (DC) or any datarates up to 10Mb/s. Transmission distances of up to 100m are achieved by Toshiba's latest APF (all plastic fibre) TOSLINK devices. As applications related to renewable energy are increasingly sensitive to losses in the generation and storage process, the new TOSLINK modules have been optimised to ensure low power consumption.

Toshiba's TOSLINK is a data transmission system that utilizes optical signals in place of electrical signals. TOSLINK does not emit any electromagnetic noise, and performs more reliably than electrical data transmission, as the optical cable is not susceptible to electromagnetic interference. The new TOSLINK models enable high speed, long distance and low consumption current optical communications, making them well-suited for transmission of control signals in energy sensitive applications including wind and photovoltaic power generation systems, control devices, battery controllers and various industrial devices.

Utilizing an original high-power, high-reliability red LED the new TOTX1350 transmitter products can be driven using low currents. Transmission distances of 40m to 100m can be achieved with a drive current of only 6mA. It is even possible to operate the transmitter with a drive current of only 1.5mA to achieve transmission distances between 0.2m and 50m. This drive current is 90% lower than that of existing TOSLINK products[1].

www.toshiba-components.com

Low Power DIN Rail Dc-Dc Converter Family in a Slim Package

CUI Inc announced a compact DIN rail dc-dc converter line to ease installation in industrial environments.

The converter family is housed in a slim 76 x 31.5 x 25.8 mm (2.99 x 1.24 x 1.02 in) DIN-Rail package with all electrical connections easily accessible via screw terminals.

It has been designed for applications where the convenience of DIN rail mounting is required, such as industrial equipment, mobile equipment, and telecom base stations. The family's 47 modules, across three series - PYB10-DIN, PYB15-DIN, and PYB20-DIN – have an output range of 10~20 W.

Available input ranges of 9~36 Vdc or 18~75 Vdc make the units ideally suited to battery-driven applications, where charging and discharging conditions require a wide input range. The devices' -40° to +85°C operating temperature range also allows the series to work reliably in harsh environments. For applications where power consumption is a concern, the PYB series delivers efficiencies reaching 91%.

The PYB family is available in single output (3.3, 5, 12, 15, or 24 Vdc), dual output (±5, ±12, or ±15 Vdc), and in 15 and 20 W versions, triple output (3.3/±12, 3.3/±15, 5/±12, or 5/±15) models. Outputs are fully regulated to within ±0.5% for overall line input conditions and ±1.0% for all load conditions. Input to output isolation of 1,500 Vdc is provided across the range of models.

Single output 15 W and 20 W models offer an output trim that allows ±10% nominal output adjustment. All parts include a remote on/off feature. Protections include continuous short circuit, over current and over voltage. The PYB series meets CISPR22/EN55022 Class B standards with limited external components. An optional heat sink is also offered on most models for improved thermal performance.

The PYB10-DIN, PYB15-DIN, and PYB20-DIN Series are available now through distribution starting at $ 37.51 for 100 pieces. Please contact CUI for volume pricing.

www.cui.com

PowerBlox™ DC-DC Regulators Offer 0.1% Line Reg

Exar Corporation (NYSE: EXAR), introduced a new line of high-power switching regulators to add to its popular PowerBlox™ family of DC-DC converter products. The XR76108, XR76112 and XR76115 are Synchronous Step Down Regulators supporting point-of-load (POL) supplies of 8A, 12A and 15A, respectively. The XR761xx family is designed to achieve excellent transient response and output accuracy using Exar's proprietary emulated current mode Constant On-Time (COT) control loop. These devices deliver core voltage rails for ASICs, FPGAs, DSPs and Network Processors in communications, networking and industrial markets.

The XR761xx family is specified with a wide input voltage range of 4.5V to 22V and delivers an adjustable output voltage from 0.6V to 18V. With its exceptional 0.1% line regulation across the entire input voltage range and 1% output accuracy over full temperature range, XRP761xx provides increased headroom to engineers for easier design implementations.

http://www.exar.com

Ultra Compact, Highly Efficient Three-Level Power Module

Vincotech, a supplier of module-based solutions for power electronics, has unveiled the new flow3xMNPC 1 modules featuring three mixed-voltage NPCs in a single flow 1 housing. Developed for 1200 V solar three-phase inverter applications, they enable engineers to design compact, space-saving inverters with excellent efficiency ratings. The flow3xMNPC 1 module performs remarkably well, achieving around 98.7% efficiency in typical 16-kHz solar applications.

Measuring 82 mm by 38 mm and 12 or 17 mm in height, these modules support three phases in one flow 1 housing. They are equipped with 1200 V IGBT4 HS3s (high speed) in the half bridge and 600 V IGBT3s with low saturation voltage and ultra fast Stealth™ diodes in the neutral path.

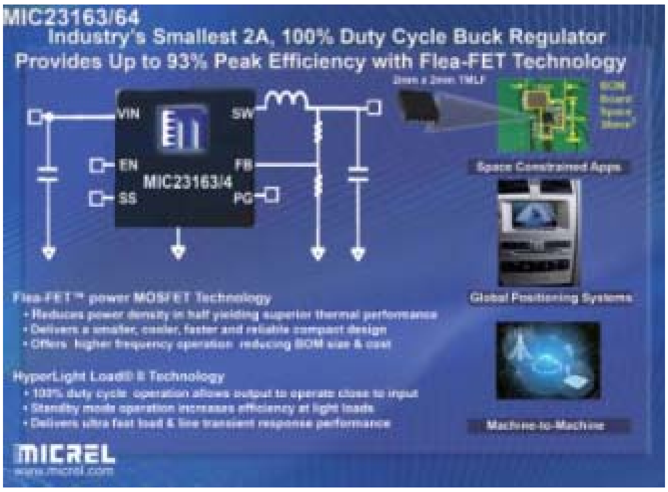
The new modules are actually dual-module solutions that combine a booster and three-phase inverter, which makes them a superior option for smaller inverters where space is limited and a small footprint is necessary. What's more, rather than using a common emitter that requires seven power supplies, the M74x topology features a common collector configuration, thereby reducing the number of power supplies for the gate driver to five.

The IGBTs in all modules are equipped Kelvin Emitters to boost switching performance and an NTC for measuring temperature. Our VincotechISE simulation tool provides flow3xMNPC 1 simulation models.

http://www.vincotech.com/flow3xmnpc-1

High Performance, 4MHz, 2A DC/DC Converter with 100 Percent Duty Cycle

Micrel, Inc. introduced the MIC23163/MIC23164, a 4MHz, DC-DC converter capable of delivering up to 2A in a small 2mm x 2mm package. These switching regulators operate from 2.7V to 5.5V with the capability of operating up to 100 percent duty cycle, allowing them to be used in multiple applications such as powering power amplifiers, solid state drives, mobile computing devices, cellular modems, and other space constrained point-of-load applications. Utilizing Micrel's patented Flea FET™ technology and Hyperlight Load™ control architecture, these devices can operate up to 4MHz with excellent light and full load efficiency. They provide an ultra-fast load transient response which minimizes output capacitance and reduces overall solution size and cost. The MIC23163/MIC23164 are available in volume quantities with 1,000 quantities pricing starting at $1.10.



The MIC23164 also incorporates an internal switch to discharge the output capacitor when the device is shut down. These devices ensure safe startup into a pre-biased output and are specified to operate from -40°C to +125 °C. They come in a 10-pin 2.0mm × 2.0mm Thin DFN package.

www.micrel.com.

IGBT Driver Cores with Space-Saving, Cost-Effective SCALE™-2+ Technology

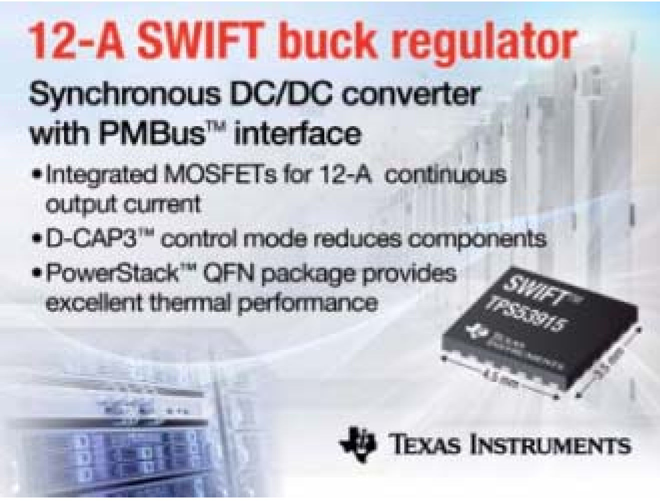
IGBT driver manufacturer CT-Concept Technologie GmbH, a Power Integrations company, has announced shipments of its first products to include its SCALE™-2+ gate driver chip set. The new SCALE™-2+ technology enables soft shutdown (SSD) to be implemented in the event of a short circuit without requiring additional components. This is particularly beneficial in applications with low stray-inductance where full Advanced Active Clamping – a method invented by CONCEPT for shutting down IGBTs or MOSFETs in a controlled manner under any circumstances - may not be necessary.

CONCEPT's well-established SCALE™-2 IGBT driver cores deliver cost, performance, size and reliability benefits. SCALE™-2+ driver technology offers high levels of integration by including an integrated trigger mechanism which limits IGBT MOSFET Collector-Emitter, or MOSFET Source-Drain voltages in the event of a short circuit.

www.IGBT-Driver.com

Industry's Highest Efficiency and Lowest Standby Power Consumption for AC/DC Supplies

Texas Instruments introduced two flyback power solutions that achieve the highest energy efficiency and lowest standby power consumption for 5- to 100-watt AC/DC power supplies. The UCC28910 700-V flyback switcher and UCC28630 high-power, Green-Mode con-

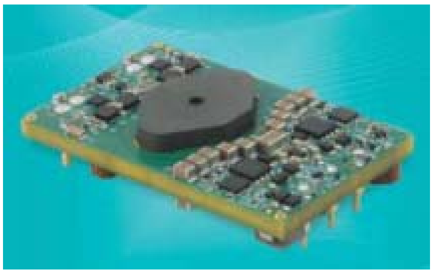


troller expand TI's leading portfolio of flyback controllers covering the complete power range of AC/DC adapters and power supplies used in personal electronics, printers, white goods and smart meters.
Combining high density with high efficiency, TI's UCC28910 switcher with integrated high-voltage power MOSFET achieves the industry's best stand-by power consumption for 5- to 10-W designs and features the lowest constant-current output tolerance of 5 percent, providing an accurate, maximum current across different input voltages. Additionally, the UCC28630 controller's ability to support primary side regulation (PSR) technology improves reliability in 10- to 100-W power supplies.
The UCC28910 achieves 80 percent average efficiency in 7.5-W designs and 78 percent efficiency at a 10 percent load. The UCC28630 achieves greater than 88 percent average efficiency in 65-W to 130-W designs, and industry-best 87 percent efficiency at a 10 percent load.
Lowest stand-by power consumption: Meets and exceeds European Commission (EC) standby regulations, including the IPP 5-star mobile charger rating of less than 30-mW power performance for no-load, stand-by power and the EC Code of Conduct (Tier 1 and 2) for 5- to 10-W designs (UCC28910) and for 30-W designs (UCC28630).

www.ti.com

Solus Topology the Next-Gen Intermediate Bus Converter Delivering 720 W in a Quarter Brick

CUI Inc has introduced its second-generation high density isolated intermediate bus converter (IBC) family - the NQBS series. The family has been specifically created to address the rising power requirements and efficiency demands in telecom systems and data centers.
Launched at the Applied Power Electronics Conference (APEC) in Fort Worth, Texas, the NQBS modules are housed in a quarter brick package and deliver a power density of 27.2 W/cm³ (445 W/in³) as well as efficiencies in excess of 96%.
These IBC devices are among the first to incorporate the company's Solus® Power



Topology, which delivers a greater power density, higher efficiency, faster transient response, and lower EMI in both isolated and non-isolated dc-dc converter designs.
Additionally, CUI has incorporated full regulation across the entire 42~60 Vdc input range and a droop load share feature with 10% current share accuracy for higher power boards.
As part of CUI's Novum Advanced Power® portfolio, the 720 W NQBS series outputs 12 Vdc @ 60 A in an industry standard DOSA footprint (58.4 x 36.8 x 12.3 mm - 2.30 x 1.45 x 0.485-inch) and provides input to output isolation of 2250 Vdc.
Additional features include insulation that meets EN60950 standards, remote on/off control, and an optional heat sink for improved thermal performance.

http://www.cui.com

DS2000A-S Series Digital Oscilloscope

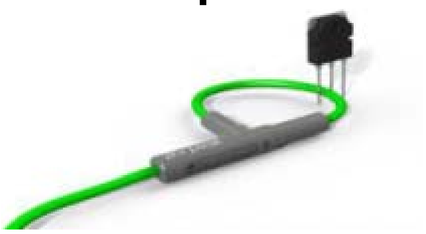
RIGOL Technologies EU GmbH introduced the DS2000A-(S) series digital oscilloscope with lots of breakthrough technologies, ranging from the analog front end to the trigger

unit. It delivers superior performance and functions in its class. Designed to reduce test time in research, development and failure analysis applications, Rigol's DS2000A-(S) series digital oscilloscopes make detecting signal and device characteristics easier than ever with comprehensive trigger functions, advanced hardware based real time waveform records, replay, search and analysis functions.
Rigol's DS2000A-(S) series represents feature-rich Digital Oscilloscopes at a bandwidth from 70MHz to 300MHz. The specially designed analog front end delivers a lower noise floor and a wider vertical range (500 uV/div to 10 V/div) at full bandwidth. It's the best choice for customers who want to do small signal tests or large signal tests or both.
DS2000A-S Series oscilloscopes are available in 70 MHz, 100 MHz, 200 MHz, 300 MHz and 2 channels varieties. New 1MOhm/50 Ohm input impedance is switchable.

www.rigol.com

www.rigol.eu

Unveil Next-Generation Rogowski CWT Current Probes at PCIM Europe



In addition to its full range of Rogowski waveform transducers, probes and industrial sensors, which includes the CWT and RCT ranges, Power Electronic Measurements (PEM UK) Ltd will be using this year's show to launch its next-generation CWT current probes for high-speed and high power-density applications.

Clip-on Rogowski current probes provide a convenient and accurate means of measuring alternating currents. PEM's latest wideband probes use an innovative shielding technique to eliminate the effects of high field strengths in today's high power-density and high-speed circuits.

Dr Chris Hewson, PEM's Managing Director, will also be introducing the new probes during his Vendor presentation on 'Next Generation Rogowski Current Probes' on Tuesday, 20th May 4.00 – 4.20pm.

PCIM Nuremberg, 20 – 22nd May, 2014; Hall 7-Stand 152

www.pem-uk.com

HO 6, 10 and 25-P Current Transducers Offer More Flexible Mounting in Small Packaging

LEM has added three new members to its HO series of PCB-through-hole mounting current transducers, which provide an aperture of 8 x 8 mm to carry the primary conductor under measurement, extending the options for this form-factor. The new models, for 6, 10 or 25 A nominal measurements of DC, AC, and pulsed signals benefit from the revised LEM Open-loop Hall-effect ASIC (Application Specific Integrated Circuit) introduced several months ago with the launch of the HO 8, 15 and 25-NP & –NSM models.

Using the latest LEM-developed ASIC, combined with Open-loop Hall-effect technology, the new devices meet the demand for high performance and quality at a lower cost.

The HO 6, 10 and 25-P models' offset and gain drift are twice as accurate (over the temperature range -25 to +85°C) as the previous generation. A high level of insulation between primary and measurement circuits, due to the high clearance and creepage distances of more than 8mm and a CTI (comparative tracking index) of 600, allows a test isolation voltage of 4.3 kV_{RMS}/50Hz/1min.

In addition, the HO xx-P series delivers better performance in other areas such as response time, power supply and noise, allowing the development of more technically advanced power electronics applications.

The transducers require a PCB mounting area of only 2.88cm^2 and weigh only 10g. They can measure up to 2.5 times the primary nominal current but also incorporate an additional pin providing an over-current detection set at 2.63 x the nominal current I_{PN} (peak value). The products also provide fault reporting in the case of memory contents being corrupted. LEM's HO xx-P transducers operate from a single supply voltage at 3.3 or 5V.

The new range delivers its output as a scaled analogue voltage; in most systems this will be converted to a digital value by an analogue/digital converter (ADC) which requires a reference voltage. The HO xx-P series can also be configured to make measurements relative to an external reference.

LEM's HO xx-P models are ideal for a range of applications where mounting flexibility offered by the aperture and a small size is needed, such as in solar combiner boxes and solar-power inverters, as well as small smart meters, variable speed drives, uninterruptible and switch-mode power supplies, air conditioning, home appliances, static converters for DC motor drives, and robotics.

The transducers are CE marked, conform to the EN 50178 standard and are recognised for industrial applications with a wide operating temperature range of -40 to +105°C. LEM offers a five-year warranty for each transducer.

www.lem.com

Automotive Motor Driver is AEC-Q100 qualified

Microchip announces the **MCP8063** - a highly integrated, cost-effective, automotive AEC-Q100-qualified motor driver that delivers superior performance in a small, 8-pin, 4x4 mm DFN package. It is also the world's first to combine all of those features with 1.5A peak phase current for the 180-degree sinusoidal drive of a variety of three-phase brushless DC motor and fan applications. This integration reduces cost and PCB area, and the high sinusoidal-drive performance provides high efficiency, low acoustic noise and low mechanical vibration for energy savings and quiet operation. Additionally, the MCP8063 includes safety features such as thermal shutdown, over-current limiting and lock-up protection.

The designers of a broad range of motor applications in markets such as the automotive, IT, industrial and home-appliances are faced with increasing regulatory and consumer demands for continued reductions in cost, space, noise and power consumption, with better performance and safety. The integrated features of the MCP8063 motor driver solve these problems cost-effectively, while providing a wide operating temperature range of -40 to +125-degrees Celsius. Additionally, it supports the sensorless driving of BLDC motors, which eliminates the cost and space of a Hall sensor.

The compact MCP8063 is a high-performance motor driver which offers high current and a wide temperature range to provide a complete single-chip solution for a wide variety of three-phase, brushless DC applications at attractive price points.

The MCP8063 motor driver works stand-alone or in conjunction with Microchip's large portfolio of PIC® microcontrollers and dsPIC® digital signal controllers. This offers a high degree of flexibility for everything from simple voltage control to closed-loop motor speed control using high-performance algorithms, such as sinusoidal sensorless drive.

To enable development with the new MCP8063 motor driver, Microchip also announced the MCP8063 12V 3-Phase BLDC Sensorless Fan Controller Demo Kit (ADM00575), which is available today, priced at $49.99 each. Additionally, this tool comes with a user-friendly configuration GUI. Microchip also supports its motor-control and driver portfolios with a full range of development solutions, including firmware, algorithms, application notes, development tools, evaluation boards, and reference designs.

The MCP8063 motor driver is available today for samples and volume production.

http://www.microchip.com/get/JMXV

Ultimate in Standby Performance

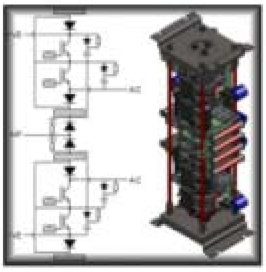
Power Integrations announced a reference design for an 8 W, universal-input auxiliary power supply that achieves zero standby power consumption** for appliance applications. Based on a member of Power Integrations' LinkZero™-LP family of ICs, DER-417 describes a universal-input, 5 V, 1600 mA flyback power supply that consumes less than 4 mW at 230 VAC and provides 1 mW of power in standby mode.

Products such as TVs, appliances, security and monitoring systems and HVAC equipment use power while waiting to be used or while monitoring sensor inputs prior to executing their proper functions. This wasted power amounts to both an environmental cost and an economic cost to households and businesses; in fact, Lawrence Berkeley National Laboratory has estimated that standby power accounts for 5-10% of residential electricity use in developed countries, and is responsible for approximately 400 million tons of global CO2 emissions each year.

www.powerint.com/sites/default/files/PDFFiles/der417.pdf.

High Megawatt 3-level Press-Pack IGBT Inverter Stacks

XYS UK, IXYS Corporation's high power subsidiary, reported wide ranging customer interest in the recent introduction of a range of standard three-level press-pack IGBT phase leg stacks with power rating up to 16 Megawatts.



IXYS UK Westcode Ltd. has introduced a range of standard three-level press-pack IGBT phase leg stacks with power rating up to 16 Megawatts. The new stack designs are available for applications at three voltage levels 3.3kV, 6.6kV and 10kV and incorporate IXYS UK's market leading press-pack IGBT technology.

The stack designs are available for applications at three voltage levels 3.3kV, 6.6kV and 10kV and incorporate IXYS UK's market leading press-pack IGBT technology. The 3.3kV option is available as a single stack, comprising a complete phase leg of four 2400A press-pack IGBTs plus the anti-parallel and neutral point clamp diodes. The phase leg is rated at 8MW.

Both the 6.6kV and 10kV solutions comprise discrete stacks of 1600A reverse conducting press-pack IGBTs and fast diode which can be configured into the phase leg. Each phase leg would require 2 IGBT stacks and 1 diodes stack. The 6.6kV stacks are rated at up to 12MW and the 10kV units are rated up to 16MW. The 6.6kVstack comprise four series devices and the 10kV stacks six. Actual power ratings will depend on how the customers configure their control system.

Each system benefits from direct water cooling to provide highly effective heat dissipation away from the devices and pre-loaded disc spring clamping to evenly distribute the applied force across the entire surface area of the device. Stacks use an isolated clamping rod system to limit the occurrence of eddy currents within the unit. The IGBT stacks also incorporate gate trigger boards and snubber circuits.

"IXYS UK has been receiving extensive and wide ranging interest for these new introductions, with potential applications ranging from renewable energy to marine applications. Only two months after launch we have several customers close to committing to their first orders as they identify this as a fast track to very high power development," commented Frank Wakeman, IXYS UK's Marketing and Technical Support Manager.

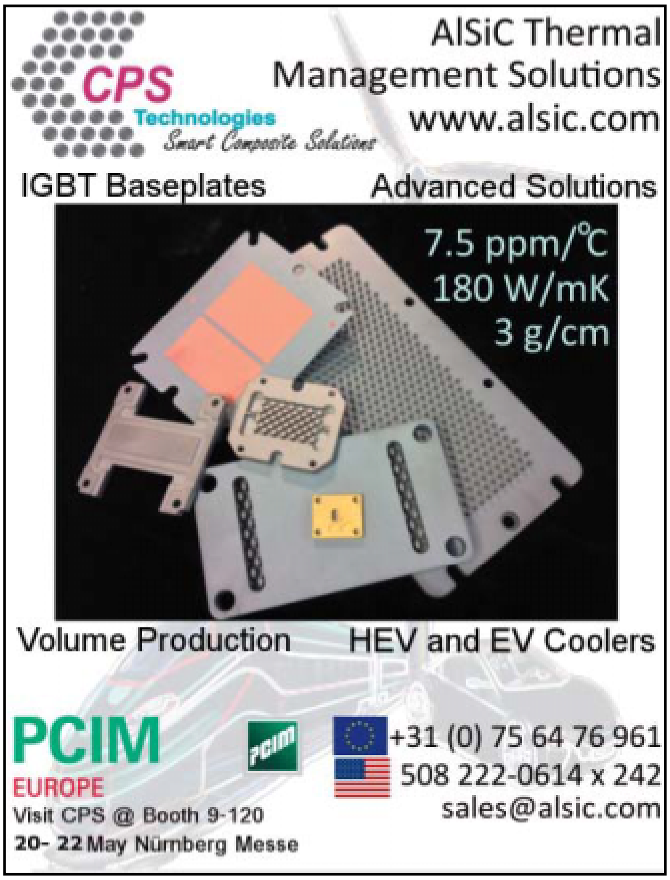
Stack part numbers are: 3.3 kV unit XA1600GV45WT, 6.6kV units XA1000GV45WT/B (IGBT) and XA1000TV45WE/B (diode) and 10kV units XA1000GV45WT/A (IGBT) and XA1000TV45WE/A (diode).

The stacks are targeted for both production and project development allowing quicker access to prototype completions after which IXYS UK can either continue to supply a stack customised to a particular specification or the components kits to fit a customer's own design. Typical applications include medium voltage drives for industrial, marine and renewable energy infrastructure applications including wind generation, plus very large drives for use in the oil, gas and steel industries.

For applications such as electrical grid control switches and HVDC applications, please contact IXYS UK to discuss other circuit topology stack solutions.

For further information please contact IXYS UK at (email: sales@ixysuk.com) or telephone: +44 (0)1249 444524 for quotation.

www.ixysuk.com

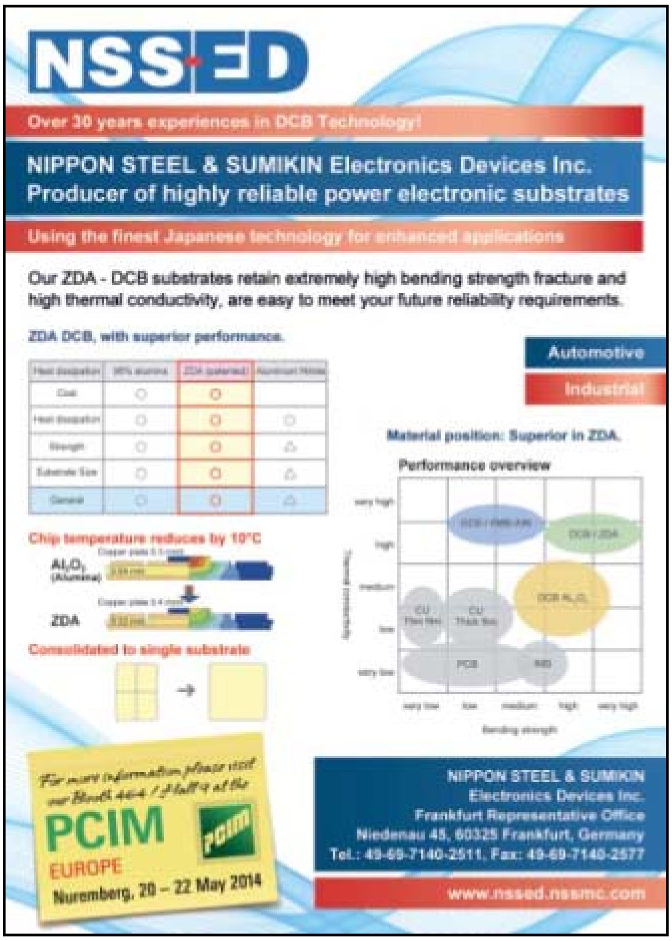


Half- and Full-Bridge Drivers to Extend Battery Life

Intersil Corporation (NASDAQ: ISIL), a leading provider of innovative power management and precision analog solutions, announced the industry's first small form factor half-/full-bridge drivers that significantly extend power usage and overall product life of multi-cell lithium ion (Li) battery devices operating from 5V to 50V. The new HIP2103

and HIP2104 bridge drivers have a configurable topology to enable half-bridge, full-bridge and three phase motor-driven applications. They provide an innovative safety feature that prevents voltage kickback, which is the leading cause of damage and deterioration of Li batteries. The HIP2103/04 bridge drivers extend battery life through a unique power management method enabling the industry's lowest sleep mode current to minimize power consumption when the device is not in use or in stand-by mode. In addition, the HIP2104 includes integrated Linear Regulator LDOs to enable direct bias from the battery and an integrated bootstrap FET, which eliminates the need for external diodes.

www.intersil.com/hip2103



High Power Ultra-Low-Ohmic Shunt Resistors

has recently announced the development of high power ultra-low-ohmic shunt resistors ideal for current detection in applications with increased power requirements, such as automotive systems and industrial equipment. The new PSR series includes PSR400, which is rated at 4W, and PSR500, guaranteed up to 5W.

Resistors in current detection applications are typically used to detect overcurrent conditions or remaining battery level. And although current sense resistors have been widely adopted in the automotive and industrial sectors, the recent trend towards greater sophistication and computerization has increased current requirements, leading

to a need for high power components. This includes a demand for high accuracy resistors with superior temperature coefficient of resistance (TCR) for stable operation in extreme temperature environments and that feature ultra-low resistance values in order to minimize power consumption.

In response, ROHM utilized high quality resistor technology cultivated for the low-power sector to develop a new lineup of high power low-ohmic shunt resistors. And high-yield precision welding technology made it possible to guarantee high rated power in the 5W class, while a high-performance alloy was adopted in the resistive metal for superior TCR in the low-ohmic region. This ensures sufficient margin even in applications with stringent temperature requirements, such as automotive systems and industrial equipment, while lightening design load.

www.rohm.com

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Specifications

Package	B_{VDSS} (V)	ID @25°C (A)	$R_{DS(on)}$ max @Vgs = 10V (mΩ)	Qg@ Vgs = 10V (nC)	Part Number
PQFN 5x6	25	100	0.95	56	IRFH8201TRPbF
	25	100	1.05	52	IRFH8202TRPbF
	30	100	1.1	58	IRFH8303TRPbF
	30	100	1.3	50	IRFH8307TRPbF
	40	100	1.4	134	IRFH7004TRPbF
	40	85	2.4	92	IRFH7440TRPbF
	40	85	3.3	65	IRFH7446TRPbF
DirectFET Med.Can	30	192	1.3	51	IRF8301MTRPbF
	40	90	1.4	141	IRF7946TRPbF
	60	114	3.6	120	IRF7580MTRPBF
D²-Pak	40	195	1.8	150	IRFS7437TRLPbF
	40	120	2.8	90	IRFS7440TRLPbF
	60	120	5.34	86	IRFS7540TRLPbF
D²-Pak 7pin	40	195	1.5	150	IRFS7437TRL7PP
	60	240	1.4	236	IRFS7530-7PP
D-Pak	40	90	2.5	89	IRFR7440TRPbF
	60	90	4	86	IRFR7540TRPbF
TO-220AB	40	195	1.3	300	IRFB7430PbF
	40	195	1.6	216	IRFB7434PbF
	40	195	2	150	IRFB7437PbF
	40	120	2.5	90	IRFB7440PbF
	40	118	3.3	62	IRFB7446PbF
	60	195	2.0	274	IRFB7530PbF
TO-247	40	195	1.3	300	IRFP7430PbF

Features:

- Ultra low $R_{DS(on)}$
- High current capability
- Industrial qualified
- Broad portfolio offering

Applications:

- DC Motors
- Inverters
- UPS
- Solar Inverter
- ORing or Hotswap
- Battery Packs

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