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Short Descriptions Proceedings

HV-SiC-MOSFET

3.3 kV/450 A Full-SiC nHPD2 (next High Power Density Dual) with Smooth Switching
Takashi Ishigaki, Seiichi Hayakawa, Tatsunori Murata, Toshio Nozoe, Hidekatsu Onose, Hiroshi Miki, Masakazu Sagawa, Tetsuo Oda, Kan Yasui, Daisuke Kawase, Yuji Takayanagi, Renichi Yamada, Hitachi Power Semiconductor Device, J; Toru Masuda, Naoki Tega, Kumiko Konishi, Ryusei Fujita, Hiroyuki Matsushima, Akio Shima Hitachi, J; Katsuaki Saito, Hitachi Europe, GB
We have developed a 3.3 kV/450 A full-SiC nHPD2 (next High Power Density Dual). The extremely low internal inductance of the package can make the best use of full-SiC. We demonstrated a fast and smooth switching of the module. We also showed superior output characteristics of the full-SiC module in traction inverter simulation with considering the reverse conduction of the module accurately.

Characterization of 3.3kV and 6.5kV SiC MOSFETs
Takui Sakaguchi, Masatoshi Aketa, Takashi Nakamura, ROHM, J; Masaharu Nakanishi, ROHM Semiconductor, D; Munaf Rahimo, ABB Switzerland, CH
Over 3.3kV SiC MOSFET is the promising technology for further contribution to the low energy consumption society. We fabricated 3.3kV and 6.5kV SiC MOSFET and demonstrated static and dynamic characteristics and avalanche capability. We will present the detail of those characteristics at the conference.

Dynamic Characterization of Next Generation Medium Voltage (3.3 kV, 10 kV) Silicon Carbide Power Modules
Ty McNutt, Jonathan Hayes, William A. Curbow, Daniel Martin, Brett Sparkman, Kraig Olejniczak, Ajith Wijenayake, Wolfspeed, USA
This paper focuses on dynamic analysis of Cree's new high-performance 3.3 kV & 10 kV all-SiC power modules, based on the third generation SiC MOSFET technology. A clamped inductive load test is utilized to analyze switching events across multiple system variables including: bus voltage, switched current, and gate resistance. This work demonstrates the superior performance of high-voltage SiC MOSFETs / power modules for a variety of different medium to high voltage applications.

3.3kV All-SiC Power Module for Traction System Use
Tetsu Negishi, Ryo Tsuda, Kenji Ota, Shinichi Iura, Hiroshi Yamaguchi, Mitsubishi Electric Corporation, J
Mitsubishi developed ahead of others 3.3kV All-SiC power module of practical use for its system composed of SiC-MOSFET and SiC-SBD. The total power loss of newly developed 3.3kV All-SiC power module is significantly reduced by 59% compared to conventional Si power module. In addition, the inverter operation reliability of developed 3.3kV All-SiC power module is confirmed by durability performance test with H bridge circuit as actual railcar traction system.

Power Converters with Wide Bandgap Devices I

Two-Switch Quasi-Resonant Flyback Converter with SiC Switches
Stefan Schmitt, Watts & Bytes, F; Jens Marten, BLOCK Transformatoren, D
An existing three-phase input power supply with a nominal output power of 240 W is reduced in size by increasing the switching frequency and utilizing SiC switches. The results shown are obtained using a practical approach which meets safety regulations. A novel gate drive circuit is introduced which allows to narrow the cost increase down to the SiC components.

Characterization of 1.7 kV SiC MOSFET Modules for Medium/High Power Current Source Inverter in Photovoltaic Applications
Luis Gabriel Alves Rodrigues, Jérémy Martin, Stéphane Catellani, Commissariat à l´Énergie Atomique et aux Énergies Alternatives, F; Jean-Paul Ferrieux, G2Elab, F
The pros and cons of SiC technology have been shown in literature, especially regarding voltage source inverter operation. Nevertheless, there is a lack of studies concerning the switching process in current source inverter structures. The purpose of this paper is to study and discuss the switching characterization of a novel 1.7 kV full-SiC MOSFET module for current source inverter suitable for large-scale photovoltaic applications. Besides that, two SiC MOSFET technologies are experimentally compared: D-MOSFET and U-MOSFET (Trench).

Power Loss Evaluation of 2.5 MHz High Frequency Inverter Based on Frequency Multiplying Method
Koji Orikawa, Satoshi Ogasawara, Hokkaido University, J; Jun-ichi Itoh, Nagaoka University of Technology, J
Nominated for the Young Engineer Award
This paper describes a 2.5 MHz high frequency inverter based on a frequency multiplying method. A proposed circuit consists of a five-phase inverter and multi-core transformers. An operation frequency of the five-phase inverter and multi-core transformer is 500 kHz which is one-fifth of an output frequency of 2.5 MHz. Therefore, the proposed circuit can realize high efficiency. In this work a power loss distribution is clarified based on theoretical analysis and experimental results.

Gate Driver Architectures for High Speed Power Devices in Series Connection
Jean-Christophe Crebier, Van-Sang Nguyen, Pierre LeFranc, , G2Elab, F
This paper shows the approach that can be applied to the conducted EMI optimization on the gate driver architecture of the power devices in series connection configuration. The simulation results and experimental results confirm the interest of the cascaded gate driver supply architecture. There is a compromise between the redesign of the power supplies and the conducted EMI perturbation of the gate driver architecture. Design guidance will be provided in the final paper.

Materials

Reliable Interconnection Technologies for High-Temperature Operation of SiC MOSFETs
Fabian Mohn, Chunlei Liu, Jürgen Schuderer, ABB Switzerland, CH
In this paper, a packaging concept for operation of SiC MOSFETs at temperatures of 200°C and beyond is presented. The concept is based on Ag-sintered chip front- and backside and Cu wire interconnection. The feasibility of the packaging concept for a SiC-based power module is demonstrated and high temperature storage, as well as active and passive thermal cycling tests are presented to verify the reliability of the proposed concept.
Sintering Copper Die-Bonding Paste Curable Under Pressureless Conditions
Hideo Nakako, Dai Ishikawa, Chie Sugama, Yuki Kawana, Motohiro Negishi, Yoshinori Ejiri Hitachi Chemical, J
The high thermal conductive and high reliable die-bonding material is highly required from the high temperature operating power modules. We are developing the sintering copper die-bonding paste that can cure without pressure. This die-bonding has characteristics of bonding-ability with Cu, Ni, Au and Ag, high thermal conductivity and high thermal cycle reliability. This is an ideal die-bonding material with good productivity, high thermal conductivity, high bonding reliability and reasonable cost.

Taking Power Semiconductors to the Next Level:Novel Plug & Play High Thermal Performance Insulated Molded Power Package
Christian Kasztelan, Thomas Basler, Manfred Mengel, Edward Fürgut, Infineon Technologies, D
Infineon has developed a novel plug & play insulated molded power package which enables highest power density by reliable thermal path from chip to application heatsink. The basic idea is to combine

the function of isolation & thermal grease in a high thermal conductive and electrically insulating layer at the package?s heat conducting side. This novel package type reduces the overall system complexity, assembly time and significantly material expenses for costly thermal grease or even thermal interface sheets.

Development of Thermal Fatigue-Tolerant Active Metal Brazing Substrates Using Highly-Thermal Conductive Silicon Nitrides with High Toughness
Hiroyuki Miyazaki, You Zhou, Kiyoshi Hirao, Shinji Fukuda, Noriya Izu, Hideki Hyuga, National Institute of Advanced Industrial Science and Technology (AIST), J; Shoji Iwakiri, Hideki Hirotsuru, Denka Company Limited, J
Newly-developed high thermal conductive silicon nitrides with high toughness was employed as the AMB substrate for the heat dissipating board. It exhibited superior thermal fatigue resistance under severe temperature cycle.

Sensorless Drives

Initial Rotor Position Determination of a Soft Starter Driven Synchronous Motor
Hauke Nannen, Heiko Zatocil, Siemens, D
Driving a permanent magnet synchronous machine directly on the power grid a soft starter is needed during start-up. For a sensorless start-up procedure, the initial rotor position must be known. This paper deals with a method for the determination and verification of the initial position. It is based on a pulsating current space vector in a predefined direction. During the machine's orientation the phase currents are utilized to monitor the correctness of the procedure.

A Robust Encoderless Predictive Current Control Using Novel MRAS Observer for Surface-Mounted Permanent-Magnet Synchronous Generators
Mohamed Abdelrahem, Christoph Hackl, Ralph Kennel, Technical University of Munich, D
This paper proposes a novel adaptation mechanism to replace the conventional fixed-gain PI controllerutilized in model reference adaptive system (MRAS) observer for estimating the rotor speed and positionof a permanent-magnet synchronous generator (PMSG). The proposed adaptation mechanism is basedon the finite control set-model predictive control (FCS-MPC) concept. Experimental results are presented toverify the feasibility of the proposed encoderless control method.

FPGA–based Sensorless Control of a PMSM at Low–Speed Range
Fernando David Ramirez Figueroa, Mario Pacas, University of Siegen, D; Cesar Gonzalez, Tecnologico de Monterrey, MX
Sensorless control schemes, based on fundamental wave models, have been exhaustively enhanced to operate at low speed ranges and are available in commercial drives. However, practical implementations fail to operate below certain frequency limits. This work examines the impact of current oversampling combined with the computational power of the FPGA in the behavior of models based on the fundamental wave equations of the machine. The proposed sensorless scheme is able to operate at a lower speed range without additional signal injection.

Application of a Position Sensorless Control to a Reluctance Synchronous Drive Including Flux Weakening
Matthias Hofer, Mario Nikowitz, Manfred Schrödl, Vienna University of Technology, AT
In this paper a position sensorless control is applied to a low cost industrial drive utilizing a synchronous reluctance machine with flux barriers. An additional system simplification and cost reduction is reached by sensorless methods to determine the angular rotor position from the machine inductances without any angular sensor. The presented drive is able to cover the whole speed range including standstill and flux weakening operation. Experiments with the physical prototype confirm the machine design and the sensorless operation.

Modular Multilevel Converter for High Voltage Applications

Four-Level MMC Cell Type with DC Fault Blocking Capability for HVDC
Viktor Hofmann, Mark M. Bakran, University of Bayreuth, D
In this paper a four-level MMC cell type with a DC fault blocking capability is presented and its functional principle is described. Furthermore, a detailed analysis on semiconductor losses is performed for different cell types and the resulting junction temperatures are calculated for each semiconductor by using a proven thermal model. Thus the maximum thermal admissible current and consequently the power transmission capability of each cell type is derived and compared along with selected features.

Virtual Submodule Applied to the Modular Multilevel Converter
Alexandre Christe, Drazen Dujic, EPFL - Ecole polytechnique fédérale de Lausanne, CH
This paper proposes a fast MMC cell loss calculation based on the virtual submodule (VSM) concept. Compared to other proposed tools, the impact of the circulating current control is taken into account. The proposed method provides a great flexibility and a significant reduction of the simulation / computational time otherwise needed to evaluate SM losses under various operating conditions.

IGCT based Modular Multilevel Converter for an AC-AC Rail Power Supply
David Weiss, Michail Vasiladiotis, Cosmin Bănceanu, Noemi Drack, Bjørn Ødegård, ABB Switzerland, CH; Andrea Grondona, ABB, SE
Nominated for the Best Paper Award
Nominated for the Young Engineer Award
In this paper, a comparisnon between IGBT and IGCT in modular multilevel converter for AC-AC rail power supply applications is presented. The comparison in this paper is done with respect to system aspects such as grid and converter failure behavior, protection and losses. Concerning losses this paper focusses on the AC-AC rail poer supply application. The converter failure behavior is discussed in genreal for all MMC applications. Finnaly measurements of the loss of cell behavior of the converter will be shown.

Development of A Full-Bridge Sub-Module for HVDC and STATCOM Markets
Jerome Perrier, Javier Chivite-Zabalza, Mike Boden, Tianning Xu, John Outram, GE's Grid Solutions, GB
A full-bridge sub-module addressing the needs of the HVDC and STATCOM markets is presented. The sub-module is the smallest repeating unit and the main building block of the HVDC and STATCOM MMC converters.
Particular emphasis is put on the design considerations behind this sub-module and also the type of tests that were completed to validate design choices.
With the addition of this full-bridge sub-module to the existing product portfolio, GE?s Grid Solutions is now able to offer to our customers a full spectrum of
technical solutions that addresses all their specific requirements.

SiC MOSFET

The new CoolSiC™ Trench MOSFET Technology for Low Gate Oxide Stress and High Performance
Dethard Peters, Thomas Basler, Bernd Zippelius, Infineon Technologies, D ; Thomas Aichinger, Wolfgang Bergner, Romain Esteve, Daniel Kueck, Ralf Siemieniec, Infineon Technologies, AT
A novel SiC trench MOSFET concept is described which balances low conduction losses with IGBT like reliability by designing the gate oxide stress low enough to fulfill requirements of industrial applications. Long term gate oxide tests reveal that the extrinsic failure rate can be confidently predicted to <1 ppm. Basic features of the performance of the 45 m ?/1200V CoolSiC? MOSFET are

presented. The favorable temperature behavior of the on-state makes the device easy to operate in parallel.

Short-Circuit Robustness of Discrete SiC MOSFETs in Half-Bridge Configuration
Nicolas Degrenne, Anthony Roy, Johan Le Lesle, Erwan David, Stefan Mollov, Mitsubishi Electric, F
This paper studies the short-circuit robustness of Silicon carbide power MOSFETs in half-bridge configuration. The energy repartition during short-circuit is inherently unstable and unequal, leading to the failure of one device before the other. The short circuit event before destruction typically lasts 50% longer in half-bridge configuration, compared to single-device short circuits. Different series of tests are realized to identify failure scenarios and mechanisms.

Design Rules To Adapt The Desaturation Detection For SiC MOSFET Modules
Teresa Bertelshofer, Andreas März, Mark-M. Bakran, University of Bayreuth, D
This paper presents an overcurrent and short-circuit detection method for high current SiC MOSFET-modules adapting the existing desaturation detection, which is state-of-the-art for IGBTs. These adjustments include separate detection paths for hard switching faults and fault under load as well as preventive gate clamping and soft shut down. Test results show reliable detection and shut down of overcurrent, HSF and FUL while not influencing normal switching behaviour.

Device Simulation Modeling of 1200 V SiC MOSFETs
Benedetto Buono, Martin Domeij, Kwangwon Lee, Krister Gumaelius, Jimmy Franchi, Fredrik Allerstam, Fairchild Semiconductor, SE ; James Victory, Mehrdad Baghaie Yazdi, Thomas Neyer, Fairchild Semiconductor, D
SiC MOSFETs for 1200 V rating were fabricated and used for comparing electrical measurements with device simulations. The MOSFET subthreshold characteristics were used for tuning the simulation model parameters for acceptor interface traps at the SiC/SiO2 interface. Good agreement between measurements and simulations was obtained for ID-VGS, ID-VDS, breakdown voltage and qualitative agreement was obtained for the reverse transfer capacitance.

Power Converter Design

Enhancing Power Density and Efficiency of Variable Speed Drives with 1200V SiC-TMOSFETs
Benjamin Sahan, Anastasia Brodt, Daniel Heer, Ulrich Schwarzer, Maximilian Slawinski, Tim Villbusch, Klaus Vogel, Infineon Technologies, D
Employing SiC-TMOSFETs to variable speed drives leads to a significant reduction in power losses even if dv/dt is reduced to 5kV/µs in order to use standard motors. This loss reduction enables lower system costs by reducing the cooling effort and thus downsizing the heatsink as well as lower operating costs due to higher energy efficiency. For a 22kW inverter the heatsink volume could be reduced by more than 50% and the calculated energy savings are 900kWh per year for a typical pump load profile.

Air Cooled SiC Three Level Inverter with High Power Density for Industrial Applications
Alexander Hensler, Thomas Bigl, Stephan Neugebauer, Stefan Pfefferlein, Siemens, D
Nominated for the Best Paper Award
Nominated for the Young Engineer Award
A dual three phase three level converter has been realized with the newest generation of SiC MOSFETs, a space saving embedding technology of power semiconductors, an optimized air cooling concept and a novel DC link configuration. The air cooled converter system has a high power density of 17,2 kW/l combined with an efficiency of 99,2%. With the new inverter design the volume could be reduced by a factor of six in comparison to a standard high performance Si-based converter.

Generic Approach for Design, Configuration and Control of Modular Converters
Lyubomir Kerachev, CMP, F; Yves Lembeye, André Andreta, Jean-Christophe Crebier, G2Elab, F
This paper deals with a generic method allowing the rapid design of power electronics converters. The proposed approach is based on the series and/or parallel association of generic power modules used to build up a complete modular conversion structure. A specific hierarchic configuration of the power modules is proposed to optimize the control and the regulation of the modular converter. A toolbox is developed to configure automatically the power modules and to implement current and voltage sensors where needed from specified electrical parameters. DC/DC and DC/AC power modules are developed and a DC/DC 24-12V 280W prototype operating in closed loop is realized to validate the approach.

Current Sensors

IGBT Gate Driver with Accurate Measurement of Junction Temperature and Inverter Output Current
Marco Denk, Mark-M. Bakran, University of Bayreuth, D
Nominated for the Best Paper Award
Nominated for the Young Engineer Award
This paper presents an advanced IGBT gate driver that includes a combined measurement of the IGBT junction temperature and the inverter output current. For this purpose, the conventional gate driver is expanded by two simple measuring circuits that determine the collector-emitter voltage and the on-chip internal gate resistor of the IGBT during the regular inverter operation. This combination of two different temperature sensitive electrical parameters enables accurate temperature and current measurement on driver level.

An Inverted Rogowski Coil: A High Speed, Wide-Band, Compact Current Transducer With High Immunity to Voltage Transients
Chris Hewson, Joanne Aberdeen, Power Electronic Measurements, GB
The paper presents a modification to previously published Rogowski coil design to achieve a small compact sensor, with a high speed, wide-bandwidth, high immunity to external voltage transients, which is better suited to measuring current in new faster switching semiconductor technologies.

Design of a 300 Amps Pulsed Current Source with Slopes up to 27 Amps per Nanosecond for Current Probe Analysis
Nathan Tröster, Dennis Bura, Julian Wölfle, Martin Stempfle, Jörg Roth-Stielow, University of Stuttgart, D
This paper presents the design of a pulsed current source with the ability to generate current impulses with an amplitude up to 300 amps and current slopes up to 27 amps per nanosecond.

New and Renewable Energy Systems

A 70 kW Next Generation Three-phase Solar Inverter with Multiple MPPTs using Advanced Cooling Concept and Stacked-PCB Architecture
Remi Freiche, Sebastian Franz, Stephan Liese, Marc Fink, Fraunhofer Institute ISE, D
The trend for three-phase solar inverters is heading to the 50 kW power class and beyond. However, for this application PCB-based inverters start to reach their limits due to the size of the electromechanical components. This paper presents a cost-effective 70 kW three-phase solar inverter with five MPP trackers achieving both high efficiency and power density. Using a stacked PCB architecture and a "hot core" cooling concept, a 500 W / dm^3 power density was achieved.

Enhanced Current Control Scheme for Large-Scale Solar Inverters
Tomomichi Ito, Akira Kikuchi, Haruo Nemoto, Masaya Ichinose, Masahiro Taniguchi, Hitachi, J

Tomomichi Ito is a senior researcher of Japanese manufacturing company, Hitachi, Ltd. He is leading 12 researchers working on renewable energy sources and several 10-MW FACTS systems. His speciality is the control theory of MW-scale grid connected inverters.

Improved Bias Supply Scheme for a Maximum Power Point Tracking Universal Topology for Low-Voltage Electromagnetic Harvesters in Battery Powered Applications
Mahmoud Shousha, Dragan Dinulovic, Martin Haug, Würth Elektronik eiSos, D
This paper presents an improved bias supply scheme for a universal topology that can be used with both ac and dc energy harvesters and provides maximum power point tracking (MPPT) at the same time. The improved bias supply scheme ensures providing a suitable bias supply voltage even if the harvester voltage is low allowing the topology to operate with very low-voltage harvesters. Experimental results are provided in this paper.

Special Session: Smart Grid & Communication

A New Configuration for a Grid Forming Converter in AC Islanded Microgrid
Hélio Antunes, Sidelmo Silva, Braz Filho, Reginaldo Ferreira, Danilo Iglesias Brandão, Federal University of Minas Gerais, BR
A MG is formed from microsources of electric power, loads and storage elements. One important converter in a MG with master-slave configuration is the grid former converter that generates a reference in voltage and frequency for isolated mode. This paper presents an analysis of an ac isolated MG composed of a new configuration for grid-forming converter called open-delta. The results show that even if the open-delta converter fails, the MG continues operating without power quality problems.

Design and Control of a DC Grid for Railway Stations
Sabah Siad, Gilney Damm, Paris Saclay University, F; Lilia Galai Dol, Alexandre de Bernardinis, EFFICACITY, F
Design and Control a direct courant Grid integrated in urbain railway station,the solution consist in recovring and storing trains breaking energy into a hybrid storage system and reusing it for non railway application such as loads in trains station like electric veheculs.The Objectifs are power flow management and voltage control of the DC MicroGrid to improve the dynamic performance of the system by controling the energy storage system.

Distributed Nonlinear Control for a MicroGrid Embedding Renewables, Train's Energy Recovery System and Storages
Alessio Iovine, Lilia Galai Dol, EFFICACITY, F; Elena De Santis, Maria Di Benedetto, L'Aquila University, I; Gilney Damm, Paris Saclay University, F
A low-level distributed nonlinear controller for a DC MicroGrid integrated in a Train Station is introduced in this paper. A number of elements are connected to the MicroGrid: two different transient time scale renewables (braking recovery and photovoltaic), two kinds of storage acting at different time-scale (a battery and a supercapacitor), and a load. The model is developed and a complete stability analysis is investigated: power balance and voltage grid stability requirements are both met. A "System of Systems" approach is utilized to develop the control laws for the DC/DC converters in order to fulfil the dedicated objective each controller has. Simulation results showing the desired grid behaviour are presented.

Reliability Enhancement of Modular Smart Transformers by Uneven Loading of Cells
Vivek Raveendran, Markus Andresen, Giampaolo Buticchi, Marco Liserre, University of Kiel, D
A Smart Transformer (ST) is a power electronics based transformer placed in the electrical distribution grid, where it can provide many advanced grid services. The advanced functionality comes with the concern of lower reliability affected by the complexity and the higher number of components. To overcome the reliability concerns, this work proposes to utilize a modular architectures by routing the

power in the cells such that cells with longer remaining lifetimes are stressed higher and the time to the next failure in the system is delayed.

Power Converters with Wide Bandgap Devices II

800 V Three-Phase LLC Series Resonant DC/DC Converter Using SiC MOSFETs
Yusuke Nakakohara, Hirotaka Otake, Ken Nakahara, ROHM, J; Tomohiko Yoshida, Mamoru Tsuruya, Power Assist Technology, J
This study presents how SiC MOSFETs can miniaturize a 5-kW DC/DC converter with LLC topology. The converter adopts a three-phase configuration and includes two types of magnetic transformers. Near 160-kHz switching frequency and 800 V input voltage are adopted. These technological combinations successfully miniaturize the power supply to a weight of 1.55 kg, including cooling fans. The power conversion efficiency reaches 98.1% at 5-kW operation.

The Destructive Energy Hidden in Supply Lines
Roland Kratz, Würth Elektronik, D
The Destructive Energy Hidden in Supply Lines: Approximately 1% of designers of switching regulators take the input lines into consideration. This means that 99% of switching regulator designs have the possibility of remaining energy on the input lines, which may affect the device negatively, lower the efficiency or destroy the switching regulator. High current oscillation can easily be overlooked because of the assumed low ripple voltage at the input cap due to the low ESR of mlccs in modern switching regulators.These oscillation can also couple into the regulation loop which irritates the developers who search for the reason within the loop and compensation networks. We will look behind this topic and detect what we can do to eliminate the risk of input line oscillations.

Optimization of a DCDC Dual Active Bridge Converter for Aircraft Application
Maximin Blanc, Yves Lembeye, Jean-Paul Ferrieux, G2Elab, F; Corentin Rizet, Sirepe, F; Arnaud Mahe, Taoufik Bensalah, Thales AES, F
Today, electricity is presented as the best energy vectore compared to hydrolic or pneumatic. This is why current researches aim to focus on power electronics converter in order to meet future electrical power demand in aircraft network. The originality of this work is to bring active conversion in those system. A demonstrator is built to prove it suits to aircraft specifications.

Highly Integrated Silicon Carbide 80 kW Resonant Inverter for High Voltage Generation Switching at 500 kHz
Ulf Müter, Klaus F. Hoffmann, Helmut Schmidt University - University of the Federal Armed Forces Hamburg, D; Arne Lunding, Bernhard Wagner, Philips Medical Systems, D
This paper presents a highly integrated inverter with a high power density based on silicon carbide semiconductors to reduce volume and weight of high voltage generators used in industrial or medical applications. The designed full-bridge resonant converter operates at frequencies above 500 kHz and a maximum output power of 80 kW.

IGBT

Dual Side-Gate HiGT Breaking Through the Limitation of IGBT Loss Reduction
Tomoyuki Miyoshi, Yujiro Takeuchi, Tomoyasu Furukawa, Masaki Shiraishi, and Mutsuhiro Mori, Hitachi , J
Nominated for the Young Engineer Award
A novel Dual side-gate HiGT (High-conductivity IGBT) with an extremely small feedback capacitance (Cres) and a function of controllable conductivity modulation was proposed. Dynamic control of stored carrier concentration right before switching by tandem drive of the dual gate makes it possible to

further reduce switching loss with conventional single-gate IGBTs. Compared to the single gate drive, dual side-gate HiGT further reduces loss during turn-on and turn-off by 12% and 30%, respectively.

An Optimized Plug-In BIGT with No Requirements for Gate Control Adaptations
Munaf Rahimo, Charalampos Papadopoulos, Chiara Corvasce, Arnost Kopta, ABB Switzerland, CH
In this paper, we introduce a new version of the Bimode Insulated Gate Transistor (BIGT), which is optimized to provide low diode conduction losses without the need for gate control adaptations. The concept is based on design modifications at both the MOS cell level and cathode injection efficiency to provide a low VF even when a positive gate signal is applied on the BIGT during diode mode conduction.

Power Rating Extension with 7th Generation IGBT and Thermal Management by Newly Developed Package Technologies
Kenichi Yoshida, Shinichi Yoshiwatari, Mutsumi Sawada, Yuichi Onozawa, Souichi Okita, Osamu Ikawa, Fuji Electric, J
The newly developed products family of 7th generation IGBT module so called 'Dual XT' which housing is widely used in worldwide. Advanced technologies in this paper achieve over 30% upgrading of current rating of the product which can create significant benefit for power conversion systems.

The Next Generation High Power Modules with Enhanced Trench BIGT Technology
Charalampos Papadopoulos, Munaf Rahimo, Chiara Corvasce, Maxi Andenna, Arnost Kopta, ABB Switzerland , CH
In this paper, we provide an outlook into how the next step in IGBT technology evolution for targeting even higher current ratings can be achieved by combining an enhanced Trench ETIGBT MOS cell platform and a BIGT integration structure. The results will be provided at module level for an industry standard 3300V HiPak. The new chip technology will offer the possibility to reach new milestones in output current capabilities for existing module footprints and also for future package standards such as for the LinPak module range which will require high current densities for minimizing the number of paralleled modules for a given power rating.

High Efficient and Soft IGBT Technology
Suguru Hondo, Yu Enomoto, Yuta Kawamoto, Akihiro Hikasa, Kazuhide Ino, ROHM, J
This paper presents our latest generation IGBT device, with optimized cell structures and thinner wafer technologies. Thanks to these improvements, we have realized 6% lower saturation voltage, faster turn-off with keeping soft switching behavior. It contributes to higher circuit efficiency up to 1.2% compared with our previous generation IGBT technologies.

Module Design

A New Intelligent IGBT Module for Quasi-Resonant Inverter Applications
Bum-Seok Suh, Wonjin Cho, Alpha and Omega Semiconductor, ROK
This paper presents an intelligent IGBT module for a quasi-resonant inverter, widely used topology in induction heating (IH) applications. The proposed module is composed of an IGBT and the integrated gate drive circuit which provides dedicated protection function to IH applications: soft start during load detection, long turn-on prevention, hard turn-on disabling, retention of minimum turn-off duration, and overvoltage protection for the IGBT in addition to conventional functions such as abnormal supply voltage protection, temperature monitoring and protection, and fault indication. The module is evaluated in the practical IH cooker to show the effectiveness of protection during the various operating conditions.

Relaxing Thermal Stress by SLC Technology and New PC-TIM
Koichi Masuda, Yoshitaka Otsubo, Tomohiro Hieda, Mitsubishi Electric Corporation, J

As design approach to increase power density of power module, the combination of SLC technology and newly developed PC-TIM is presented. To reduce thermal stress, SLC technology increases chip mounting area from conventional structure by 33%. And new PC-TIM, which has coefficient of heat transfer 4 W/m K and maximum operating temperature 150°C is developed. This combination contributes to decrease 50% of thermal resistance and also ? Tj swing in comparison with conventional technology.

Lifetime Estimation Model of HVIGBT Considering Humidity
Yumie Kitajima, Kenji Hatori, Shinichi Iura, Keiichi Nakamura, Yasutaka Kusakabe, Kazuhiro Kurachi, Mitsubishi Electric Corporation, J; Eugen Wiesner, Eckhard Thal, Mitsubishi Electric, D
This paper describes the lifetime estimation model of HVIGBT considering humidity. The proposed lifetime estimation model includes humidity acceleration factor derived from performed H3TRB tests. The H3TRB tests of HVIGBTs were performed with different humidity, temperature and voltage conditions to find the acceleration factors. Finally, we estimated the lifetime of HVIGBT with combination of those three factors by our new lifetime estimation model. In addition we found out that humidity has a big impact on HVIGBT lifetime.

Effects of Influencing the Individual Leg Inductance in Case of Paralleling Modules on Basis of XHP 3 and EconoDUAL
Matthias Wissen, Daniel Domes, Waleri Brekel, Thomas Holtij, Andreas Groove, Infineon Technologies, D
Modular inverter designs enable scalability and therefore adaption of current rating. This trend is supported by power modules in half bridge configuration that are connected in parallel to the DC link. The switching behavior of the modules in parallel is, amongst other, inherently influenced by the way of the connection of the modules to the DC busbar. Constraints of this connection with respect to symmetrical switching of the power modules in parallel are discussed in this paper.

Breakdown of Gate Oxide of SiC-MOSFETs and Si-IGBTs Under High Temperature and High Gate Voltage
Menia Beier-Möbius, Josef Lutz, Technical University of Chemnitz, D
New results of gate oxide stress tests with the step-by-step increase of the gate voltage are shown for SiC-MOSFETs. In comparison to these results, a gate stress test with stepwise increase of the gate voltage was carried out for Si-IGBTs as well. For both tests, the test temperature was set to 150°C with the last voltage step leading to the intrinsic breakdown. The test was done for three different manufacturers of SiC-MOSFETs and two different manufacturers of Si-IGBTs.

Control Techniques in Intelligent Motion Systems

Harmonic Speed Control for Repetitive Mechanical Systems
Van Trang Phung, Mario Pacas, University of Siegen, D
The paper deals with harmonic speed control in repetitive mechanical systems. In the proposed method, each harmonic in the spectrum of the speed error is regulated by either a proportional-integral (PI) controller or by a resonant part in case of using a harmonic speed controller or a PI-resonant speed controller, respectively. The harmonic speed controller provides information used for the load torque estimation which is utilized to detect single-point defects in the bearings of the machine.

Hybrid Curent and Acceleration Control of Servo Drives
Josef Wittmann, Rainer Hagl, University of Applied Sciences Rosenheim, D; Ralph Kennel, Technical University Munich, D
The presented hybrid current and acceleration control improves the load disturbance behavior of servo drives significantly - without additional sensor effort. The feedback signal of the acceleration control loop is calculated from the position data of the motor encoder. Hence, position measuring errors have an influence on this control loop and lead e.g. to speed ripple. Therefore, the presented design of the acceleration control loop consider both, the sensitivity to load and position measuring errors.

Analysis of Instantaneous Switching Frequency of a Hysteresis Based PWM for Control of Power Electronics
Malte Thielmann, Axel Klein, Michael Homann, Walter Schumacher, Technical University of Braunschweig, D
Delta Sigma analog converters are usually comprised of an analog modulator and a digital low pass filter. The delta sigma signal processing, directly processes the high frequent bitstream. One advantage of using the bitstream instead of a filtered signal is a high bandwidth in the control loop. To fully utilize this, a new PWM-modulator was presented in 2015. The switching frequency of this modulator depends on various parameters. This paper focuses on the choice of parameters to define the frequency and its standard deviation.

Natural-Sampled, Quasi-Continuous and Synchronous Pulse Width Modulator Enables Field Oriented Control for High Speed Drives
Jens Onno Krah, Markus Höltgen, Technical University Cologne, D; Jochen Pieper, Christoph Klarenbach, Beckhoff Automation, D
The contribution presents a new FPGA based control scheme for high speed drives which combines the advantages of space vector modulation, field oriented control and synchronous, natural-sampling PWM without drawbacks. A digital tracking loop delivers a quasi-continuous commutation signal and VHDL based signal processing replaces analog devices. The switching frequency can be reduced to increase efficiency due to lower current distortions without any sub oscillations.

Special Session: Passive Components

Estimating the Pulse Performance of Wirewound Power Resistors
Bertram Schott, Vishay Electronic, D
We present a method, based on numerical solutions of the time dependent 1D thermal di usion equation with internal heating, which allows for estimating the maximum permissible pulse load that can be put on a wirewound resistor. This method works quite well from very short pulses to almost continuous load. The results for di erent pulse durations follow a t-rule and hence can be scaled to each other. Therefore, the pulse handling capability of almost any set of model parameters can be extrapolated from only few simulations based on the respective scaling properties.

Inductance versus DC Current Measurements on the Anhysteresis of Magnetic Material
Jörn Schliewe, Stefan Schefler, Stefan Weber, Matthias Köppen, Achim Siersch, EPCOS, D
In this paper we present a special measurement setup to characterize the saturation behavior of inductive components. The inductance versus dc-bias behavior on the anhysteresis of the magnetic material has been measured. This measurement procedure gives a distinct solution no matter in which material state the component has been before. The resulting curves can directly be used for the recently presented method for simulating small signal inductance versus dc-bias measurements.

Experimental Evaluation of Capacitors for High Power Resonant Converters
Petar J. Grbovic, Huawei Technologies, D; Miroslav Vasić, Jesús A. Oliver, Pedro Alou, Jose A. Cobos, University of Madrid, ES

A dc-dc converter has been proposed in order to obtain ultra-efficient (nominal efficiency 99.5%), ultra-compact (50kW/dm3) dc-dc- converter where the input voltage is changed in a very wide range (between 300V and 1000V). Due to the very wide range of the input voltage, the proposed converter is implemented as a combination of a series resonant converter and an ordinary PWM converter. The resonant capacitor is one of the most important parts of the system due to high effective current that it has to conduct. This paper presents experimental results obtained during the selection of the most adequate capacitor technology for the resonant capacitor.

Medium Frequency Transformer Design and Optimization
Marko Mogorovic, Drazen Dujic, École Polytechnique Fédérale de Lausanne, CH
Nominated for the Best Paper Award
Nominated for the Young Engineer Award
This paper describes the technical challenges tied to modeling and design optimization of the medium frequency transformer (MFT) for power electronic applications, namely emerging solid state transformers (SST).

SiC-Systems

A Novel Gate Drive Concept to Eliminate Parasitic Turn-on of SiC MOSFET in Low Inductance Power Modules
Andreas März, Teresa Bertelshofer, Mark-M. Bakran, University of Bayreuth, D; Martin Helsper, Siemens, D
In this paper a new gate drive concept for low inductance SiC MOSFET power modules is presented. Experimental results show that the proposed 3-level turn-off strategy will prevent parasitic turn-on under fast switching operation. This will significantly reduce turn-on and reverse turn-off losses of SiC MOSFETs as well as reduce overvoltage of the bodydiode at turn-off.

Evaluation of Current Measurement Accuracy for a Power Module with Integrated Shunt Resistors
Matthias Spang, Niklas Hofstoetter, SEMIKRON Elektronik, D
The integration of shunt resistors in power modules represents a simple, cost-effective and compact solution for measuring the output current of voltage source inverters. Challenges that have to be addressed include voltage isolation, measurement tolerances and inductive coupling effects. In this paper, a standard 17mm module with integrated shunt resistors is presented together with a delta-sigma modulator for isolation and analog-to-digital conversion. The measurement accuracy is evaluated by simulations and measurements.

Optical Power Isolation Enables Novel IGBT and Sensor Applications
Jan-Gustav Werthen, Mort Cohen, L2W Energy, USA
The topic "Optical Power Isolation Enables Novel IGBT and Sensor Applications" describes an entirely new device that provides 100% isolated electric power transmission. Based on laser-powering over optical fiber, the optical power isolator converts the transmitted laser light into useable power. This novel technology enables powering of sensors and IGBT circuitry located in high voltage environments.

Power Electronics Optimization

Development of a High Efficient MPPT for Space Applications Using GaN Power Transistors
Cornelius Armbruster, Christian Schöner, Fraunhofer Institute ISE, D; Torben Schönbett, Alfons Klönne, Rainer Merz, University of Applied Sciences Karlsruhe, D
Nominated for the Young Engineer Award
In this work an evaluation platform for a solar maximum power point tracker (MPPT) for power

conditioning units in space applications is described. By implementing this topology together with gallium nitride power transistors good heat dissipation, a high power density, a high efficiency of more than 97 % and a continuous power point optimization of the photovoltaic module can be achieved.

Parasitic Inductance Analysis of a Fast Switching 100 kW Full SiC Inverter
Matthias Kegeleers, Julian Körner, Stefan Matlok, Maximilian Hofmann, Martin März, Fraunhofer Institute IISB, D
Nominated for the Young Engineer Award
A method for optimising the parasitic inductances in fast switching applications with additional snubber capacitors is presented. The improvements are carried out using 3D field simulations which allow for a commutation loop design verification of complex three-dimensional designs in early design stages. The simulation results are then validated with measurements on a 100 kW full SiC-inverter for automotive traction.

Design Method for the Minimization of CM Inductor Volume with Consideration of Core Saturation in EMI Filters
Bilel Zaidi, Arnaud Videt, Nadir Idir, University of Lille (L2EP), F
Nominated for the Best Paper Award
Nominated for the Young Engineer Award
EMI filters are necessary in many applications in order to meet EMC standards, which significantly increases overall cost and volume mainly because of the common-mode choke. In this paper, a new method to calculate the minimum volume of the inductor is proposed. It takes into account core saturation issues that may greatly impact inductor volume. Consequently, it is shown that in some cases, increasing the inductance up to an optimal value can significantly reduce the filter volume.

Cooling Thermal Management

Temperature Swing Issue, How a Passive Two-Phase Cooling Loop Can Improve the Power Electronic Lifetime
Vincent Dupont, Cyrille Billet, Thomas Nicolle, CALYOS, BE
Capillary Loops (CPL or LHP) can be used for passive cooling of high power electronics and are characterized by a variable heat transfer coefficient as a function of power i.e. if no power is applied no heat is transferred. This unique behavior associated with cold plate thermal inertia can be used to smooth the virtual junction cycling amplitude that permit to significantly increase the power module lifetime compared with the active standard liquid cooling solutions.

New Electro-Thermal Model for a Multichip Power Module Used in a Motor Drive
Merouane Ouhab, Radoslava Mitova, Miao-Xin Wang, Schneider Electric, F; Zoubir Khatir, Ali Ibrahim, Jean-Pierre Ousten, IFSTTAR, F
This paper presents a new analytical electro-thermal model of a multichip power module. The model is dedicated to real-time conditions of a motor drive, to calculate dies temperature during operation and to estimate remaining useful lifetime in further work.

A Double Side Cooled Electronic Power Module
Jacques Favre, APSI3D, F; Jean-Michel Reynes, IRT Saint Exupery, F; Jean-Pierre Fradin, Claudia Cadile, Sébastien Sanchez, Dominique Elzo, ICAM, F; Emmanuel Marcault, CEA Tech, F
For the first time we have realized true double side cooled power module. To characterize such a 3D power module, an electro thermal fluidic bench was developed likewise an electronic system to generate active power losses within each module power component. All fluidic parameters were recorded likewise junction temperature after the single power pulse. A comparison is made between expected / simulated thermal behavior of a single IGBT power die to experimental results using this complete bench tester.

Metering and Diagnostics and Standards

Monitoring of Current Balance in Parallel-connected Power Converters
Lorenzo Giuntini, GE Consumer & Industrial, CH
Power semiconductors are often paralleled to drive currents beyond the single module current rating. However, current sharing between them is not necessarily granted. Therefore, parallel converters would benefit from monitoring of effective current sharing. This paper introduces a simple, low-cost current balance monitoring technique based on encoding the current measurement as a digital signal. The effectiveness of such technique is proven by simulation as well as experimentally.

Online IGBT Temperature Measurement Method Using a Greybox Model
Georg Pangalos, Malte Päsler, Holger Kapels, Fraunhofer Institute ISIT, D
A novel temperature measurement method using only gate signals is presented. The temperature dependency of the internal gate resistance is used. First a transfer function of the equivalent gate circuit is derived and transformed into discrete time. Measurement data from the gate circuit, i.e. the voltage on both sides of the external gate resistance w.r.t. the emitter potential are taken and used for parameter identification of the greybox model. From these parameters the value of the internal gate resistance, which is temperature dependent, is derived.

Impact of Temperature Imbalance on Junction Temperature Identification for Multiple Chip Modules Using TSEPs
Jose Ortiz Gonzalez, Olayiwola Alatise, Li Ran, Philip Mawby, University of Warwick, GB
Junction temperature sensing using Temperature Sensitive Electrical Parameters (TSEPs) is a method widely used. Two factors characterize the use of TSEPs in SiC: a smaller chip size and reduced temperature sensitivity. Assuming an average temperature for paralleled chips can give wrong estimations depending on the magnitude of the difference. This paper evaluates the impact of the temperature imbalance between chips on the junction temperature estimation using TSEPs and its implications

Passive Components and New Materials

Evolution of Magnetics in Power Electronics Applications and Facing the Challenges of Future Electronics Industry
Kapila Warnakulasuriya, Andrea Polti, Murata Power Solutions, GB; Farhad Nabhani, Teesside University, GB
It is a widely accepted fact that magnetic components have not gone through its evolution at a competitive or even at a sufficient speed compared to the evolution of electronics. In this paper a compressive coverage is given on the evolution of magnetics from conventional wire wound components to planar magnetics to PCB integrated and on chip magnetics. The suitability of each generation of magnetics for different areas of applications is discussed with practical examples. The development of ultra-high power high frequency magnetics also discussed based on developments done by the Author.

High Performance Common-Differential Mode Chokes for High Efficient EMI Filters
Thiemo Kleeb, Juliane Hinze, Peter Zacharias, University of Kassel, D
Converter operation of several 100 kHz in the lower kW power range requires very high filter attenuation, because of EMI standard limitations. Combined common-differential mode chokes can take advantage of attenuating both common and differential mode noise effectively. Therefore, these components can reduce the effort and the power loss of EMI filters significantly.

Dimensioning and Testing Planar Inductors for High Frequency Operation
Gérard Delette, Gaëlla Frajer, Cyril Rado, Pierre Perichon, Florence Servant, CEA-LITEN, F; Hervé Chazal, G2Elab, F; Olivier Isnard, CNRS, F

The presentation deals with the the operation of passive components (inductors) in high frequency power converters. A prototype of planar inductor made of NiZn spinel ferrite has been designed in order to minimize the thermal heating due to power losses. Experimental results obtained after implementaion in a boost converter are discussed.

Advanced Wide Bandgap – GaN

Investigation of GaN-HEMTs in Reverse Conduction
Richard Reiner, Patrick Waltereit, Beatrix Weiss, Rüdiger Quay, Oliver Ambacher, Fraunhofer-Institute IAF, D
This work investigates the reverse conduction characteristic of 600 V-class GaN-HEMTs. The behavior of a conventional HEMT is analyzed and compared to the reverse conduction of an improved HEMT structure with integrated free-wheeling diodes. The characteristics of both structures are measured on exemplarily fabricated devices. Furthermore, the behaviors are explained with regards to the intrinsic layouts.

Dispersion of Electrical Characteristics and Short-Circuit Robustness of 600V Emode GaN Transistors
Matthieu Landel, Cyrille Gautier, Denis Labrousse, Stéphane Levebvre, Fadi Zaki, Zoubir Khatir, ENS Cachan - SATIE, F
Matthieu LANDEL is going to present to you his experimental work on the short-circuit capability of 650 V GaN transitors.

Mechatronic Design of 2 kW SiC DC/AC Converter with 200 W/inch
Thomas Menrath, Stefan Matlok, Stefan Endres, Stefan Zeltner, Bernd Eckardt, Fraunhofer Institute IISB, D
Goggle's Little Box Challenge has shown that with a SiC based solution highest power densities can be reached in the 400 V voltage range. The Fraunhofer IISB approach has a power density of 201 W/inch (86.5 mm x 75.5 mm x 25 mm = 0.163 dm^3 @ 2kW) and is based on a 6-switch power topology with latest 900 V SiC MOSFETs. The key to high power densities is a well-designed mechatronic assembly.

A Full SiC Module Operational at 200°C Junction Realized by a New Fatigue-Free Structure
Hiroshi Notsu, Hisato Michikoshi, Kenji Fukuda, National Institutee of Advanced Industrial Science and Technology (AIST), J; Dai Ishikawa, Yoshinori Ejiri, Hitachi Chemical, J; Satoshi Hatsukawa, Sumitomo Electric Industries, J
A full-SiC module for 200°C operation was successfully developed. To get a highly reliable attachment structure, the authors focused on keeping the sintered copper joint layer in the elastic region. There are two essential factors. One is a thin copper layer sandwiched by a roughly one order thicker SiC and substrate. The other is to get an active metal brazed substrate's coefficient of thermal expansion close to SiC. The module was operated over 35,000 power cycles at 200°C junction.

A Novel SiC Power Module with 3D Integration
Jinchang Zhou, ON Semiconductor, USA
A 3D stacked power module with interposer is introduced at the first time. Unlike conventional structural or other double-sided cooling modules, the power devices are stacked over and connected with interposer with via. In this way, power density is greatly increased with smaller module size. The module featured with ultra-low parasitic, high operation temperature (> 200 0C), and low thermal resistance with double sided cooling, is a great fit for SiC power module requirement. The process to manufacture such a module with high robustness, reliability as well as of process simplicity is also addressed.

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Power Electronics in Automotive

Influences of WPT-Coil Losses and Coupling Coefficient on the Resonance Circuits of Wireless Power Transfer Systems
Christof Ziegler, Stefan Weber, EPCOS, D; Georg Heiland, Finepower D; Denis Kraus, Technical University of Munich, D
Charging of electrical vehicles by Wireless Power Transfer (WPT) is currently in the main focus of automotive industry. The concept of an easy to use charging without need to connect a cable to the vehicle is seen as a promising technology to push the market for electric cars. Due to their open concept, WPT-systems offer a lot of parameters for variation. This paper deals with the influence of the real parameters of a WPT-coil on the efficiency of the power transfer.

6 kW Bidirectional, Insulated On-board Charger With Normally-Off GaN Gate Injection Transistors
Stefan Endres, Christoph Seßler, Bernd Eckardt, Stefan Zeltner, Fraunhofer Institute IISB, D; Tatsuo Morita, Panasonic Corporation, J
This paper describes a bidirectional insulated on-board charger (OBC) based on normally-off GaN gate injection transistors (GaN-GIT). It will show that by using 600 V GaN GITs in a totem pole PFC together with a CLLC converter with variable turns-ratio a complete bidirec-tional insulated 6 kW on-board charger can be realized in only 2 dm^3. Besides the description of the topology, especially the modular buildup of the prototype will be shown, as well as measurements.

650V, 7mOhm SiC MOSFET Development for Dual-Side Soldered or Sintered Power Modules
Monty Hayes, Delphi Automotive Systems, USA; Brett Hull, Jeffrey Casady, John Palmour, Wolfspeed, USA
The paper will cover the development of a 650V, 7mOhm SiC MOSFET that can be wither soldered or sintered for dual-side cooled power modules for electric drive vehicles.

A Novel Spectral Control Method for an Automotive Gallium Nitride DC-DC Converter
Christian Korte, Stefan Götz, Eduard Specht, Porsche Engineering Group, D
This paper presents a nover control method for an automotive DCDC converter, which controls the output voltage spectrum in addition to the primary control target.

Control and Drive Strategies in Power Converters

Digital Control of Hard Switched Converters by Phase Modulated Pulse Width Modulation PMPWM
Stefan Matlok, Bernd Eckardt, Bernd Seliger, Martin März, Fraunhofer Institute IISB, D
Nominated for the Young Engineer Award
Controlling PWM converters may be an ungrateful task where the small signal behavior changes with every different operation point. By analyzing the effects of PWM to transient response, a new control scheme was born. As both phase- and pulse width is modulated (PMPWM), it is possible to achieve a linear transient behavior in both buck- and boost directions, independent of DCM, BCM or CCM. Enjoy this presentation for implementing stable, more efficient and high performance control loops.

Non-Linearities Compensation Technique for VSI Fed AC Drives
Mauro Di Monaco, Giuseppe Tomasso, Ciro Attaianese, Umberto Abronzini, University of Cassino and Southern Lazio, I
This paper deals with a recursive non-idealities compensation method for Voltage Source Inverter (VSI) in the field of electrical drives. It is based on a step-by-step voltage compensation on the basis of the current error evaluated within each control interval. It allows reducing the VSI output voltage distortion that influences the torque of AC motor.

Novel Control Scheme for the Internal Energies and Circulating Currents of Modular Multilevel Converter
Yeqi Wang, Rainer Marquardt, University of the Federal Armed Forces Munich, D
This paper presents a novel control structure for Modular Multilevel Converters (MMC). It enables improved dynamic and steady state behaviour of the (internal) arm energies and arm currents. Minimized capacitor size and a reduction of control complexity are main advantages. The new method is based on space vector partitioning into twelve (or more) sectors in combination with multiplexing of the control variables.

Suitable Turn-Off Strategies for IGBTs with a High Desaturation Current During Short Circuit Failures Detected with the 2D – Short Circuit Detection Method
Stefan Hain, Mark-M. Bakran, University of Bayreuth, D
For IGBTs with an extremely high desaturation current, a fast fault detection method is just one part of reliable short circuit protection. It has to be combined with a fast reacting and suitable turn-off strategy which allows the power semiconductor to endure the fault event without any damage. This paper presents the suitability of different turn-off strategies for short circuit events for IGBTs with a high desaturation current, detected with the 2D - short circuit detection method.

Special Session: Capacitors

Ceramic Power Capacitors and Optimized Packaging
Markus Koini, Javier Martinez, Markus Puff, EPCOS, AT
The increase in power density and the miniaturization in power electronics yield to higher temperatures, which raises also the demands on the capacitor. Furthermore, customer's needs on size and packaging can be very diverse. CeraLink? is able to provide high temperature stability and is already available in a modular system. Nevertheless, there is still a demand for an even more flexible system. A new backend-variant was developed which is capable of meeting requirements and maintaining properties of CeraLink?.

Ultra Capacitors - Capacitor Based Energy Storage
Jan-Hendrik Ernst, Maxwell Technologies, D; Robert Lynds, Catalin Popescu, Mark Sutherland, Maxwell Technologies, USA
Ultra-capacitors are capable of storing and discharging energy very quickly and effectively. Due to their many benefits like high power density, high cycling ability, low temperature performance and many more, ultra-capacitors are currently being utilized in thousands of different applications. The speech will contain a description of applications and will later concentrate on the utilization of ultra-capacitors to improve renewable integration efficiency

Review of Film Capacitor Trends and Design Changes as a Result of Improved Technologies in Power Electronics
Ayse Kartal, EPCOS, D
The SIC technology further fuels the trend towards more compact and efficient designs within power electronics. This allows higher switching frequencies leading to more efficiency in power systems as well as downsizing of the complete system and much higher power density. The design of capacitors used in power electronics such as DC - link and AC filtering components, will be challenged especially in terms of higher temperature and high frequency operation requirements. This presentation will focus on two main points for capacitors:1) Effects on raw material to withstand higher temperatures and tougher environmental conditions; 2) Effects on construction and design of capacitors to ensure reliable, robust components.

New Concepts of Capacitor Designs in Power Electronics
Thomas Ebel, FTCAP, D

A clear trend in power electronics is to increase the power density of the passive components like Aluminium electrolytic capacitors and metallized film capacitors. That means to increase the ripple load current of given capacitors, to increase lifetime of the component and/or to operate the components at higher switching frequencies. FTCAP has developed new concepts for those applications. Cubic axial capacitors with entire laser welded Al-metal housing are one candidate to increase significant the ripple current load, having a 27% bigger surface and allowing a better heat sink connection and a significant life time enhancement. Whereas the patented Fischer-Link concept of metalized film capacitors reduces the parasitic inductances to a minimum value below 10 nH/capacitor, allowing low loss operation of a assembled capacitor bank at higher switching frequencies.

SiC Modules Diodes

Design and Analysis of a Low-Inductive Power-Semiconductor Module with SiC T-MOSFET and Si IGBT in Parallel Operation
Christian Müller, Infineon Technologies, D
The parallel operation of SiC T-MOSFET and Si IGBT is analyzed with focus on operating conditions and the consequences for the performance. By addressing different control schemes for the parallelized switches, the impact on the performance is discussed and optimized operating parameters are presented. It is shown that the switching performance is determined by the control scheme significantly and only more sophisticated controlling methods allow high switching frequencies for the parallel operation.

1.7 kV High-Current SiC Power Module Based on Multi- Level Substrate Concept and Exploiting MOSFET Body Diode during Operation
Slavo Kicin, Stanislav Skibin, Christof Bernhard, Enea Bianda, Francisco Canales, ABB Corporate Research, CH; Samuel Hartmann, Fabian Fischer, Pauline Morin, Robert Gade, ABB Switzerland, CH
We present switching performance of a high-current 1.7 kV SiC half-bridge (phase-leg) module based on the platform of the ABB module of a new generation - LinPak. It is based on a multi-level substrate concept allowing high flexibility in power module design requiring paralleling of many semiconductor devices. A MOSFET body diode must be used during operation since the module do not contain any Schottky diodes. The module was carefully optimized by electromagnetic and thermal simulations before its assembly and testing.

All SiC Module with 1st Generation Trench Gate SiC MOSFETs and New Concept Package
Thomas Heinzel, Fuji Electric Europe, D; Yoshinori Iwasaki, Mikiya Chounabayashi, Masayoshi Nakazawa, Susumu Iwamoto, Yasuhiko Oonishi, Motohito Hori, Hideaki Kakiki, Osamu Ikawa, Fuji Electric, J
Recently the main requirements in the market are further downsizing and higher efficiency of power conversion systems. For this reason, enhanced power density of the power modules will be the key to succeed. In this paper, electrical characteristics for all SiC modules with the 1st generation trench gate SiC MOSFETs and new concept package were presented. In addition, it was demonstrated that 1 rank extension for inverter capacity could be accomplished by applying all SiC modules against conventional Si modules.

Robust SiC JBS Diodes for the Application in Hybrid Modules
Lukas Kranz, Renato Amaral Minamisawa, Lars Knoll, Sven Matthias, Andrei Mihaila, Charalampos Papadopoulos, Athanasios Mesemanolis, Elena Mengotti, Giovanni Alfieri, Vinoth Kumar Sundaramoorthy Enea Bianda, Munaf Rahimo, ABB Switzerland, CH
We report on electrical characteristics and reliability tests of 1.7 kV SiC JBS (Junction Barrier Schottky) diodes. Diode turn-off characteristics show that currents up to 225 A can be switched off safely. 1000 hours of THB-HVDC (Temperature Humidity Bias-High Voltage Direct Current) tests at a voltage of 1360 V (80% nominal) have been passed without blocking degradation. Finally, SiC diodes

were implemented in a hybrid 62Pak, leading to a reduction in switching losses by 85% when compared to the full Silicon reference module.

Power Converters with Wide Bandgap Devices III

Design and Performance of a 200 kHz GaN Motor Inverter with Sine Wave Filter
Franz Stubenrauch, Norbert Seliger, University of Applied Sciences Rosenheim, D; Doris Schmitt-Landsiedel, Technische Universität München, D
Nominated for the Best Paper Award
Nominated for the Young Engineer Award
This paper analyses Gallium Nitride semiconductor devices as an alternative for future motor inverters. Due to the small switching loss the PWM frequency range can be extended up to 500 kHz. This allows the use of motor filters with small component size. As a result, high motor efficiency, low torque ripple, high control bandwidth and nearly ideal sinusoidal output voltages are achieved. A hybrid sine wave filter consisting of an analog and a digital part is presented and optimized to achieve low power loss and high current control bandwidth. A 3-phase GaN motor inverter with 200 kHz PWM frequency verifies the system design.

Reducing dv/dt of Motor Inverters by Staggered- Edge Switching of Multiple Parallel SiC Half-Bridge Cells
Thomas Fuchslueger, Hans Ertl, Technical University of Vienna, AT; Markus A. Vogelsberger, Bombardier Transportation, AT
Nominated for the Young Engineer Award
A novel concept for reducing the output voltage dv/dt of SiC PWM motor inverters is proposed, which keeps high semiconductor switching speed. Each converter phase leg is formed by a parallel arrangement of switching cells. These half-bridge legs are PWM operated such that a small time-delay is given between the legs. The output voltages of the legs are combined via an interphase transformer network to a total output showing staircase-type switching edge behavior resulting finally in a much lower dv/dt at the motor terminals.

Highly-Reliable Flyback-Based PV Micro-Inverter Applying Power Decoupling Capability Without Additional Components
Hiroki Watanabe, Jun-Ichi Itoh, Nagaoka University of Technology, J
This paper discusses a verification of an electrolytic capacitor-less PV micro-inverter aiming for high reliability and volume reduction. In the proposed converter, the power decoupling is achieved by small capacitors without the additional component. From the simulation result, the second-order harmonics of the grid frequency on the DC side is reduced to less than 1% in comparison with the DC component.

Compact Highly Efficient 3-kW MHz Inverter Based on SMT SiC MOSFETs
Fabian Denk, Christoph Simon, Michael Heidinger, Rainer Kling, Wolfgang Heering, Karlsruhe Institute of Technology (KIT), D
In this work we present a compact highly efficient MHz inverter based on newest SMT SiC MOSFETs. The SiC FET in 7L D2PAK is expected to show an excellent switching performance due to its short connection pins and separate driver source pin. This theoretically excellent switching performance is confirmed by a simulation with a semiconductor efficiency of 99.4%. Based on this, a compact prototype with SMD heatsinks was designed. A short-circuit-test shows an excellent switching performance at 2.43 MHz.

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System Reliability

Power Cycle Testing of Sintered SiC- MOSFETs
Ralf Schmidt, Ronny Werner, Siemens, D; Jeffrey Casady, Brett Hull, Adam Barkley, Wolfspeed, USA
In this contribution it is shown that the concept of virtual junction temperature can be transferred from Si-devices to SiC-MOSFETs when using the body diode under negative-biased gate. It enables precise temperature assessment in power cycle tests. Although the stiff SiC dies produce severe stress on the die attach during cycling, it could be shown that with an Ag-sinter die attach outstanding power cycle capability can be achieved. More than 1 million cycles at a temperature swing of 110K were tested until cracks in the DBC led to a failure.

Synchronous Observing Methodology of Surface Images and Energy Data at Power Chip Destruction
Toshiya Tadakuma, Akiko Goto, Teruaki Nagahara, Junji Yamada, Mitsubishi Electric Corporation, J
I will introduce dynamical observing method for IGBT destruction with 1million fps ultrahigh speed camera and synchronous data of voltage and current as short film.

Active Current Trajectory Control (ACTC) - for Hot Swap, Capacitor Discharge, Circuit Breaker and Current Shaping
Juan Sanchez, Kennith Kin Leong, Sebastian Uitz, Volodymyr Yakobniuk, Gerald Deboy, Infineon Technologies Austria , AT
This paper aims to introduce a new algorithm: active current trajectory control, which could improve modern hot swap controllers by fundamentally tracking the V/I trajectory across the SOA of the device. The concept actively controls the gate in the linear region to limit the current and controls the shape according to the SOA boundary lines. Furthermore, the algorithm de-rates the SOA boundary in real time. Therefore, the device never operates outside of SOA, in a sense it never fails due to in-rush.

Impact of Humidity on Railway Converters
Christian Zorn, Nando Kaminski, University of Bremen, D; Michel Piton, ALSTOM, F
In traction applications HV-IGBTs are subjected to changing and particularly demanding climatic conditions. A new test methodology is proposed to derive chips' mission profiles from realistic mission profiles of the railway vehicle and to more accurately assess the status of degradation/health of the IGBT modules. This will help to more precisely predict the remaining useful life or schedule preventive maintenance of the railway traction converters.

Energy Storage and Power Quality Solutions

A Comparative Study on Si-SJ-MOSFETs vs. GaN-HEMTs Used for LLC-Single-Stage Battery Charger
Lukas Keuck, Patrick Hosemann, Benjamin Strothmann, Joachim Böcker, University of Paderborn, D
Typical battery chargers consist of two stages: PFC-rectifier and isolated DC-DC-converter. In order to increase the power density and charger's lifetime, integrating both stages should be considered. However, today's single-stage battery chargers suffer from increased stressing variables such as high RMS-currents and high capacitor peak voltages. Gallium nitride (GaN) based devices are very promising candidates for reducing these stressing variables as will be proved by this paper with a solution based on a LLC-type resonant converter.

Investigation and Optimization of the Accuracy of Current Sensors for High Voltage LFP-Batteries
Simon Bischof, Thomas Blank, Marc Weber, Karlsruhe Institute of Technology (KIT), D
A highly accurate low cost current measurement system for Lithium-Ion Battery Management Systems is presented. It provides current measurement for currents between -40 A and +40 A under operating conditions between -20°C and +70°C. Three error compensation methods have been investigated.

The sensor fulfills the requirements of norm DIN EN 62619 and can be used to provide an accurate state of charge estimation for the extremely flat state of charge over voltage curve for battery storage systems equipped with lithium iron phosphate cells.

High-Efficiency UPS Protection for Industrial Applications
Lorenzo Giuntini, Massimiliano Brioschi, GE Consumer & Industrial, CH
Power electronics, and particularly variable frequency drives, enable energy efficiency improvements. When the application requires power continuity, uninterruptible power supplies (typically, double-conversion topology) are deployed to ensure back-up power. Alternative, high-efficiency operation of such UPS systems unlocks further energy saving potential in industrial applications. This paper discusses the efficiency benefits while analyzing the power quality implications, assessing the compatibility with AC drives.

1.5kW Digital Totem Pole PFC Design for Air-Conditioner and Performance Comparison Using IGBT, SiC and GaN
Wei Wu, Infineon Technologies Americas, USA
A 1.5kW digital totem pole PFC implementation with low cost current and voltage sensing circuit which is suitable for cost-sensitive inverter air-conditioner. The digital controller is XMC1000 series industrial microcontroller. Prototype hardware and firmware has been built. Conductive EMI has been measured and compared to traditional boost topology. System efficiency also be measured and compared among IGBT, SiC MOSFET and GaN switches.

Advanced Si Power Semiconductors

Diode Parameters Design Simulation and Experimental Validation against Silver Migration Phenomena in High Voltage Switching Application
Mattia Gianfranco Gentile, Ettore Vittone, University of Turin, I; Paolo Mirone, University of Naples Federico II, I; Luigi Merlin, Vishay Intertechnology, I
Metallic Electro Chemical Migration(ECM)is a phenomenom has long been recognized as a significant failure pathway. In this work, ECM was investigated and analyzed in commercial silicon power diodes.Dedicated test have been performed to study the Ag ECM triggering and evolution.2DTCAD simulation were used to analyzed the ECM phenomena on diode edge termination, identifying design solutions able to mitigate such effect. Finally, the proposed devices has been experimentelly validated and results highlight a significant reduction of devices failure

Reliability Improving of Power Semiconductor Discharge Switch by Means of LTJT Technology
Alexey Grishanin, Valentin A. Martynenko, Alexey Khapugin, Mikhail Malygin, Oleg Frolov, JSC Electrovipryamitel, RU; Konstantin Nishchev, Mikhail Novopoltsev, Ogarev Mordovia State University, RU
This paper presents investigation results of reliability improving of power semiconductor discharge switches operating in ultra-high current density ranges, by means of silicon structure optimization and LTJT technology.

New Generation Large Area Thyristor for UHVDC Transmission
Jan Vobecky, Karlheinz Stiegler, Marco Bellini, Urban Meier, ABB Switzerland, CH
Third generation of six inch thyristors is introduced with 5.5 - 6.25 kA rating for the future converter valves in UHVDC. Using new design features we further thinned the silicon wafer and reduced the ON-state voltage by about 9 %. Compared to previous generation, the 8.5 kV blocking capability is maintained and the leakage current is reduced. With the recovery time below 500 µs, the efficient and stable converter valves are available for the rated power of 8 to 12 GW.

The Next Generation 4500V / 3000A BIGT Stakpak Modules
Franc Dugal, Andreas Baschnagel, Munaf Rahimo, Arnost Kopta, ABB Switzerland, CH
This paper is introducing the next generation of StakPak module. This Stakpak module is based on a 4500V BIGT chips which combine both IGBT and diode mode operation in a single structure. This newly developed chip has been optimized for hard switching application, which together with the improved Stakpak module layout yields the most powerful IGBT-based device up to date with a current rating of 3000A.

STMicroelectronics' new Super-Junction Technology with Fast Intrinsic Diode Ideal for the Most Demanding High Efficiency Bridge Topologies and ZVS Phase-Shift Converters-Comparison Analysis in 2kW AC-DC Switch Mode Power Supply
Antonino Gaito, Alfio Scuto, Cristiano Gianluca Stella, Giuseppe Sorrentino, STMicroelectronics, I
Power supply designers are now the necessity to increase the power density and have an improved thermal management; Topologies with very low losses are used and power devices with new requirements are requested. this articles focuses more on the behavior of MDmesh(tm) DM6 MOSFETs vs MDmesh(tm) DM2 MOSFETs, used in a 2kW AC-DC switch mode power supply with full digital control based on the STM32F334C8 microcontroller and on the performances of MDmesh(tm) DMx devices vs the main competitors providing MOSFETs with fast diode technology.

Low Voltage AC/DC Over-Current Breaker with 650-V IGBTs
Jan Fuhrmann, David Hammes, Hans-Günter Eckel, University of Rostock, D
Over current breakers are essential and also challenging for smart AC or DC grids. For lower voltages up to several 100 V full-silicon solutions can be used instead of hybrid or mechanical solutions for high voltages. In the literature several solutions with JFETs are described. Due to the exotic JFET semiconductor, another solution with IGBTs, whose gate-emitter voltage is lowered to reach a defined cut-off current, is presented within this paper. This concept is explained and measurements are presented.

An Advanced Si-IGBT Chip for Delivering Maximum Overall System Performance
Narender Lakshmanan, Thomas Radke, Mitsubishi Electric Europe, D
An advanced Si-IGBT based on a 'Full-Gate' scheme which utilizes a monolithically integrated current mirror emitter opens the way forward to achieving high electrical performance and the optimization of the dv/dt during turn-on.

High Energy Harvesting in High Current/Voltage Induction Heating Application Using the new Ultra Filed Stop IGBTs Technology
Vittorio Crisafulli, ON Semiconductor, D; Leon Zhang, ON Semiconductor, CN
The need to increase power density and having compact and cheaper system is increasing. The main effective way is to to increase switching frequency. This leads more losses in the transistors. In this paper the new generation of IGBTs called Ultra Field Stop (UFS) are introduced. These are based in an Ultra Field Stop Technology and thin wafers. These are able to operate at high frequency due to the lower switching losses. By decreasing the thickness of the device the UFS offers very low conduction and switching losses.

Automated Test Bench for the Measurement of Si-IGBT and SiC-MOSFET Hybrid Switches
Michael Meissner, Sebastian Fahlbusch, Klaus F. Hoffmann, Helmut Schmidt University- University of the Federal Armed Forces Hamburg, D
Hybrid switches consisting of a Si-IGBT and a SiC-MOSFET are a promising alternative for power loss reduction especially in resonant topologies. The parallel connection of two different power semiconductors combines a lot of parameters which have to be analysed in detail. In this paper a concept of an automated test bench for measuring lots of operating points of such a hybrid switch with a minimum of personal attention and time is presented.

New-Generation Trench Schottky Rectifiers (TSR) with Superior Electrical Performance
Ju-Hsu Chuang, Wesley Chih-Wei Hsu, Jia-Jan Guo, Yu-Hung Chang, Sung-Yin Wu, Lite-on Semiconductor, TW
A new-generation Trench Schottky Rectifier (TSR) is demonstrated with superior performance. It proves to conduct 37% higher forward current than the conventional TSR, better power figure-of-merit (BV)2/Ron and more improved switching characteristics than the conventional TSRs, enabling high frequency and high efficiency in system applications.

118a A Technology Platform for Reverse-Conducting Integrated Gate Commutated Thyristors with 94 mm Device Diameter
Maria Alexandrova, Tobias Wikström, ABB Switzerland, CH
This contribution discusses the development of a new technology platform for outer ring gate, reverse-conducting IGCTs. Two products were developed for application in modular multi-level converters for STATCOMs, distinguished by the low switching frequency that pronounce the IGCT's benefits over other device concepts, such as the IGBT.

Wide Bandgap Devices I

Measurement Scheme to Model an SiC MOSFET for Simulating its Switching Behaviors
Tatsuya Yanagi, Hiroyuki Sakairi, Hirotaka Otake, Naotaka Kuroda, Ken Nakahara, ROHM, J; Hiroaki Tanigawa, Keysight Technologies, J
This research discusses the measurement methodology to model an SiC MOSFET for accurately obtaining its switching behaviors. The device model we employed is based on a polynomial expression. We obtain the Id-Vds characteristics of the device in its operation area using a switching test circuit. The parasitic capacitances are measured via S-parameters under the on- and off-state conditions. The device model based on these data sufficiently reproduced the transient behaviors of the device.

A Performance Comparison of SiC Power Modules with Schottky and Body Diodes
Christopher Schmidt, Martin Röblitz, SEMIKRON Elektronik, D
For the Design of SiC MOSFET modules the selection of the right chipset is essential. To get the best performance it has to be chosen every time for every application individually. One of the major questions is the choice of the freewheeling diode, which can be either the integrated body diode or an additional Schottky diode. This paper discusses the advantages and disadvantages of both solutions by means of examples for two power classes. Mechanisms which have a significant influence on the conducting and switching losses are investigated.

Comparison between 1200V 5th generation SiC MPS Diode and Silicon Power Diode in DC/AC Hybrid Circuit Breaker
Kenan Askan, Michael Bartonek, Eaton Industries, AT; Fabio Brucchi, Infineon Technologies, I
A comparison between the 5th generation 1200V SiC merged pn/Schottky diode and the 1200V 4th generation Si diode in an Hybrid Circuit Breaker application (HCB) is presented. The HCB can interrupt a detected 10 kA fault in around 330 µs. The surge current capability of both technologies is analyzed. Observations on dynamic-static current sharing and forward characteristics are reported. The results are used to design the most appropriate technology for highest reliability and most compact HCBs.

Impact of Dynamic On-Resistance of High Voltage GaN Switches on the Overall Conduction Losses
Eduardo de Oliveira, Christian Nöding, Peter Zacharias, University of Kassel, D

One of the biggest concerns using GaN-based switches is the possible increase of the dynamic on-resistance Rdyn when applying high voltage swings to the drain. Such dynamic behavior of the on-state resistance has a direct impact on the conduction losses, being more noticeable at higher switching frequencies. To assert its impact on the conduction losses, the obtained Rdyn will be measured, mathematically modelled and compared among several GaN semiconductors.

Calorimetric Measurement of Wide Bandgap Semiconductors Switching Losses
Sven Bolte, Norbert Fröhleke, Joachim Böcker, University of Paderborn, D
In order to achieve high accuracies in simulation and optimization of power converters, it is necessary to have exact loss models of all components. Though wide bandgap semiconductors have comparable low switching loss, it is still not negligible. Unfortunately, the fast switching makes it difficult to measure the switching loss with well-established methods like the double-pulse test. Hence, this paper proposes a calorimetric method for measuring switching loss in wide bandgap semiconductors.

System Level Comparison of Si IGBTs and SiC MOSFETs
Levi Gant, Sujit Banerjee, Xuning Zhang, Gin Sheh, Monolith Semiconductor, USA; Andrew Lemmon, Ali Shahabi, The University of Alabama, USA
This work leverages a custom designed 5kW DC-DC converter in order to make a head-to-head comparison, in terms of efficiency and achievable power volumetric density, of similarly rated Si IGBTs and SiC MOSFETs.

Comparison of the Short Circuit Capability of Planar and Trench SiC MOSFETs
Douglas Pappis, Lucas de Menezes, Peter Zacharias, University of Kassel, D
An investigation about the short circuit capability of planar and the new trench SiC MOSFETs is presented, providing a performance comparison between 1200 V / 40 m? MOSFET from Wolfspeed (planar) and ROHM (trench) were tested. As expected, the trench SiC MOSFET can withstand longer short circuit times without damages nevertheless its inherent smaller chip area in comparison to equivalent-rated planar devices, easing considerably the task of detection for safe turn-off (50% longer time).

Characterization and Optimization of SiC Freewheeling Diode for Switching Losses Minimization Over Wide Temperature Range
Xuning Zhang, Levi Gant, Gin Sheh, Sujit Banerjee, Monolith Semiconductor, USA
This paper presents the dynamic characterization of SiC Mosfet body diode and SiC schottky diode with loss and charge comparison under different temperature conditions. A pulse tester is designed with the capability of measuring the current and voltage of both switching and freewheeling devices. Tturn-on waveforms are compared under different test conditions. Turn-on loss and charge comparison results are presented for optimizing SiC freewheeling diode for switching loss minimization over wide temperature range.

On Developing a dV/dt Rating for Commercial 650V- and 1200V-Rated SiC Schottky Diodes
Thomas Barbieri, Gang-Yao Wang, Edward Van Brunt, Brett Hull, Jim Richmond, John Palmour, Wolfspeed, USA
The dV/dt ruggedness of commercial SiC Schottky (JBS) diodes is explored in an attempt to identify an upper failure limit and characterize the impact on long-term reliability. A high-speed pulse generator was used to deliver voltage slew rates up to 800 V/ns. Commercial 650V- and 1200V-rated diodes were subjected to a repetitive voltage slew rate of 400 V/ns, and then tested for avalanche ruggedness. The results demonstrate that the extreme dV/dt stress does not cause immediate failures and does not introduce latent weakness.

SiC power MOSFET with Monolithically Integrated Schottky Barrier Diode for Improved Switching Performances
Huaping Jiang, Changwei Zheng, Dynex Semiconductor, UK; Xiaoping Dai, Zhuzhou CRRC Times Electric, CN; Maolong Ke,Chinese Academy of Sciences, CN

A SiC MOSFET featuring an monolithically integrated SBD is proposed in this paper. With the optimization of the gate structure, the maximum electric field in the gate oxide is suppressed below 3 MV/cm which benefits to the long term reliability. Futhermore, the switiching loss as well as the current overshoot during turn-on process are lowered owing to the absense of the externally antiparalelled SBDs.

Dual On-State Gate Driver Concept for Improved Drive of Silicon Carbide MOSFETs
Sebastian Fahlbusch, Fabian Fisahn, Michael Meissner, Ulf Müter, Sebastian Klötzer, Klaus F. Hoffmann, Helmut Schmidt University- University of the Federal Armed Forces Hamburg, D
A novel gate drive concept with two separately adjustable on-state gate source voltage levels for improved driving of SiC-MOSFETs is presented. It allows enhanced use of SiC-MOSFETs' conduction properties in combination with fast and efficient switching operation. The impact of the concept is tested and compared with a conventional gate drive circuit in a buck converter equipped with a TO-packaged SiC-MOSFET. The buck converter operates at 50kHz, 600V dc-link voltage and output power up to 12kW.

High Speed, Thermally Enhanced, Small Footprint SiC Power Modules for Cost Sensitive Applications
Adam Barkley, Marcelo Schupbach, Scott Alan, Wolfspeed, USA
The paper presents a new design approach which delivers a superior SiC-based module with improved thermal and electrical performance and significant cost reduction when compared to available SiC-based "baseplate-less" modules.

Power Modules

A Power Cycling Test Bench Dedicated to the Test of Power Modules in a Large Range of Cycling Frequency
Francois Forest, University of Montpellier, F; Serge Bontemps, Microsemi PMP, F
This paper presents new developments of a power cycling test bench targeted to perform very high numbers of cycles at low ?TJ (>one billion of cycles, 10 to 20°C). This test bench is based on operation of a PWM bridge inverter in which the power devices are the modules to be tested and allows performing power cycling tests in a large range of cycling frequency (0.01Hz to 100Hz).

Resin Flow Simulation for Transfer Molding Technology
Ken Sakamoto, Yutaro Hanawa, Mitsubishi Electric Corporation, J
The resin flow simulation to prevent wire sweep in Transfer molding technology for the newest DIPIPM production is presented. Wire sweep depends on the condition of mold resin viscosity, mold injection velocity and direction of mold flow. In this paper, these factors are analyzed to reduce the wire sweep by resin flow simulation. As consequence, optimized molding condition is found out to complete higher quality of DIPIPM.

Development of High Thermal Performance Automotive Power Module with Dual Sided Cooling Capability
Yangang Wang, Yun Li, Yaqing Ma, Shiwu Zhu, Mingliang Jiao, Jun Yu, Zhenlong Zhao, Chundong Wu, Yibo Wu, Paul Mumby-Croft, James Booth, Matthew Packwood, Steve Jones, Xiaoping Dai, Guoyou Liu, Dynex Semiconductor, GB
High performance, high reliability with low weight/volume and low cost power semiconductor module are required for driving hybrid and electric vehicles because of the harsh operating and market environments. In this work, development of a high thermal performance automotive power module with dual sided cooling capability is discussed. The concept, design and manufacture of the module are presented, by which the thermal, electrical and mechanical performance, as well as reliability are enhanced.

Intelligent Power Modules with Common Footprint for both Single-phase and Three-phase AC Input Motor Drives
Jonathan Harper, ON Semiconductor, D
Innovation in intelligent power module package design and improvements in IGBT performance enable cost-effective solutions in the same module footprint which cover both single-phase and three-phase AC input power options. These improvements allow single-phase operation up to 4kW in the smaller module series and over 7.5kW in the larger module series.

Optimized Layout of 1700V LoPak1 IGBT Power Module by Holistic Design Approach
Sven Matthias, Samuel Hartmann, Athanasios Mesemanolis, Raffael Schnell, Franc Dugal, Arnost Kopta, ABB Switzerland, CH; Leonel Soberano, Dandy Jaducana, Jean-Marc Renard, IMI Philippines, PH; Andra Irace, Michele Riccio, University of Napoli, I
In this paper, a design method is presented, which takes into consideration various performance targets and combines the power of multiple simulation techniques in order to implement a virtual prototype. With this method, multiple interactions are taken into consideration during the early stages of design, such as thermal behavior, resistive losses, static and dynamic current sharing between paralleled chips as well as electrical oscillations during short circuit operation, thus achieving fast and accurate design.

Paralleling of LinPak Power Modules
Andreas Baschnagel, Daniel Prindle, Silvan Geissmann, Fabian Fischer, Samuel Hartmann, Raffael Schnell, Gontran Pâques, Arnost Kopta, ABB Switzerland, CH
Introduced in 2015 [1,2], the LinPak (1700 V, 2 x 1000 A) was designed specifically to enable easy scaling of the output power of Voltage Source Converters through paralleling of phase leg IGBT modules. The LinPak has been tested under typical application conditions. In this paper, we will show the excellent dynamic current sharing of the LinPak and methods to achieve the best performance in all operating conditions, including short circuit SOA.

A New Generation of 600V Intelligent Power Module for Consumer and Industrial Motor Drive Applications
Bumseung Jin, Kang Yoon Lee, SungDae Shin, Geun-Hyoung Lee, David Jo, Taesung Kwon, Fairchild Korea Semiconductor, ROK
This paper introduces a new motion control 600V module of SPM3 PKG product which utilizes the newly developed Field Stop trench IGBT with advanced Extreme Fast freewheeling diode with Direct Bonded Copper substrates for high thermal performance. Especially, this module offers high power density with low IGBT and FRD losses. Also, the adopted IGBT turn on performance is optimized by its own characteristic for better Electro-Magnetic Interference performance.

Super Mini DIPIPM for Automobile
Naoki Ikeda, Hiroyuki Hata, Hongbo Zhang, Mitsubishi Electric Corporation, J
A newly developed power module for inverter driving air-conditioner of electric vehicle and hybrid electric vehicle is presented in this paper. By using the optimized wafer process and assembly process, the new power module enables the package size to be small as it dramatically reduces the mounting space in comparison with conventional product and discrete configuration. The ratings is 30A/600V for 2.2kW class motor drive and the package size is 38.0×24.0mm.

Cooling Systems

Thermal Characterization Analysis of IGBT Power Module Integrated with a Vapour Chamber and Pin-Fin Heat Sink
Yiyi Chen, Bo Li, Yuying Yan, Wei Gong, University of Nottingham, GB; Fang Qi, Yangang Wang, Steve Jones, Dynex Semiconductor, GB

I'm Bo Li, a research fellow in university of nottingham

Silicone-Based Enablers for Thermal Management in Power Electronics
Thomas Seldrum, Marin Demulier, Vincent Delsuc, Dow Corning Europe, BE
Smaller form factors and higher power densities are part of the key drivers for the continuous improvement of electronic systems. Part of the success of the development and implementation of such new technologies imparts to the development of thermally conductive materials required to handle the heat management. This presentation highlights silicone-based products (encapsulant, gap filler and adhesive) that have been engineered to meet these thermal management needs.

Innovative Design in IGBT Cold Plate
Chihwei Wei, Kevin Wu, Larry Lin, Amulaire Thermal Technology, TW
By means of MIM technique, a complex geometric cold plate design, U-cup(tm), is achieved. This new design is shown to reach higher thermal performance, lower pressure drop, and lighter part weight via CFD analysis and on-site measurement.

Reliability of the Direct Cooling Type Cold Plate with Ni Clad Layer
Kazuhiko Minami, Atsushi Otaki, Ichiro Ota, Showa Denko, J
In this report, the improvement of reliability is reported by the Direct cooling type cold plate with Ni clad layer. Aluminum insulated substrate with Ni clad layer restrain to deform aluminum at Heat cycle, and is not seen the wrinkle.But cracks are propagated at Ni/Al interface in Ni/Al clad. So, Ni/Ti/Al clad layer is not seen delamination and wrinkle after Heat cycle. Next step, In the power cycling test, power cycling life of Cold plate with Ni/Ti/Al wiring layer is twice longer than Ni plating.

Testing, Selecting, and Applying Metallic Thermal Interface Materials for Harsh Environment Applications
David Saums, DSA LLC, USA; Timothy Jensen, Indium Corporation, USA
Selection and application of increasingly specialized thermal interface materials (TIMs) for power semiconductors, diode lasers, RF modules, and other devices in challenging system operating conditions will be described, especially describing developments with metallic TIMs for harsh and specialized applications in commercial and military and aerospace electronic systems. Comparative test data from several sources will be presented for varying test requirements.

Two-Phase Liquid Cooling for Electric Vehicle IGBT Power Module Thermal Management
Itxaso Aranzabal, Inigo Martinez de Alegria, Inigo Kortabarria, University of the Basque Country (UPV/EHU), ES; Nicola Delmonte, Paolo Cova, University of Parma, I
The main goal of this work is to show the advantages of two-phase cooling technologies for thermal management of high power electronics modules, with a SKIM909GD066 motor inverter as the test vehicle fot thermal/fluid analysis. Then, the dissipated power, the heat transfer coefficient and the fluid temperature are set in 3-D FEM (Finite Element Method) based thermal model to simulate two-phase cooling of IGBTs at the motor inverter.

Evaluation of Leadframe Power Modules for Automotive Drive Applications
Bao Ngoc An, Maurizio Kempf, Michael Meisser, Horst Demattio, Benjamin Leyrer, Thomas Blank, Marc Weber, Karlsruhe Institute of Technology (KIT), D; Johannes Kolb, Schaeffler Technologies, D
For automotive applications the need for highly reliable as well as cost-effective power modules is growing more and more. This leads to a demand for novel packaging technologies and new materials, especially insulation materials as an alternative to ceramics. This work will compare the thermal performance of a novel copper leadframe IGBT half bridge power module with an epoxy resin based insulation sheet and a second leadframe module with an insulated graphite sheet.

Exploring Novel Second Level Cooling Methods for Low Profile IPMs
Khatri Danish, Rajeev Krishna Vytla, Okawa Katsumi, Jin Pei, Infineon Technologies Americas, USA

This work explores novel second level (topside) cooling methods and their thermal performance benefits using pyrolytic graphic sheets for the forst time on low profile IPMs used in low power motor drive applications such as hot water circulation pumps and air conditioning fans. The results show that using PGS as heat pipe and spreader leads to a significant (>30%) increase in power output capability.

Reliability

Inverter Power Module Lifetime Estimation for HEV and EV
JeHwan Lee, HanGeun Jang, SangChul Shin, KiYoung Jang, JinHwan Jung, Hyundai Motors, ROK
In Hybrid Electric Vehicle operation, a three phase inverter of PWM switching method generates the power dissipation of conduction and switching losses in IGBTs and diodes. The power loss causes an increase of junction temperature that is important feature for the performance and reliability of inverter. In this paper, the thermal model is developed first to estimate the junction temperature irrespectively of various driving conditions and then the model is used to estimate the reliability of power module by considering the thermal stress conditions over the HEV lifetime.

The Enhanced Reliability of the Double Sided Cooled Package with Integrated Internal Isolation
Inpil Yoo, Marina Schmitz, Infineon Technologies, D
DSC package considered as a thermally optimized solution. but at the same time the reliability of the package can be improved without eliminating internal isolation which leads inhomogeneous material match inside of the module.in this paper the approach to improve the reliabilty is described and corresponding verificaiton is presented

Determination of State-of-Health and Remaining Lifetime of Power Modules
Jörg Franke, Christian Herold, Lukas Tinschert, Josef Lutz, Technical University Chemnitz, D
A method for remaining lifetime determination of power modules is presented. The bond shear force of bond wires after certain power cycles was compared to power cycling test results. A difference in remaining lifetime determination of approximately 50% was found. The work focusses on elaboration of a model of dependency of remaining shear force to the number of power cycles as well as the validity of power cycling tests results for remaining lifetime statements. Another indicator scanning acoustic microscopy of substrate solder is investigated to determine the relation between decreasing area of solder connection and remaining lifetime.

Shoot Through and Avalanche Behavior of High Speed Fet Converter
Florian Kapaun, Rainer Marquardt, University of the Federal Armed Forces Munich, D
Extremely high availability and reliability is of prime importance for many future applications of power electronics. In the past, these requirements were demanded in high power applications, mainly. Here, semiconductors with press-pack housings combined with multiple series connection have been applied with very good results. Unfortunately, neither the press-pack housings nor the multiple series connection of semiconductors are the preferred concepts of future development in power electronics. At first glance, alternative concepts of bypassing or disconnecting failed semiconductors by means of mechanical switches or fuses may be considered. But, a closer look reveals that they are in severe conflict with improved integration, miniaturization and reliability. In this paper, a new concept for fault tolerant converters is presented. It has been tested with MOSFET devices in SMT-housings, in the first step.

Reliability Investigation on SiC based Diode and MOSFET Modules Developed for High Power Conversion in Medical X-Ray Applications
Alexander Otto, Rainer Dudek, Sven Rzepka, Fraunhofer-Institute ENAS, D; Mohamad Abo Ras, Tobias von Essen, Berliner Nanotest & Design, D; Markus Bast, Armin Hindel, Ronald Eisele, FuE-Zentrum FH Kiel, D; Ulf Müter, Helmut-Schmidt University, D; Arne Lunding, Philips Medical Systems, D

In the BMBF funded PowerBlock+ project high power converter modules for x-ray generators in medical applications based on SiC diodes and SiC MOSFETs have been developed. In this paper, comprehensive investigations in terms of thermal characterization as well as in terms of reliability analysis, including power cycling testing and FE simulation, which were performed on these modules, will be discussed in more detail.

Mission Profile Based Reliability Evaluation of Building Blocks for Modular Power Converters
Frederik Hahn, Markus Andresen, Giampaolo Buticchi, Marco Liserre, Christian-Albrechts-University, D
Power electronics is a key technology and has been applied to an increasing number of applications. A challenge of the design is to be cost effective while fulfilling the reliability requirements. Since the thermal cycling is one of the most severe causes of failure in power electronics, this paper presents a test bench for the thermal testing of power converters. An application tailored mission profile is used to stress the converters under the future operating conditions to evaluate the design. This is particularly important for modular power converters consisting of several building blocks, which cannot be tested easily. For thermal design evaluation the electrical behavior of a single building block is emulated and the junction temperatures of the power semiconductors are recorded. As a study case, the thermal behavior of an Modular Multilevel Converter (MMC) with nearest level modulation is given to demonstrate the approach.

Thermal Calculation Methodology for Lifetime Estimation of Semiconductor Devices in MMC Application
Yijun Ye, Josef Lutz, Guang Zeng, Technical University of Chemnitz, D; Rodrigo Alvarez, Pablo Correa, Siemens, D
This paper describes different thermal calculation methods and their impacts on the lifetime estimation of power electronic devices in Modular Multilevel Converter (MMC) application. An algorithm based on the Fast Fourier Transform (FFT) is presented, which enables a fast and precise lifetime estimation for up to several hundred devices. The advantages and limitations of this method are discussed in detail.

Thermal Management and Packaging I

In-Situ Transient Testing of Run-in and Degradation Effects of Thermal Interface Sheets in Power Switch Assemblies
Gabor Farkas, Zoltan Sarkany, Attila Szel, Mentor Graphics, HU
Power assemblies can be characterized by thermal transient testing at their actual position. Some layers show high stability (die, ceramics etc.), others vary during the lifetime (die attach, TIM sheets).TIM materials can be selected by a preliminary test in standard conductivity tester. Then their change at run-in, TIM curing and reliability testing is followed in structure functions, where thermal resistance and capacitance values can be used for precise identification of structural elements in a heat conducting path.

Material Design and Process Conditions of Pressureless Sintered Silver for 200/-40 ºC Thermal Cycling Reliability
Masafumi Takesue, Tomofumi Watanabe, Naoya Nakajima, Bando Chemical Industries, J
This work turned out that pressureless sintering is a promising candidate for die-attach material in post-Si power devices. SAT and cross sectional SEM images of the test pieces sintered under optimized conditions show that pressureless sintering provided a dense silver layer even after 1000 cycles of the 200/-40 ºC thermal cycling test.

Performance Comparison of fast Silicon and Silicon Carbide Devices Used with Conventional PCBs and Embedded Into PCBs
Peter Zacharias, Juliane Hinze, University of Kassel, D

Modern semiconductor switches based on silicon carbide (SiC), gallium nitride (GaN) but also Silicon (Si) cause higher and higher di/dt and dv/dt magnitudes in power electronic circuits. To utilize maximum switching efficiency and achieve minimum over voltages at the devices commutation loops have to be designed very carefully. One option to minimize commutation inductance is the embedding of the semiconductor chip into the printed circuit board itself.

Power Electronic Package for Double Sided Cooling Utilizing Tile-Level Assembly
Maximilian Schmid, Gordon Elger, Johannes Pforr, Technical University of Applied Sciences Ingolstadt, D
Double side cooling of high power modules brings huge advantages in thermal management, miniaturization and cost reduction. It's suitable for current semiconductor materials, but more important for the new wide bandgap materials with only small chip sizes. This paper discusses possible assembly strategies and layout improvements based on simulations.

Packaging Solutions for Mitigating IGBT Short-Circuit Instabilities
Paula Diaz Reigosa, Francesco Iannuzzo, Frede Blaabjerg, Aalborg University, DK
The short-circuit ruggedness of IGBTs is often limited by high-frequency oscillations. One of the main factors influencing the occurrence of such oscillations is related to the package internal stray elements, especially the emitter inductance. However, the electrical coupling between the gate circuit and the main circuit is usually given little attention. This study is important to reach conclusions on the package design requirements for optimum performance under switching and short-circuit operations.

Thermo-Mechanical Optimisation of Press Pack IGBT Packaging Using Finite Element Method Simulation
Michael Varley, Ashley Plumpton, Dynex Semiconductor, GB
A demonstration of the use of Finite Element Method simulations in quantifying the trade-off between mechanical robustness, reliability and thermal and electrical performance in the design of Press Pack IGBTs. Results from experiments and from simulations are presented. The paper discusses how for specific applications, choices will have to be made between switching performance and thermal resistance, or between manufacturing yield (and by implication cost) and long term power cycling reliability.

Thermal Impedance Matrix Characterization of Co-Packed Discrete IGBT and Diode
Alberto Salinaro, Fairchild Semiconductor, D; Hans-Peter Hoenes, ON Semiconductor, D
In this paper, the TDIM - thermal dual interface measurement method - is applied together with the analysis of structure functions and the superpositon principle to obtain the thermal impedance matrix of a 120A, 650V IGBT co-packed with a free-wheeling diode. The junction-to-case thermal resistance RTJC for each thermal path starting from each junction is be determined. Moreover, since the dice are thermally coupled through the lead frame, cross-coupled thermal resistances cannot be neglected.

The Effect of 3 mol% Y2O3 doped ZrO2 on the Flexural Strength of AlN Ceramics
Jong Seol Yoon, Ki Soo Jun, Kyong Hwan Kim, KCC Corporation, ROK
The reinforced AlN with 3YSZ have flexural strength of 420 MPa and heat conductivity of 140 W/mk respectively.It is suitable to apply the DCB ceramic substrate.

HT Lead-free and Sinter Materials for WBG Power Semiconductors
Minoru Ueshima, Tetsu Takemasa, Senju Metal Industry, J; Shijo Nagao, Katsuaki Suganuma, Osaka University, J
Ag flake paste sintering has been introduced in our previous study, as a novel die-attachment method that shows remarkably low temperature and pressure of the process conditions, as well as the excellent temperature stability. In the present study, we have carried out the Ag flake die-attach tests with the actual materials such as SiC, Si and DBC substrate. The wide temperature ranges of thermal cycle tests have been thus achieved: ?T = 220 and 290 _C for Si and SiC die-attach, respectively.

Passive and Active Two-Phase Cooling for Power Electronics Applications
Devin Pellicone, Advanced Cooling Technologies, USA
As the power density demand for power electronic devices increases, the effective dissipation of the waste heat generated during operation becomes critical. Existing air and liquid cooling solutions are approaching their usable limits and advanced cooling solutions are needed to continue to advance power electronic technologies and applications. This paper will describe the use of passive and active two-phase cooling technology to enable higher energy densities and improve device performance.

Feasibility Study, Combining High-Power MOSFETs in a Power Module Using Advanced Thermal Management
Martin Schulz, Maximilian Slawinski, Infineon Technologies, D
Currently, an often discussed way of improving is to exchange IGBTs using MOSFETs.The present work deals with the influence of thermal aspects to the efficiency of power semiconductores. Special care is taken to observe and explain the differences arising from the devices' charakteristic. Measurements conducted on prototypeas as a feasibility study are presented and discussed. It is explained why thermal management becomes even more critical when using MOSFETs.

DC-DC Converters

Hybrib Power Converter Using Si IGBT Power Module & SiC MOSFET
Benoit Peron, Joseph Magniez, Centum Adetel, F
Soft switching hybrid topology mixing Si IGBT & SiC Mosfet dedicated to the power converter having a high thermal cycle during a long time, in a competitive market.

Application of a Buck-Boost Converter for Highly Dynamic Power Smoothing in Industrial Applications
Jochen Staiger, Swen Bosch, Heinrich Steinhart, HTW Aalen, D
This paper gives attention to the smoothing of maximum power peaks of a load by means of a dynamic energy storage system, which is based on a bidirectional dc-dc converter and electrolytic capacitors. The energy storage was exemplarily designed for a metal forming machine, which shows high power peaks related to the mean power consumption during one forming process. At this, the energy storage system is connected to the dc-link of the machine.

High Power Density GaN Interleaved Bidirectional Boost Converter with Extended Cooling Capability
Konstantin Siebke, Thorben Schobre, Niklas Langmaack, Regine Mallwitz, Technical University Braunschweig, D
Implementation of a 5 kW high power density bidirectional interleaved boost converter using GaN e-HEMTs. An extended cooling system is implemented using top side copper heat spreader which allows almost to double the output power.

Single-Ended Boost DC-DC Converter Cascade System for High Boost Rate and High Efficiency in Residential Fuel-Cell System
Ryoga Kiguchi, Yasuyuki, Nishida, Chiba Institute of Technology, J
Although a boost dc-dc converter with a high boost rate is needed in fuel-cell applications while the single-ended boost converter does not offer a higher efficiency, an indirect dc-dc converter with a HF transformer is applied in the products. Though, it results in a bulky, heavy and costly converter. As an alternative, a dc-dc converter consisting of two single-ended boost converters in cascade connection has been investigated in this study.

An Isolated Bidirectional DC-DC Converter for Energy Storage Systems
Mofakkharul Islam, Bebro Electronic, D; Masuma Nasrin, Independent University Bangladesh, BD; Abul Bashar Sarkar, Kempten University of Applied Sciences, D

This paper proposes a new design and implementation of an isolated bidirectional dc-dc converter to interface between a high voltage DC bus (HVDC) and a low voltage DC battery (LVDC). It features zero voltage switching regardless of the direction of the power flow, resulting in lower switching losses and an efficient converter. The details operation principles, as well as the design considerations, are presented. The simulation and experimental results have validated the characteristics of the converter. A prototype, which interfaces a 400V dc bus and 48V battery bank with a power rating of 2.5kW, was developed to verify the validity and applicability of this proposed converter.

Modeling of ZVS DC-DC Converter for Charging and Voltage Balancing of Energy Storage Elements
Dimitar Arnaudov, Nikolay Hinov, George Kraev, Gergana Vacheva, Technical University of Sofia, BG
The following paperwork presents a model of a ZVS DC-DC converter for charging and voltage balancing of energy storage elements connected in series. The advantages of the proposed circuit are the opportunity for charging current control, small switching losses, suitability for realization of identical modules for several cells, capability to increase the number of the cells being charged. The developed models of the converter and its control system allow model based design of such converters.

Modeling of Multiphase Converter for Charging of Energy Storage Elements
Stoyan Vuchev, Dimitar Arnaudov, Nikolay Hinov, Ivan Nedyalkov, Technical University of Sofia, BG
The following paper considers modeling of a multiphase DC-DC converter for charging of energy storage elements in the environments of MATLAB and LTspice which allows model based design to be done. The proposed circuit is realized on the base of the resonant inverter topology with reverse and limitation diodes. Main advantages are the system modularity and ZVS. Experimental examinations are carried out for verification of the obtained simulation results.

Advanced Power Converters for Energy Storage Systems for Light Traction Vehicles
Miroslav Hruška, Skoda Electric, CZ; Martin Schulz, Infineon Technologies, D
DC - DC Converters for Energy Storage Systems - traction batteries and supercapacitors.Design of powerfull Buck / Boost DC Chopper and 2 - Quadrant DC Chopper with IGBT modules for charging / discharging of traction batteries for trolleybuses and trams.

Compact Diode-Less Bidirectional GaN Based Buck Converter for Mobile DC-DC Applications
Sebastian Klötzer, Ulf Müter, Sebastian Fahlbusch, Klaus F. Hoffmann, Helmut Schmidt University-University of the Federal Armed Forces Hamburg, D
In this paper, the switching and conduction performance of a commercially available 650 V, 65 mOhm enhancement-mode gallium nitride HEMT is evaluated. Based on the measurements, the operation strategy for use in a bidirectional diode-less 400 V, 5 kW buck converter with high power-density is derived. When challenging timing constraints are met, switching frequencies above 400 kHz at the worst-case operating point can be reached by using boundary conduction mode and soft turn-on.

Seven Reasons why Power Designers Should Implement 48V to 1V Direct Conversion
Bob Cantrell, Martin Hägerdal, Ericsson Power Modules, SE
Conventional distributed power architectures include an intermediate conversion stage as a matter of course, to convert the nominal 48V input to a regulated 12V bus that is distributed to downstream 12V-input converters positioned close to the point of load. Attention is turning once again to the strengths of a single-stage conversion from regulated 48V down to voltages as low as 1V to supply the CPU core. Such conversion can be achieved efficiently and cost-effectively thanks to the latest power MOSFETs and control techniques. This presentation highlights the seven key reasons why power designers should implement 48V to 1V direct conversion.

Inductor Current Mapping Analog Controllers for Power Inverters and DC/DC Converters
Alexei Nikitin, Avatekh, USA; Ruslan L. Davidchack, University of Leicester, GB
We present analog Inductor Current Mapping (ICM) controllers for power inverters and DC/DC converters that offer multiple ways to optimize the cost-size-weight-performance tradespace. A basic

ICM controller is voltage-based and does not require any current sensors, or additional start-up and management means, and can be used for robust and high quality voltage regulation for various loads, including highly nonlinear loads. Adding current sensing enables current and/or power regulation.

Power Converters for Efficiency and Renewable Energy

Analysis of a Novel Buck-Buck Single Stage LED-Ballast
Alexander Pawellek, Thomas Dürbaum, Friedrich-Alexander-University Erlangen, D
The paper presents the very promising buck-buck single stage topology for LED lighting applications. The highly efficient ballast convinces with its simplicity in structure and control. It provides a ripple-free LED current, while performing an inherent PFC action at the input. The in-depth investigation and optimization is validated by a practical setup.

Energy Efficient, GHz Excited Plasma Lighting System
Kamil Kompa, Slawomir Niespodziany, KOMPA Sp. z o.o, PL
Plasma light is a new, growing technology. Its energy efficiency is comparable to LED lighting solutions, but higher power levels reached, make it a perfect solution for industrial, indoor and outdoor applications. Its wide light spectrum and flickerless operation make it a suitable choice for television industry. It is a young and still expensive technology, but it is suitable for applications where high-end parameters are required.

Constant Current Paralleling Controller for Mid-Power LED
Michael Heidinger, Christoph Simon, Fabian Denk, Wolfgang Heering, Rainer Kling, Karlsruhe Institute of Technology (KIT), D
This paper presents a novel approach for safely paralleling LED-strings and protecting the remaing LEDs after a failure. That way it's possible to construct high luminance SELV-compliant low voltage LED arrays using large numbers of mid-power LEDs, while a constant-current conventional LED driver may still be used. By using dissipative constant-current sinks, complexity and cost can be reduced, while not compromising efficiency.

A Novel Mains Operated LED Driver Using a GaN AC Switch
Dominique Bergogne, Othman Ladhari, Léo Sterna, Pierre Perichon, CEA-Léti, F
It is now common to use LEDs for lightning, especially in mains operated circuits. The challenge has long been to reduce the DC bus capacitor value and to propose new circuits to interface a high voltage AC source with low voltage DC load (LEDs). In this paper a novel structure, rectifier bridge free, using a single AC power stage, is proposed. It implements newly developed GaN AC switches to get the most of the circuit structure.

Electronic Ballast for Gas Discharge Lamp Based on Input- Series Output- Series Resonant Converter
Kaspars Kroics, Riga Technical University, LV
The paper discusses design of input-series and output series (ISOS) LLC resonant inverter for discharge lamp power supply. Voltage stress of each main switch is half of input voltage. The input voltage balancing problem also is addressed in the paper. First of all the operation of the converter is analyzed on the simulation model and after that the presented converter are verified on experimental prototype with 3 phase AC input voltage and 3 kW output power.

Control Loop Design for Closed-Loop Class-D Amplifiers with 4th Order Output Filter
Franz Maislinger, Hans Ertl, Technical University of Vienna, AT; Goran Stojcic, Florian Holzner, Bernecker + Rainer Industrie-Elektronik, AT
A closed-loop control concept for a class-D power amplifier with two-stage LC output filter is presented which minimizes distortions (due to DC link voltage ripple, timing- and interlock-delay errors or on-state voltage errors) but keeps the natural cut-off frequencies defined by the LC filter. The control is

implemented using a simple PI controller which is enhanced by a single or double capacitor filter current feedback achieving good dynamic response (e.g. Butterworth) at high switching-noise rejection and avoiding any dissipative damping.

Novel Gate Driver Technology for the Series Connection of Power Semiconductors
Johannes Kemper, Hako, D; Boris Fiedler, Max Planck Institute for the Structure and Dynamics of Matter, D; Klaus F. Hoffmann, Helmut-Schmidt University, D
The paper presents a high voltage switch that is build up of independent switching modules. Each module is supplied by the voltage drop across the switch during the blocking phase. The control signals are transmitted to all switches simultaneously by a free air infrared link. The active gate control guarantees good voltage sharing during switching as well as static phase.

Redundant Operation Mode of the Three-Level Advanced-Active-Neutral-Point-Clamped Converter for Wind Energy Application
David Hammes, Sidney Gierschner, Yves Hein, Hans-Günter Eckel, University of Rostock, D
AANPC converter consists of partial converters based on halfbridge modules. Low-inductive short-circuit failures can be destructive. This allows a redundant operation at reduced power after a failure, since half of the DC-link voltage is still provided. Behaviourcan be advantageous for an offshore wind energy plant. This paper investigates possibilities of the redundant operation mode for a permanentmagnet synchronous generator of a wind energy plant.

Implementation of Extended Kalman Filter for PMSG Considering the Dynamics of the Mechanical System
Mohamed Abdelrahem, Christoph Hackl, Ralph Kennel, Technical University of Munich, D
This paper presents a study and experimental verification of a sensorless control strategy for permanent-magnet synchronous generators (PMSGs) based variable-speed wind turbines. The proposed method is based on an extended Kalman filter (EKF) for estimating the rotor speed and position and the mechanical torque of the PMSG. Experimental results are presented to verify the feasibility of the proposed sensorless control method.

Evolution of Bidirectional Power Architectures
David Bourner, Vicor Corporation, USA
Bidirectional power applications have a set of features and limitations that are considered in this submission. Particular building blocks we term "power components" lend themselves well to these power system architectures. This paper explores the rationale supporting the development of a new power component which will make the design, development and commissioning of these systems much more straightforward.

Modular and Compact 1 MW Inverter in One 19 " Rack for Storage and PV
Patrick Hercegfi, Stefan Schönberger, Fraunhofer Institute ISE, D
A highly compact and modular 1 MW inverter meeting the demand for flexible sizing of battery systems is presented. Eight units with 125 kW each are mounted in a single 19 inch rack and support hot swapping. Two different operational modes optimized for use in low and medium voltage grids are shown. Small form factor and high efficiency is made possible by new SiC half bridge modules, high current PCBs, modular iron powder chokes and cold plates. Efficiencies up to 98.5 % have been achieved.

A New Step Towards the Power Electronics Design Automation
Lyubomir Kerachev, CMP, F; Yves Lembeye, André Andreta, Jean-Christophe Crebier, G2Elab, F
This paper presents the development of a generic process flow dedicated to the design of power electronics converters. A Process Design Kit has been created to build up power converters in an analogical way as it is done today in the field of microelectronics. The proposed design method is based on power building blocs and design rules allowing fast prototyping of power converters. A toolbox is created to generate automatically the output fabrication files from the requested electrical

specifications. A DC/DC 24-12V 280W prototype operating in a closed loop is built to validate the approach.

Passive Components and New Materials

Comprehensive AC Performance Analysis of Ceramic Capacitors for DC Link usage
Kirill Klein, Eckart Hoene, Klaus-Dieter Lang, Fraunhofer-Institute IZM, D
The paper presents results of comprehensive study on X7R, X6S, X7T and CeraLink capacitors. Cs and ESR of capacitors were measured, compared to datasheet values, and completed with large amplitude measurements (Iac=1A) for different DC-Voltages, frequencies and higher temperatures (RT/80°C /125°C). Based on results design rules are derived and verified on 650V/30A low inductive GaN switching cell module.

High Performance DC Link Capacitor/Bus Sourcing Dual Infineon HybridPACKTM Drive Inverters for EV Applications
Michael A. Brubaker, Terry Hosking, Wayne Liu, SBE, USA; Tomas Reiter, Infineon Technologies, D; Carsten Wüst, David Kuschnarew, hofer eds GmbH, D
Evaluating a single DC link capacitor/bus to support two HybridPACK Drive inverters, thus enabling a significant improvement in power density, weight and cost for EV applications. Detailed knowledge of the drive cycle is required along with full thermal characterization to demonstrate the required life. Transient thermal simulation results and experimental data are provided. These results are utilized to define practical topologies and power limits for one DC link feeding two HybridPACK Drive modules.

An Evaluation Circuit for DC-Link Capacitors Used in a Single-Phase PWM Inverter
Kazunori Hasegawa, Ichiro Omura, Shin-ichi Nishizawa, Kyushu Institute of Technology / National Institute of AIST, J
Evaluation of dc-link capacitors in terms of power loss, ageing, and failure rate will play an important role in power converters. This paper presents an evaluation circuit for dc-link capacitors used in a single-phase PWM inverter. The evaluation circuit produces a practical ripple current waveform and a dc bias voltage into a capacitor under test with a downscaled voltage-rating inverter, which is equivalent to those or the full-scale inverter. Theoretical analysis and experimental results verify the effectiveness of the evaluation circuit.

IGBT Switching Behavior with Parallel Surge Arrester for Medium Voltage Applictation
Fabian Hohmann, Mark-M. Bakran, University of Bayreuth, D
In this paper an IGBT with parallel surge arrestor for protection is examined. Next to energy and overvoltage consideration a simulation is made to proof the measured parasitics and show influences of different parameters.

Using Powder Materials to Replace Air-Gaps for Fringing Flux Reduction
Paul Winkler, Wulf Günther, Acal BFi Germany, D
As Acal BFi Custom Service for Magnetic Components (CSMC) we offer our clients customised inductors and transformers, which are made especially for their unique application. We offer a consultant service during design process, trying to help them to find the design they are looking for. Inductive devices in a wide range of power and frequency can be realised using the wide source of soft magnetic materials, our company is dealing with.

Partial Discharge of Inductives in a High Frequency Application
Michael Schmidhuber, Herbert Jungwirth, SUMIDA Components Modules, D
Partial discharge is one of the old challenges when designing an inductive component. SiC and GaN respectively the high switching frequency reveal new challenges when a high package density becomes the most important factor. Theirfore investigations have been made to analyse the inception

voltages of various wire types on different frequencies. This essential knowledge is to be considered at the early design stage of the product.

Design of Inductive Components for Triangular Current Mode (TCM) Inverters up to 500 kW
Tobias Appel, Spezial-Transformatoren-Stockach, D; Jan Fuhrmann, Hans-Günter Eckel, University of Rostock, D
Silicon carbid unipolar devices offer fast switching even for high-voltage and high-current inverters. This can reduce the size and weight of the filter choke. If a quasi resonant switching technique is used to minimize the turn-\textsc{on} losses of the semiconductor, the ripple current increases massively increases while the necessary inductance reduces. This results in challenges for the inductor, which can be handled. The new inductor design results in lower losses and factor four lightweight and smaller choke.

Study of the Influence of an Air Gap on Dimensional Resonance in MnZn-Ferrite Cores
Wolfgang Hauser, Manfred Albach, Friedrich-Alexander-University Erlangen, D
MnZn-Ferrite cores have a high permeability as well as a high effective dielectric constant. Therefore wave propagation phenomena occur in the frequency range of several hundred kHz. In GaN and SiC applications this is going to be an emerging problem when it comes to developing HF-Magnetics. Thus this paper deals with the influence of air gaps on these wave propagation phenomena which can classified as dimensional resonance.

A Novel Approach to Calculate the Reluctance of Air-Gaps in Ferrite Cores
Erika Stenglein, Manfred Albach, Friedrich-Alexander-University Erlangen, D
Magnetic circuit theory is a reasonable approach to quickly estimate the inductance. The air-gap reluctance strongly depends on air-gap size, shape and position. Several calculation methods for the air-gap reluctance have been proposed. However, those approaches either have been restricted to small air-gaps or are not valid for arbitrary air-gap position or shape. This paper introduces a novel approach to quickly predict the air-gap reluctance as a function of air-gap size, shape and position.

Inductive Components for Solar Power Conversion in a Harsh Next Decade Environment
Michael Schmidhuber, SUMIDA Components Modules, D; Marco Jung, Fraunhofer Institute IWES, D
The author presents a new 25 kVA PV inverter for a harsh next decade environment. To achieve the requirements new active and passive components are necessary. New Silicon Carbide (SiC) semiconductors together with a new cooling concept and an improved packaging shall lead in smaller passive components and thus to an increased power density of 1 kg/kW as wells as in a higher robustness against harsh environmental conditions.

Systemsimulations with EMI-Filter in an Automotive HighVolt Environment
Stefan Schefler, Stefan Weber, EPCOS, D; Christoph Keller, Konstantin Spanos, Robert Bosch, D
The goal of this work is to realize a simulation model of a high volt automotive EMI filter. Themodeling emphasis is on creating a physical structure. The creation leaded to a fullytransparent structure which enables the developer to change parameters without losing thephysical basics of the filter. In a real test setup the influence of the filter was compared tomeasurements. It can be seen, that it works sufficiently.

Sensors, Metering, Diagnostics

Current Measurement Device for High and Fast Changing Currents
Felix Himmelstoss, Karl Edelmoser, Technikum Vienna, AT
Measuring large and fast changing currents is not so easy. Here a special design of a coaxial shunt is presented. Due to the construction, the parasitic inductance is nearly zero. The field inside the shunt is also nearly zero and by choosing of the resistive material, which is also magnetically conducting,

external magnetic fields are reduced. The evaluation unit consisting of a differential amplifier and an ADC is placed inside the space which is field-free.

Measurement of Current and Magnetic Field in a Power Electronic Building Block using Coupled Inductors
Patrick Deck, Jan Hannig, Christian Peter Dick, TH Köln, D
This paper presents the evaluation of different methods for measuring and balancing current in a novel power electronic building block topology using coupled incuctors. To find the ideal method for the measurement of current or magnetic field a selection of currently purchasable and self-designed sensors has been evaluated concerning their sensitivity, accuracy, costs and the required space on a PCB. Based on the results of this survey a recommendation will be given on which sensor to use in future projects on coupled inductors.

Comparative Analysis of the Measurement Techniques to Characterize SiC-Power-Modules
Christian Schulte-Overbeck, Zhiyu Cao, Faheem Khan, Fahad Hussain, Srujan Grandhi, Denis Weiss, AEG Power Solutions, D
Comparative Analysis of the Measurement Techniques to Characterize SiC-Power-Modules

Open-Loop Hall-Cell Current Transducers with Integrated Sigma-Delta Modulators
Fabrice Salvi, David Jobling, Pierre Turpin, LEM Switzerland, CH
An open loop current transducer is presented in which a sigma-delta modulator has been added after the analog signal processing. The advantages of this architecture are explained. The design of the single ASIC containing Hall cells and all the active electronics is described. A typical system, in which the transducer is connected to different digital filters, is presented along with the main performance parameters.

Magnetoresistive Sensors for Angle, Position and Speed Measurement in Small-and Micro-sized actuators
Rolf Slatter, Rene Buß, Sensitec, D
Magnetoresistive (MR) sensors are not only used for measuring rotational and linear motion, but also for switching applications and highly dynamic current measurement. Increasing demand for MR sensors results from more complex demands on the sensors for high performance electric drives. The sensors must not only be accurate and dynamic, but also robust under difficult operating conditions with very high reliability. Recent market trends are generating additional demands, with respect to compact dimensions and energy efficient operation.

Insulation Health State Monitoring of Traction Machines Based on Online Switching Transient Exploitation
Markus A. Vogelsberger, Bombardier Transportation Austria, AT; Clemens Zoeller, Thomas M. Wolbank, Hans Ertl, Technical University of Vienna, AT
Today's motor insulation in railway traction applications are operating very close to borderline. Increased electrical stress on the machine's insulation system in case of inverter -fed operation (e.g. high du/du; SiC) leads to additional insulation strain/aging.
The paper proposes an Online Insulation Monitoring Approach that is able to detect incipient insulation defects (before breakdown), by evaluation of the motor transient current's response. The paper presents experimental results of a 1.4 MW ASM traction motor for railway applications.

Comparison of Fundamental Active and Reactive Power Determination Methods in Single-Phase Systems
Swen Bosch, Heinrich Steinhart, HTW Aalen, D
In this paper, a comparison of fundamental active and reactive power determination methods in single-phase systems is presented. The structures of four different methods are shown and the results are compared. At this, the behavior of the determination methods at ideal conditions and at distorted conditions are investigated and the results are presented.

Practical Experience with EMI of Radio-Communication System Versus Power Electronics Based on the SiC
Jan Leuchter, University of Defence, CZ
The paper disscussed immunity of an airbore radion communication system against low and high power interfering signals of power electronics. Modern avionics power switching electronics can provide undesireable responses which requires immunity testing of the radio receiver. The paper focuses on interferences which occur in the chain of intermediate frequency processing and the effects which compromise the radio immunity. The technology od SiC is discussed.

Wide Bandgap Devices II

Short Circuit Capability of 650 V Normally Off GaN E-HEMT and MOSFET-HEMT Cascode
Douglas Pappis, Kevin Göbel, Peter Zacharias, University of Kassel, D
An investigation of the short circuit capability of 650 V GaN power switches is presented, focusing on a E-HEMT, besides two MOSFET-HEMT Cascode. At nominal gate voltages, all devices are damaged under short circuit with drain voltage above 300 V, preventing safe turn-off. Lowering the gate voltage, an unstable range occurs between 250 V and 350 V. Bellow, responses are similar to Si-MOSFETs. High levels of gate current have been identified.

Advantages of Using 650V SiC MOSFETs in High-Frequency DC-DC Converters
Antonino Gaito, Giuseppe Sorrentino, STMicroelectronics, I
Electrical and thermal behaviors of a DC-DC boost converter are evaluated when new 650V SiC MOSFET device is used as main switch. The performance of the SiC device are compared to the latest generation of silicon devices. The new SiC switch raises the bar, enabling systems with higher efficiency and giving to the market systems with more green impact.

Cross Conduction of GaN HFETs in Half-Bridge Converters
Jan Böcker, Carsten Kuring, Sibylle Dieckerhoff, Technical University Berlin, D; Oliver Hilt, Joachim Würfl, FBH Ferdinand-Braun-Institute Berlin, D
Cross conduction in GaN HFETs is particularly critical due to the high dv/dt and small gate-source capacitances. The turn on peak current and increased turn on losses due to cross conduction are investigated for two normally-off GaN HEFTs in a half bridge topology. It is shown that a lower turn off gate driver voltage level reduces cross conduction and can minimize the total device losses, despite higher dead time conduction losses.
Design Rules for Paralleling of Silicon Carbide Power MOSFETs
Salvatore La Mantia, STMicroelectronics Application, D; Luigi Abbatelli, Carlo Brusca, Maurizio Melito, Massimo Nania, STMicroelectronics, I
Increasing the capability of a power switch by using several individual MOSFETs connected in parallel is a common practice with silicon semiconductor devices. This paper deals with the issues linked to paralleling the silicon carbide (SiC) MOSFETs. Based on the experimental validation of paralleled discrete devices the investigation focuses on the main electrical parameters affecting the performance of the paralleled switch.

Influence of an Emitter Sense Pin on the Switching Behavior of SiC BJTs in Standard Discrete Housings
Christian Bödeker, Melanie Adelmund, Nando Kaminski, University of Bremen, D; Ranbir Singh, GeneSiC Semiconductor, USA
Since fast switching silicon carbide (SiC) devices come usually in "traditional" standard packages, i.e. the TO-220-3L or the TO-247-3L, their full potential cannot be utilized. One of the main disadvantages of these packages is the common stray inductance of the load and the driving circuit. This can be remedied by using a sense pin or Kelvin contact. In this work, the influence of different packages with and without sense pin on the switching behavior of fast switching SiC BJTs is investigated by measurements.

Designing Manufacturable and Reliable Printed Circuit Boards Employing Chip Scale eGaN® FETs
Michael de Rooij, Alana Nakata, Efficient Power Conversion (EPC) Corporation, USA
Designers are becoming more familiar with the PCB design rules that affect manufacturability for eGaN FET and which are less forgiving compared to traditional MOSFETs due to their relatively smaller sizes. This paper will cover the various guidelines for PCB design that maximize the performance of eGaN FETs and reliability yet still rely on existing PCB manufacturing capabilities.

Impact of Circuit Carrier Technologies on MHz-switching of GaN Half-Bridge Circuits
Norbert Seliger, Franz Stubenrauch, University of Applied Sciences Rosenheim, D; Christian Brendel, Dr. Johannes Heidenahain, D; Doris Schmitt-Landsiedel, Technical University of Munich, D
The aim of this study is to analyze the influence of three different circuit carrier technologies on switching power loss of 650V hard-switching GaN devices. Limitations and solutions for half-bridge circuits operating at MHz-switching are investigated by modeling and experiments on a prototype.

Thermal Management and Packaging II

MMC AlSiC as Alternative for Molybdenum in Power Press-Pack Semiconductor Design. Investigations of Electric Conductivity Properties of AlSiC
Alexey Grishanin, Valentin A. Martynenko, Vyacheslav Eliseev, Anton Samoylov, JSC Electrovipryamitel, RU; Konstantin Nishchev, Mikhail Novopoltsev, Ogarev Mordovia State University, RU
This paper demonstrates results of experimental investigations of metal-matrix composite AlSiC electric conductivity. The described investigations allow come to the conclusion that AlSiC can be used for compensating discs of high voltage press-pack semiconductors with fully compression contacts, due to its physic-mechanical properties an electric conductivity.

Sintered Ag Joints on Copper Lead Frame TO220 by Pressure Sintering Process with Improved Reliability and Bonding Strength
Ly May Chew, Wolfgang Schmitt, Jens Nachreiner, Heraeus Deutschland, D
Silver sinter materials have attracted rising attention to use as interconnect materials in the power electronic devices mainly due to the requirement for devices with longer lifetime, higher efficiency, lower manufacturing cost and the most important is devices that do not contain lead. Thermal conductivity increases with increasing density of sintered Ag joints. The main focuses of this study were to increase the reliability of sintered Ag joints on lead frame TO220 and to shorten the total process time.

A New Alternative Non-Pressure Silver Sinter Process by Using IR
Wolfgang Schmitt, Ly May Chew, Robert Miller, Anna Wolf, Heraeus Germany, D
Silver sinter materials have attracted rising attention to use as interconnect materials in the power electronic devices mainly due to the requirement for devices with longer lifetime, higher efficiency and lower manufacturing cost. In this study, the non-pressure sintering process was carried out by IR radiation instead of under a conventional programmable oven. The results show that the sintering process time can be shortened to one fourth of the time compared to the conventional sintering in a programmable oven.

High Reliability Large Area Substrate Solder Interconnect by Embedded Mesh Technique
James Booth, Michael Varley, David Slack, Paul Mumby-Croft, Steve Jones, Xiaoping Dai, Dynex Semiconductor, GB; Karthik Vijay, Indium Corporation, GB
Power semiconductor packages experience thermal fatigue at the substrate-baseplate interface during operation. This paper discusses reliability improvements to this interconnection by utilising new solder alloys and a technique of embedding a copper mesh within the solder joint. The aluminium wirebond

technique is compared to the metal mesh technique by passive thermal cycling IGBT modules with Al2O3 ceramics and copper baseplates. FE simulation is also carried out for both techniques.

Transient Current Distribution with Paralleling Dies and Paralleling Half Bridges in Multichip Power Modules
Helong Li, Wei Zhou, Fang Qi, Daohui Li, Yangang Wang, Steve Jones, Xiaoping Dai, Dynex Semiconductor, GB
This paper addresses the transient current distributions in the multichip half bridge power modules where two types of paralleling connections with different current commutation mechanisms are considered: paralleling dies and paralleling half bridges. It reveals with paralleling half bridges, the high side paralleled devices have much smaller transient current imbalance even though with the same mismatched stray inductances.

Influence of the Power Semiconductor Packaging on the Failure Characteristic for Safety-Critical Applications
Michael Gleißner, Mark-M. Bakran, University of Bayreuth, D; Hussein Khalid, Mitsubishi Electric Europe, D
The packaging of power semiconductors determines their failure characteristic. Wire-bonded modules fail with an undefined state reaching from not ideal short-circuit to explosion depending on the failure energy. In contrast, an ideal short-on failure characteristic is known for press-pack and sandwich-structure modules. Some safety-critical applications require an ideal short-on failure. The failure characteristic depending on packaging and energy is investigated by destruction tests.

Double Side Sintered IGBT + FRD, 650V/ 200A, in a STO247 Package for High Performance Automotive Applications
Francois LeHenaff, Alpha Metals Lötsysteme, D; Gustavo Greca, Paul Salerno, Jeffrey Durham, Monnir Boureghda, Alpha Assembly Solutions, USA; Anna Lifton, Apha, NL; Jean Claude Harel, Satyavrat Laud, Renesas Electronics, USA; Weikun He, Mentor Graphics, GB
Francois Le Henaff received the M.Eng. degree in Material science from the University of Limoges, France in 2010 and the Ph.D. degree in electronics from the University of Bordeaux, Talence, France in 2014. His research topic was related to die-attach technologies. Since 2014, he has been with Alpha Assembly Solutions, Langenfeld, Germany, as the head of Alpha European Applications Center and he leads the material and technology development in Europe.

Control of Power Electronic Converters

Reactive Power Operation of a Single Phase AC-AC DAB Converter
Martin Jagau, Michael Patt, Technologienetzwerk Allgäu, D
Transformers are used when galvanically isolated energy transfer is necessary. Traditional transformers are bulky and consist 80% of copper and iron. Since the 1960s the demand for refined copper has increased by 250% from 5 mil tons to 20 mil tons. Due to the increasing high demand of copper a continuous price increase in the next years is expected. To guarantee the availability of copper for the next decades and to counteract the expected price increase, it is essential to find resource friendly alternatives.

Use of FPGAs to Develop Energy-Saving DC-DC Control
Ben Jeppesen, Intel FPGA, GB; Ge Gao, Imperial College London, GB; Jason Katcha, Half Moon Ventures, USA
FPGAs give complete flexibility in the digital control of switching power converters. This paper describes reference designs for single and two-phase bi-directional DC-DC converter control using FPGAs. Model-based design is used to develop from offline simulation to real-time implementation, including real-time simulation of the power electronics on the FPGA. Using PI with PWM as a

benchmark, control algorithms based on hysteresis control are developed. Hysteresis control is shown to reduce switching losses for the same control specification.

Comparison of Three Model Based Junction Temperature Control Systems to Increase the Lifetime of IGBT-Power- Modules
Maximilian Nitzsche, Julian Wölfle, Nathan Tröster, Martin Stempfle, Jörg Roth-Stielow, University of Stuttgart, D
This paper presents a comparison of three different junction temperature control systems to increase the lifteime of IGBT-power-modules.

A New Modulation Technique to Control the Switching Losses for Single Phase Three-Level Active-Neutral-Point-Clamped-Inverters
Johannes Ruthardt, Julian Wölfle, Matthias Zehelein, Jörg Roth-Stielow, University of Stuttgart, D
This paper presents a new modulation technique to level the power loss distribution of the semiconductor devices in an single phase three-level active-neutral-point-clamped-inverter.

Comparison of FPGA Based Control Strategies (DDSRF-PI vs. State-Space Control) for Grid Connected Inverters under Grid Disturbances
Emanuel Mittwede, Johannes Kern, Stefan Schönberger, Benjamin Stickan, Fraunhofer Institute ISE, D
In the TestLab Power Electronics at Fraunhofer ISE many utility-scale PV inverters are tested under grid disturbances and it emerged that many of them have problems to control the current under these conditions. Therefore an FPGA based state-space control approach as well as a state-of-the-art DQ-PI-control approach are evaluated, implemented and tested in real environment, proving their good control performance using a comparatively low-cost fully FPGA based solution.

STNRGPF01: A New Driver for Interleaved PFC Based on Mixed Signal Control
Sebastiano Messina, Marco Torrisi, Giuseppe Di Caro, STMicroelectronics, I
A new digital device STNRGPF01 of STMicroelectronics, for Interleaved Boost PFC converters (IPFC) will be shown. The presentation will describe how easy it is to design an Interleaved PFC in Continuous Conduction Mode at fixed frequency with average current mode control. Starting from PFC specifications the STNRGPF01 can be configured by a dedicated software tool customizing the application. In this way, STNRGPF01 can be managed like an analog device, while offering all the advantages and the flexibility of digital solution.

Quasi-Constant Frequency Secondary Side Controlled Flyback Concept with Variable ON-Time
Arash Pake Talei, Kin Kennith Leong, Gerald Deboy, Giuseppe Bernacchia, Infineon Technologies Austria AG, AT; Alexander Connaughton, Graz University of Technology, AT
This paper introduces the novel Quasi-Constant Frequency Secondary Side Controlled Flyback concept with Variable ON-Time (VOT) control. The Flyback is controlled from the secondary side with communication to the primary side switch occurring through the coupled inductor itself, eliminating the need for opto-isolators and additional windings. The VOT control can achieve near constant frequency, ZVS or Q-ZVS, minimum output voltage ripple after load steps, minimized EMI, and natural overload current limiting.

Sensorless Control of a Bridgeless PFC Using a Low Pass Filter Model and a Linear PR Controller
Felipe López, Francisco Azcondo, Alberto Pigazo, Paula Lamo, University of Cantabria, ES
This paper proposes a new current sensorless solution applicable to control bridgeless PFCs converter. In comparison to single-phase, conventional PFCs, bridgeless ones increase the efficiency due to the absence of a bridge diode. Its efficiency can be further increased by avoiding the input current sensing. Instead, the input current is estimated: all the non-idealities of the inductor and the converter are modeled with a low-pass filter to obtain the grid current.

Optimised Modulation of Five-Phase Open-End Winding Drive
Ivan Zoric, Martin Jones, Liverpool John Moores University, GB; Milan Darijevic, Siemens AG, D
Paper presents a novel approach for multilevel multiphase drives modulation, based on different strategies combinations, with regard to dc-link voltage stability and other relevant drive parameters. This optimal modulation method is developed for a six-level five-phase open-end winding drive, with regard to the most dominant constrains in high-power industrial and automotive applications. Experimental results confirmed robustness and efficiency of the proposed concept.

Characterizing the Conducted EMI Performance of a Power Module Through Passive Measurement
Yu Liu, Infineon Technologies, D; Sergey Kochetov, BMW, D; Thomas Smazinka, Fraunhofer Institute IISB, D; Andreas Lindemann, Otto-von-Guericke-University, D
A novel EMI test procedure has been investigated, optimized and modified. The approach in this form makes possible to estimate the conducted EMI performance of power electronic modules without parameterization of the system environment.

A New Approach for Digital Controlled Power Supplies Regarding Pulsed Plasma Nitriding Systems
Lisa Franke, Lutz Zacharias, Mirko Bodach, Ringo Lehmann, Westsächsische Hochschule Zwickau, D; Andreas Böhm, Plasmanitriertechnik Dr. Böhm, D
In this paper a new implementation of a microcontroller based platform including the integration of digital power into Plasma Nitriding Systems using pulsed power supplies and the approach of a current feedback control is described. Main results of the investigations:
- Adaption of the pulse frequency of the control signal during the process
- Reliable fast peak current detection & fast turn off of the IGBT
- Current feedback control for test arrangement with equivalent circuit
- Digital power used as intelligent control unit

Power Supplies, Control and Drive

Combination of Forward-Voltage Measurement and Short-Circuit Detection for High-Voltage RC-IGBTs
Patrick Münster, Daniel Lexow, Dennis Cordt, Hans-Günter Eckel, University of Rostock, D
One possibility to determine the collector current´s direction of high-voltage IGBTs is the forward-voltage measurement via the high-voltage desaturation (HV DESAT) methode. In this paper the blocking capacitance of the DESAT diodes is used to detect short-circuits, without impairing the quality of the forward-voltage measurement. The presented detection is able to distinguish between low- and high-inductive short-circuit type 1, short-circuit type 2 and switching transients during normal turn-on.

Gate Driver IC for GaN GIT for High Slew Rate and Cross Conduction Protection
Aaron Qingwei Cai, Arnel Carrera Herreria, Howard Ban How Sin, Panasonic Industrial Devices Semiconductor Asia, SG; Liter Siek, Nanyang Technological University, SG
High Drain-Source voltage and current slew rates enable low switching losses and high frequency operation. However, it increases the chances of cross conduction. In this work, a driver IC was developed to drive the GaN GIT at high slew rates (>150V/ns) while having built-in active miller clamp and self-generated negative voltage rail for cross-conduction protection. Experimental results show

that the GaN GIT gate driver IC outperforms other methods by allowing faster slew rates and larger immunity to cross conduction.

Gate Drivers For Medium Voltage Applications
Pierre Lefranc, Sokchea Am, David Frey, Rachelle Hanna, Benoit Sarrazin, G2Elab, F
This paper presents a gate driver system for Medium Voltage applications up to 30kV. A signal and a power transmission fonctions are optimized to propose a first gate driver for such insulation voltage capabilities. A virtual prototyping tool and experimental results validate the proposed methodololy for the design of gate drivers. Insulation materials are also experimentaly validated.

Diode Effects Bring Liefetime Risks to Series Resistors
Wolfgang Frank, Infineon Technologies, D
The pulse power capability of resistors is often underestimated in cases of bootstrap and desaturation detection (DESAT) circuits. They are in series with diodes and operated with transient reverse voltages in combination. The critical cases of operation are different for bootstrapping and DESAT events. Both cases are explained in the final paper. It proves by simulation and measurements that pulse currents as well as reverse recovery effects can have a severe impact on the lifetime of resistors which are series-connected to such diodes.

FPGA Based Control of an Three Level Neutral Point Clamped Inverter
Markus Schaefer, Martin Hofmann, Sebastian Raab, Ansgar Ackva, University of Applied Sciences Wuerzburg-Schweinfurt, D
The accurate control of the line current, the robustness and the dynamic behavior are major factors within grid connected inverters. Due to weak grids additional properties are required. Direct current control in combination with multilevel inverters give opportunities for future system designs. As major requirements increases within those system very fast data processing is indispensable. To meet the mentioned demands FPGAs are an alternative to state of the art MCUs.

Investigation of Magnetical Coupler Immunity Against External High Frequency and Density Magnetic Field
Bernhard Strzalkowski, Analog Devices, D
Novel magnetical isolators provide signal isolation using micro transformers deposited on the top of an IC. As the transformers don't have ferromagnetic core concentrating internal magnetic flux, secondary winding doesn't distinguish between internal and external flux. External magnetic flux induces noises disturbing properly signal transmission. Appropriate windings arrangement and signal conditioning ensure reliable signal transmission. This paper shows magnetic field immunity of iCoupler. Tests have been performed in high density/frequency magnetic field environment. Test results confirm theoretical noise margin value.

Ultra Linear Switching Rectifiers (ULSRs) for High-Quality Regulated 3-Phase AC to DC Conversion
Alexei Nikitin, Avatekh, USA; Arlie Stonestreet II, Kyle D. Tidball, Ultra Electronics ICE, USA; Ruslan L. Davidchack, University of Leicester, UK
We present an Ultra Linear Switching Rectifier (ULSR), a regulated 3-phase AC/DC converter with an associated simple analog controller, characterized by exceptional power quality. A ULSR is wild frequency compatible, significantly exceeds the requirements on the power factor and on the limits of the reflected current harmonics imposed by DO-160, and provides a very well regulated DC output with small transient responses and fast recovery times in full range of the output powers.

Start-Up Operation of Active Three-Phase Third Harmonic Injection Rectifiers
Markus Makoschitz, AIT Austrian Institute of Technology, AT; Michael Hartmann, Schneider Electric, AT; Hans Ertl, Vienna University of Technology, AT
Previously, it has been shown that B6 rectifiers with DC-side smoothing inductor can be enhanced by an active circuit (based on the third harmonic injection principle) to a unity power factor high input

quality mains currents system. The active extension hence has to be able to boost its DC-link for proper current handling during nominal load operation of the B6 rectifier. Therefore, a specific short-term voltage/current control concept is required which is described and analyzed in this work.

State-of-the-Art GaN Power IC-based 150 W AC-DC Adapter
Tom Ribarich, Stephen Oliver, Navitas Semiconductor, USA
Traditional AC-DC adapter design has plateaued with only small improvements in efficiency and power density. With new high-frequency topologies, wide bandgap powertrains and new magnetic materials, major improvements are seen in adapters from 25 W to 200 W. This paper provides a detailed analysis of a 150W AC-DC adapter using CrCM PFC and LLC control with monolithically-integrated gate-drive GaN powertrain, achieving a 100% density increase vs. typical adapters.

Which Should Be Chosen in Three-Phase Diode Rectifier, Single-Bridge or Double-Bridge?
Ryu Kawakubo, Yasuyuki Nishida, Chiba Institute of Technology, J
This paper deals with comparison of characteristics of the single and the double three-phase-bridge diode rectifier to obtain technical information to choose appropriate one. To do so, some key characteristics of the rectifiers to be evaluated in the process to choose an appropriate topology have been discussed and picked out. Some discussion to explore an appropriate topology referring to simulation results has been given.

Digital Control of Active Resistance Emulation in Three Phase Rectifiers with Current Injection Principle
Radoš Vreljakovic, Predrag Pejovic, School of Electrical Engineering, RS; Milan Darijevic, Siemens, D
Digital control of active resistance emulation in three phase rectifiers witch current injection is presented in this paper. Two different realizations of active resistance emulation are explained and compared. Application of this method in current injection circuit increases system efficiency, while keeping optimal harmonic quality of input (phase) currents. Paper presentes simple, but robust realization, based on output current measurment and closed-loop control.

Power Inverters

Noise Mitigation in HV Tests Sourced by A Static Frequency Converter by Means Of Changing PWM Signal's Carrier Frequency
Mazen Alzatari, Janusz Szczechowski, ABB, D
Dr. Mazen Alzatari is a research and development engineer from the company ABB AG in Halle from Germany. He is interesting in the field of power electronic converters which are used for high voltage testing. More efficent and less complexity software/hardware are his main focusing working points.

Novel Active Ripple Filtering Schemes Used In Little Box Inverter
Rajesh Ghosh, Mudiyula Srikanth, Schneider Electric, IN; Radoslava Mitova, Miao-Xin Wang, Schneider Electric, F;; Damir Klikic, Schneider Electric, USA
Two novel schemes and control methods are presented for input current ripple reduction, and to improve the power density and reliability of single-phase inverter by reducing the size of the DC bus capacitor. Comparative analysis of the proposed schemes versus legacy schemes is also presented.

Experimental Study of Si- and SiC-Based Voltage Source Inverters
Klaus Sobe, Fabio Brucchi, Infineon Technologies Austria, AT
The present paper shows an experimental comparison of well-established three-level Silicon IGBT based inverters and two-level inverters based on SiC MOSFETs. Design hints to improve the cost-performance trade-off for both solutions are demonstrated and discussed.

Double-Loop Controlled Grid-Connected Inverter
Yury Skorokhod, Dimitriy Nitkin, Sergey Dyakin, Transconverter, RU; Sergey Volskiy, Moscow State Aviation Institute Technical University, RU
The paper presents the developed principle of the double-loop controlled inverter used in grid-tied photovoltaic conversion systems. The system block diagram and primary equations are described. The prototype 6.7 kVA output power inverter is developed and verified. The derived test results are provided and analyzed. This paper may be interesting for engineers developing power conversion systems comprising PV-panels and a grid-tied inverter.

Design and Realization of a 100kHz-100kW Series Resonant Inverter with SiC-MOSFETs Connected in Parallel for a High Frequency Induction Heating Application
Yildiray Baskurt, Haldun Karaca, Dokuz Eylul Universitesi, TK
Design and the realization of a high frequency series resonant inverter system for Induction Heating purpose. Parallel connection of SiC-Mosfet modules have been examined. Additonaly a new metodolgy for resonat tracking has been introduced

AC-Sweep Analysis and Verification of an AC Power Source with Virtual Output Impedance for Validation of Grid Connected Components
Peter Jonke, Markus Makoschitz, Biswas Sumanta, Johannes Stöckl, AIT Austrian Institute of Technology, AT; Hans Ertl, Vienna University of Technology, AT
The AC-sweep analysis and verification of an AC power source with virtual output impedance - which is mainly used for the development, validation and testing of grid connected components is presented in this work. Main objective of such specific test equipment is the integration of a control scheme for virtual grid impedance instead of using expensive and bulky hardware. The small signal bandwidth of the proposed system is at least 2 kHz, which requires a minimum target switching frequency of 200 kHz.

Technological Possibilities of New Silicon-Carbide Mosfets in Power-Inverter for the Inductive Energy Transfer
Martin Warkentin, Faical Turki, Thomas Vosshagen, Paul Vahle, D
This abstract includes the development of an gate driver with an boost circuit for the new silicon carbide mosfet modules to switch them with an 140 kHz frequency. Also an oscillating test circuit is build up to verfiy the switching losses and the resulting maximum output power for using them in an inverter for the inductive energy transfer.

Five-Level Cascaded Flying-Capacitor Converter
Sidney Gierschner, David Hammes, Hans-Günter Eckel, University of Rostock, D; Max Beuermann, Siemens, D
A new five-level converter is developed based on the three-level Flying-Capacitor (FC) converter. When extending existing three-level converters to a higher number of voltage levels, the more complex topology creates commutation circuits that consist of several power semiconductors as well as capacitors. Nevertheless commutation circuits have to be as low inductive as possible causing high complexity of the bus bar.

A Generalized Approach to the Analysis and Control of Modular Multilevel Converters
Patrick Himmelmann, Marc Hiller, Karlsruhe Institute of Technology (KIT), D
A general method to derive the control strategy for arbitrary modular multilevel topologies is presented. This includes the external currents and also the purely internal currents. The number of internal currents is derived from the topology. A strategy for arm symmetrization with arbitrarily controllable powers is given.

On Energy Balancing for a Full-Bridge MMC with Distributed Energy Storage Devices
Gerrit Henke, Mark-M. Bakran, University of Bayreuth, D

In this paper, a new approach to integrating energy storage (ES) in an MMC is examined. ES are not included in every MMC arm and circular currents are injected to maintain power balance within the MMC. It is shown that only a fraction of the MMC submodules need to be equipped with ES in order to maintain constant output power.

Comparison and Evaluation of Modular Multilevel Converter Topologies for Li-Ion Battery Systems
Matthias Luh, Thomas Blank, Marc Weber, Karlsruhe Institute of Technology (KIT), D
Various concepts for Modular Multilevel Converters (MMC) with integrated battery cells that offer considerable advantages in flexibility and efficiency have been introduced within the current decade. We compared different MMC topologies with integrated battery cells for 3-phase applications and will present their simulation results as well as a prototype. We also provide practical considerations for Modular Multilevel Battery System for high performance stationary/automotive battery systems.

Improved Efficiency Power Converters

Progress of High Power Multilevel Converters: Combining Silicon And Silicon Carbide
Christopher Dahmen, Rainer Marquardt, University of the Federal Armed Forces Munich, D
At present, Modular Multilevel Converter (MMC) are applied mainly for HVDC and developed further for future HVDC-Grids and Large Drives. While Half-Bridge submodules are currently preferred - because of lower losses and expenses - fully electronic fault management and protection will become a key requirement for future systems. A new submodule topology for MMC is presented, combining Si- and SiC-Switches, which meets these requirements and enables essential power loss reduction.

Direct Torque Control with Variable Level Discretization for Automotive Drives
Eduard Specht, Stefan Goetz, Christoph Aschauer, Christian Korte, Porsche Engineering Group, D
We present a scalable multilevel direct torque control method for multilevel converts with variable number of levels. In constrast to other methods, we do not require look-up tables for the generation of the output and are not limited to certain pre-defined number of levels or level amplitudes.

Analysis and Modeling of Efficiency Curve Dip in VRM with Low Output Inductance
Ann Starks, Zhiyang Chen, ON Semiconductor, USA
VRM performance requires a high efficiency solution in a small form factor. In order to achieve higher performance designs of VRM are moving to low-inductance solutions. An efficiency dip is always associated with low inductance VRM. For the first time, the efficiency curve "dip" is fully characterized, explained and simulated. This paper provides a novel simulation model of efficiency "dip" in the low output inductance VRM. The impacts of switching frequency, output inductance, MOSFET technology and application conditions are discussed to illustrate the effect on the "dip" and the simulation model is validated with experimental data.

EMI Considerations on MHz Inverters
Christoph Simon, Fabian Denk, Michael Heidinger, Rainer Kling, Wolfgang Heering, Karlsruhe Institute of Technology (KIT), D
Wide band gap devices promise higher efficiency and power density by increased switching frequency. However this is accompanied with higher filter effort to keep compliance with EMI regulations.This paper will present an estimation method for interference voltage caused by a resonant inverter operated at 1.8 MHz and for the filter effort to meet the standards, both supported by measurement. It concludes with a comparison of the benefits with the effort of a high switching frequency.

Analysis of the Impact of Silicon Carbide Modules in Wind and Traction Applications
Itziar Kortazar, David Ortega, Igor Larrazabal, Ingeteam, ES; Mrinal Das, Wolfspeed, USA

The use of Silicon Carbide semiconductors is a promising solution for converters optimization. In this publication the benefits of using it on existing Power Converters for Wind and Traction application is presented.

High Efficiency LLC-Based AC-DC Converter for Wide Load Voltage Range Applications
Navid Daniali, Euro Engineering, D
Design of a high efficiency LLC based AC-DC converter for wide load voltage range applications with three control loops is presendted in this paper.

A Novel Approach to Reduce Losses in Boost PFC Stage of a 90W-Adapter
Eva Schmidt, Daniel Kübrich, Thomas Dürbaum, Friedrich-Alexander-University Erlangen, D
Power supplies of consumer products require new strategies in order to further reduce losses. The study presented here deals with an improved PFC stage under consideration of various operating points and passive components. Detailed analyses based on numerical simulations allows to optimize a standard worldwide mains design. Additionally, the benefits of narrowed input voltage ranges can be quantified. More efficient and smaller designs become possible. The results are confirmed by measurements.

How the heck do I Measure a Gate Drive Slewing at 70kV/Us?
Bart Schroder, Cleverscope, NZ
Cleverscope have built a 120 dB CMRR isolated channel oscilloscope and signal generator for proving the performance of three phase inverters when under load. The system may be used to measure gate drive performance and impedance, timing characteristics, dynamic switch losses, EMI generation, Safe Operating Area and use these values to conduct a trade-off analysis. This presentation works through a gate drive evaluation using measured results.

Thyristor Rectifier for Permanent Magnet Wind Generators
Philip C. Kjaer, Ionut Trintis, Morten Risskov Knudsen, Stig Lund Pallesgaard, Vestas Wind systems A/S, DK; Peter Mongeau, Vestas Wind Systems, USA; Sébastien Touzard, Nabil Meziti, Semikron SARL, F
This paper reports on an investigation to improve efficiency in a wind turbine's generator-side converter. A thyristor phase-controlled rectifier is considered as replacement for the forced-commutated voltage-source converter, universally adapted in full-conversion wind turbines with permanent-magnet generators. The paper defines power capability vs generator speed and dc-link voltage level, with an accompanying closed-loop control scheme. Power loss analysis shows a fair improvement of the power conversion efficiency.

Evaluation of an Isolated DC-DC Converter for a Micro Inverter
Naoki Koike, Shinichiro Nagai, Pony Electric, J; Hiroki Watanabe, Nagaoka University of Technology, J
This paper investigates influence of the diameter of the litz wire to a transformer of an isolated DC-DC converter at high frequency.The usefulness of the smaller diameter of the litz wire with the isolated DC-DC converter at the high frequency was quantitatively shown in this paper.

STMicroelectronics Super-Junction and UltraFAST MOSFET vs IGBT Technologies in Low Power Motor Drives
Carmelo Parisi, Gaetano Belverde, Alessio Corsaro, STMicroelectronics, I
Market is demanding for efficient, compact and robust systems in the motor drive applications.STMicroelectronics offers a wide choice of power switch technologies to meet different operating conditions and the market requirements, such as IGBT, UltraFAST Power MOSFET and the newest Super-Junction Power MOSFET.A detailed comparison, in terms of electrical and thermal performance, among the three aforementioned technologies, assembled in the ST's Intelligent Power Module SLLIMM(tm)-nano, is provided in a low power motor drive application.

Active Switch Impact on CCM Totem-Pole PFC Efficiency
Matt O'Grady, Ke Zhu, Jonathan Dodge, John Bendel, United Silicon Carbide, USA
This paper presents the impact of active switch selection on an efficiency sensitive application using totem-pole power factor correction (TPPFC) topology in continuous conduction mode (CCM). Wide band gap (WBG) switches that provide low reverse recovery are a key enabler for a CCM TPPFC implementation. Several WBG based CCM TPPFCs with very high efficiency have been presented. As CCM TPPFC becomes a promising solution to reach 80 Plus Titanium efficiency standard, an appropriate selection guide of WBG active switches becomes pressing. A device loss model is developed for TPPFC topology based on datasheet characteristics and double pulse test results. The accuracy of the proposed model is verified with a 1.5 kW-CCM TPPFC testing platform operating at 100 kHz under low line (115 VAC) and high line (230 VAC).

Dc Bus In Industry a New Way Towards Energy Efficiency
Fernando Luiz Marcelo Antunes, Andre dos Santos Lima, Antonio Alisson Alencar Freitas, Aderaldo Racarte Guedes, Edilson Meneiro Sá Jr. Federal University of Ceara, BR
In this paper, it is proposed the conception of dc grid applied in industry. It is discussed the use of a dc bus supplying through inverters a group of induction motors, synchronous permanent magnet motors (SPMM). A supercapacitor-based enegy storage system is connected also to the dc bus for recovering of break energy and fast supply energy during motors starting. The dc bus supplies inverters connected to motor and could have a big tolerant level of voltage variation. With the utilization of supercapacitor recovery systems, new industry standards should be adopted and the use of complex bidirectional rectifiers could avoided once the energy of break and starting of motors will be controlled at the dc grid. Moreover, bidirectional rectifiers for high current has critical response for motor´s break energy recover and they are expensive when compared to traditional high current rectifiers.

Automotive, Traction and Aerospace

The Highest Power Density IGBT Module in the World for xEV Power Train
Akihiro Osawa, Keiichi Higuchi, Akio Kitamura, Daisuke Inoue, Yoshikazu Takamiya, Souichi Yoshida, Hiromichi Gohara, Masahito Otsuki, Fuji Electric, J
This paper demonstrates that the new 1200A/750V IGBT module which has the highest power density of about 700kVA/L for xEV power train. The new IGBT module target to the 200kW class motor.

J1-Series Modules with Integrated Cooler for Electric and Hybrid Vehicles
Tatsuya Kawase, Mikio Ishihara, Noburu Miyamoto, Kazuaki Hiyama, Shinsuke Godo, Mitsubishi Electric Corporation, J
This paper presents a new direct-cooled IGBT module with integrated cooler dedicated forElectric vehicle (EV) and Hybrid electric vehicle (HEV) power-train inverter applications.

Power MOSFETs for Low Voltage and High Current Automotive Applications- 48V Bus Systems
Rajagopalan Jagannathan, Marco Atzeri, Hans-Peter Hoenes, ON Semiconductor, D
In order to meet the strict CO2 emissions regulations 48V systems are an increasing trend among Automotive OEMs. Low voltage, high current MOSFETs are key components in such applications. In this paper the performance of MOSFETs in TO-Lead Less package based on latest 100V dense trench technology is discussed. Technology, package, thermal and switching performance, PCB layout and symmetry requirements for standalone and parallel operations are discussed based on simulations and measurements done on a reference design PCB.

Electrothermal Stresses in SiC MOSFET and Si IGBT 3L-NPC Converters for Motor Drive Applications

Zarina Davletzhanova, Olayiwola Alatise, Jose Ortiz Gonzalez, Sylvia Konaklieva, Roozbeh Bonyadi, University of Warwick, GB
This paper uses motor drive simulations as well as experimental results from a single phase 3L-NPC converter with Si/SiC devices to investigate the problem of electrothermal stress distribution in converter power modules.

High Efficiency and Ruggedness Intelligent IGBT Technology for EV/HEV
Vittorio Crisafulli, ON Semiconductor, D
The interest in commercial EV and HEV is driven by efforts to improve energy efficiency and reduce toxic emissions. High voltage/current IGBTs play a key role in these application. The paper introduces a new intelligent IGBT for traction applications. These new generation uses the latest Field Stop 3 IGBT and diode chip technology. Further electrical characteristics are presented as well as the intelligent features embedded in the IGBT Structure: high precise temperature and current sensor.

Highly Integrated Power Unit Based on Double Sided Cooling IGBT Module
Yun Li, Shiwu Zhu; Yaing Ma, Yangang Wang, Mingliang Jiao, Chundong Wu, Zhenlong Zhao, Jun Yu, Dynex Semiconductor, GB
This paper presents an Integrated Power Module (IPM) and an Integrated Power Unit (IPU) which are based on the IGBT double sided cooling technology. The IPU can be used as the motor control inverter in the electric vehicle. While the IPM used in the IPU is packaged with latest 650V trench field-stop IGBT device and double sided cooling technology. With the double sided bonding and cooling technology, reliability and thermal performance of this IPM have been greatly improved. Compared with the traditional single sided cooling module, thermal resistance has been reduced by 23% according to the test. Equipped with the active gate driver technology, power losses of the IPM have been greatly reduced. Operation of IPU system with battery voltage up to 450V and output phase current 450Arms has been achieved. Test results of the IPU system are also introduced.

Efficiency Increasing by a Variable DC Link Voltage in Combination with a Bang-Bang Controlled Inverter for an Automotive Application
Magnus Böh, Andreas Lohner, Noureddine El Amrani, TH Köln, D
By adjusting the DC link voltage the losses can be decreased due to the less DC link voltage which is switched. Furthermore, even more efficiency can be reached, by modifying the modulation method of the inverter. Due to the using of a bang-bang current controlled inverter the switching frequency is mainly depending from the back-emf voltage of the machine, the DC link voltage and the motor inductance. By adjusting the DC link voltage it is possible to optimize the switching frequency.

Magnetic Leakage Azimuth Pattern of a 7 Kw Wireless Electric Charging System in Different Environments
Leandro Percebon, Daniel Kuerschner, Qualcomm CDMA Technologies, D
This paper presents a study of the magnetic leakage field pattern of a 7 kW wireless electric vehicle charging (WEVC) system. The leakage field was measured in different test configurations and environments which afterwards were used to validate simulation models. The impact on magnetic field pattern when changing test environment and test setup are presented and its results are used to carry out discussion and suggestions on upcoming standards to measure magnetic leakage field of WEVC.

Innovations for IGBT Based Power Modules in HEV Drivetrain Applications
Thomas Geinzer, Martin Gleich, Alexander Schwarz, Infineon Technologies, D
To ensure compact design and cost efficiency for the next generation of hybrid and electric vehicles (HEV), it is important to improve IGBT based power modules not only for the main inverters. This paper describes how both targets can be reached by use of a novel technology for IGBTs and by enhanced package concepts with innovative cooling and interconnections technologies. Utilizing these innovative technologies leads to an enormous reduction of the footprint as well as costs for inverters as a key for the success of HEVs.

Estimation of the Losses in Si and SiC Power Modules for Automotive Applications
Dounia Oustad, Menouar Ameziani, Dominique Lhotellier, VEDECOM, F; Stéphane Lefebvre, Meckael Petit, ENS Cachan, F
This paper compares 1200V-120A Silicon Carbide (SiC) MOSFET module with 600V-100A Silicon (Si) IGBT module performances in different converter topologies (2 and 3 level inverters) and it focuses on the prediction and the study of the veracity of a losses model (both conduction and switching losses) in Si IGBT and SiC MOSFET power modules used for electric vehicle applications. It shows a test case based on an experimental estimation of losses with a double pulse test circuit. The behavioral model is only linked to the knowledge of the IGBT, MOSFET and diode characteristics obtained from datasheets. Then, it is compared with experimental measurements. The veracity of these models is evaluated, the errors are quantified and if necessary, additional characterizations that will be performed to complete the data from datasheets will be identified. An estimation of the losses with sufficient accuracy will be obtained for different switching conditions (voltage, current, temperature, gate resistance and stray inductance).

DC/DC-Converter with Optimised Power Density for Integration of Multifunctional Fuel Cell Systems in Modern Aircraft Application
Mathias Warncke, Klaus F. Hoffmann, Sebastian Fahlbusch, Helmut Schmidt University- University of the Federal Armed Forces Hamburg, D
For the future integration of a multi functional fuel cell system "MFFCS" in more electrical aircrafts "MEA", weight and mass optimised power converters are required. In aviation, the system reliability and the system mass have higher priority than achieving highest possible system efficiency. Therefore, a power density optimized DC/DC converter has been developed which is designed for operation within the harsh environmental conditions evoked by high cooling temperature of the MFFCS.

High Perfomance Power Electronics

Influence of Different Switching Frequencies and Modulation Techniques on IPMSM and Inverter Losses Optimizing the Overall Drive Train Efficiency
Martin Stempfle, Yuying Han, Julian Wölfle, Nathan Tröster, Jörg Roth-Stielow, University of Stuttgart, D
The paper shows the benefit of using a variable switching frequency and modulation technique on the driving cycle WLTP3. Therefore the inverter and the machine losses are analysed.

Finite Control Set Model Predictive Control of a PMSM Fed by a Multilevel Inverter
Cristian Vargas, Simon Feuersänger, Mario Pacas, University of Siegen, D
This paper presents a finite control set model predictive control (FCS-MPC) of a permanent magnet synchronous machine (PMSM) fed by a three level neutral point clamped voltage source inverter (3L-NPC VSI), in which the torque and flux producing current components iq and id in the rotating reference frame, the neutral point voltage, and the switching frequency are controlled. The switching frequency is controlled by means of the number of commutations required to change from one space vector to the next. This paper shows simulation as well as measurements on a low voltage inverter to validate the approach. Additionally, a comparison between Model Predictive Control and Field Oriented Control is carried out concerning steady state and dynamic performance. The preliminary results are presented, yet the code must be optimized to reduce the sample time and eliminate some dead times. Final results will be shown in the final paper.

Current Control Delay Reduction for FPGA-Based Servodrive
Lev Rassudov, Balkovoi Aleksandr, Moscow Power Engineering Institute, RU
The parallel processing power of an FPGA together with model predictive control strategies enables ultimate performance of a servodrive in terms of tracking precision and control bandwidth. In the paper the Dynamic model quasi-continuous current control with regular feedback sampling control approach

is presented. It enables to significantly decrease the current control delay time in case of high current reference oversampling rates and low PWM inverter output voltage amplitude. The theory was proved by simulation and experimental results.

Optimal Compensation Capacitors Maximizing Coreless Inductive Power Transfer
Yohan Wanderoild, Romain Grezaud, Gael Pillonnet, Dominique Bergogne, Adrien Morel, CEA-Léti, F; Hubert Razik, Laboratoire Ampère, F
This paper first describes the differences between two coupled coils and the conventional transformer model. Based on this statement, the most popular compensation topologies are then studied. Finally, a specific design methodology is introduced and experimentally validated to maximize the wireless power transfer with a coreless transformer.

Switching Loss Minimization Using Two-Configuration Predictive Control for a Thermo-Hydraulic Linear PMSG
Daniel Bernet, Karlsruhe Institute of Technologie (KIT), D; Robert Seifert, Technical University of Dresden, D
An adaptive two-configuration predictive control for the combustion process coupled application of an inverter-fed thermo-hydraulic linear permanent-magnet synchronous generator for mobile machinery is proposed.
The thereby required rectangular current trajectories and very high efficiency are achieved by combining loss minimizing switching sequences and force deviation reducing duty cycles.

Energy Storage Battery Protection System with Externaly Triggered Melting Fuses
Mitja Koprivsek, ETI, SI
This paper would like to show the new approach how to create the right solution for protection of electric energy storage batteries in order to prevent heavy damage in case of sever electrical fault, e.g. direct short circuit between both electrical poles. One of existing and well accepted solutions are melting fuse intended for use in DC circuits with batteries. Proposed paper presents battery protection system with externally triggered melting fuses, which means new generation of protection against short-circuit arc fault in every electrical energy storage battery.

Approach of Optimization of Power Leveling System Using Multi-energy Storage Devices
Toshihiro Shimao, Koji Kato, Keisuke Nakano, Yoichi Ito, Sanken Electric, J; Hitoshi Haga, Nagaoka University of Technology, J; Kenji Arimatsu, Katsuhiro Matsuda, Tohoku Electric Power, J
An energy storage system is integrated into a power-grid to compensate for the power fluctuation from renewable energy systems. This paper proposes a high-efficiency and low-cost energy storage system for the power-grid. The proposed system combines multi-energy storage devices such as a LiB and an EDLC for reducing the cost incurred by the system for the complete operation period. Experimental results demonstrate that the proposed control method effectively compensated for the power fluctuation from the renewable energy system.

Single-Phase PWM-Based Unity Power Factor Rectifier with Adaptive Predictive Current Control
Swen Bosch, Jochen Staiger, Heinrich Steinhart, HTW Aalen, D
In this paper, the control of a unity power factor rectifier with an adaptive predictive current control structure, realized in the natural frame, is presented. The control structure is easy to implement, requires only low computational effort and offers very good results regarding THDi and power factor. The hardware is based on a LCL-Filter, a single phase leg and a divided dc link, where the neutral is connected to the midpoint. Due to the applied hardware setup, the presented control structure can be easily adapted to three-phase systems.

Software Tools and Applications

Design of Test-system for EMC Investigations of Systems with Magnetron
Jan Leuchter, Quang Huy Dong, University of Defence, CZ
The aim of this paper is to introduce design of automated workstation, which was created for testing of the electromagnetic compatibility (EMC) of the system with magnetron. Measurement of EMC determines the behavior of electrical systems from the perspective of electromagnetic radiation with electronic circuits. The main part of the automated workstation design includes the program design with environment Vee Pro, which can be allow to remotely control the measuring device. This paper describes the workstation design and some results of experimental checking and testing of EMC of the system with magnetron.

Development of LabVIEW Models for Resonant Power Converters
Tsveti Hranov, Nikolay Hinov, Technical University of Sofia, BG
The paper presents the modeling of electronic energy converter in the popular development system LabVIEW. The various hardware extensions and software capabilities it allows an intuitive, easy and comfortable way to examine, study and prototype various kind of devices in the field of the power electronics industry. The investigated devices are the full-bridge resonant inverter with reverse diodes and the series full-bridge resonant DC-DC converter.

A Novel Detailed Analysis of the Flyback Converter Utilizing a Transformer with Nonlinear Magnetizing Inductance
Panagiotis Mantzanas, Thomas Duerbaum, Friedrich-Alexander-University Erlangen, D
Recent investigations have demonstrated that the efficiency of a flyback converter can be increased by employing a transformer with saturable magnetizing inductance. For a proper design, the converter waveforms have to be accurately predicted. This paper proposes an analytical calculation method for the waveforms of this flyback converter. In contrast to circuit simulators, a high computational efficiency as well as a high accuracy is obtained at the same time.

eDesignSuite: A New Design Tool for Digital Power Solutions
Carmelo Giuseppe Viccica, Marcello Palano, Natale Porto, STMicroelectronics, I
STMicrolelectronics has developed an Interleaved Boost PFC converter, based on a digital IC (STNRGPF01), and has added to eDesignSuite web portal a new design module for addressing the development of mixed (analog/digital) signal application. Our tool is an expert system that provides a complete schematic, sizing analog parts and creating the customized firmware for STNRGPF01.

Design MMC-Based Multi-Port DC Hub for Multiterminal HVDC Grids
Epameinondas Kontos, Haris Papadakis, Michalis Poikilidis, Pavol Bauer, Delft University of Technology, NL
It is foreseen that in the future, projects that operate at different voltage levels would need to get interconnected to form larger and more stable dc grids. To achieve this, a multiport dc-dc converter design based on modular multi-level converters (MMC) is proposed. The design and control requirements of a multi-port dc-dc converter are elaborated and its operation within an HVDC grid is verified using Matlab/Simulink.

Direct-Model Predictive Control for Fault Ride-Through Capability Enhancement of DFIG
Mohamed Abdelrahem, Ralph Kennel, Technical University of Munich, D
This paper proposes a direct-model predictive control (DMPC) system for fault-ride through (FRT) capability enhancement of doubly-fed induction generators (DFIGs) in variable-speed wind turbine systems (WTSs). The proposed FRT strategy uses the DFIG-rotor inertia to store the surplus energy during the grid voltage dips/faults. Moreover, the proposed FRT strategy enhances the ability of the DFIG to inject active and reactive power to the grid during serious voltage dips/faults.

AutoCrearTM - a Novel Software Tool for Automatic Creepage and Clearance Analysis
Michael Martinek, Jürgen Pröll, Oxana Kleinöder, e-laborate Innovations, D; Günther Greiner, Friedrich-Alexander-University Erlangen-Nürnberg, D

AutoCrear is a novel software tool for automatic creepage and clearance analyses on CAD data. Creepage and clearance are important safety issues in the design of electric assemblies and there are strict regulations which define minimum distances between different voltages. AutoCrear allows for an exact and automatic computation of all possible creepage and clearance paths and, thus, optimizes the construction of electric assemblies by detecting product errors in the early design stage.

Power-Hardware-In-Loop Setup for Power Electronics Tests
Giovanni De Carne, Marius Langwasser, Xiang Gao, Giampaolo Buticchi, Marco Liserre, Christian-Albrechts-University, D
Evaluating the power electronics behavior in real grid conditions is challenging. In simulation, large grids can be simulated, however the power electronics, cannot show realistic performances, due to simplified models adopted. Instead, lab experiments give more accurate analysis, but in smaller scale. The Power-Hardware-In-Loop (PHIL) evaluation solves this problem, simulating complex grids in software, and interfacing them with real hardware by means of an interface converter.

Ensuring Fast Turn-Around Times for A Programmable Digital Power Controller
Markus Schnell, Jörg Oehmen, Infineon Technologies, D
Programmable digital power controller promise fast turn-around times for new product development and customer change requests. By only changing a few lines of code, the system can behave very differently. This capability is also a liability of a programmable controller: To ensure the actual behavior of the system conforms to the desired behavior, it is necessary to keep the effects of changes under control. In this paper, we show the influencers of turn-around time when building systems with programmable digital power controllers and highlight approaches from state-of-the-art large scale system development to realize fast turn-around times.

A New Optimization Algorithm for Power Electronics Using the Mixed Integer Linear Programming Method
Marco Schilling, Tobias Reimann, Technical University Ilmenau, D; Ulf Schwalbe, ISLE Steuerungstechnik und Leistungselektronik, D
This contribution presents an new optimization method for the hardware design of power electronics. A practical design and optimization example of a 5kW drive train inverter will be presented after the introduction of the optimization process. The benefit of the presented method is the structured approach - unexperienced design engineers will get experience and a "feeling" for the influence of the system components to the overall system behavior.

Novel Efficient and Reliable Network Simulation by Means of Lipschitz Constants
Carsten Kuring, Technical University Berlin, D; Julian Dobusch, Thomas Dürbaum, Friedrich-Alexander-University Erlangen, D
Optimization of power electronic circuits is commonly based on a simulations using time-discrete modelling. Complex circuits can be presented by a set of linear differential equation systems. Utilization of Lipschitz enables a self-adapting zero observation. Reliability of the implemented algorithm is determined by the smallest predefined step size. In comparison to grid sampling, computing efficiency is improved as high resolution sampling is only applied to the extent it is locally needed.

Hardware-in-the-Loop Parallelization for Fully Automated Testing of "AVL E-Storage BTE"
Selimcan Deda, Roland Greul, Guenter Prochart, AVL LIST, AT
This abstract presents an approach to test the functionality of E-Storage Battery Tester & Emulator (BTE) System in an automated FW build process and test automation. The special attention is given to parallelized HIL systems to overcome limited IO capacity and processing power of a single HIL device.

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Keynotes

Keynote: Long Distance Charging Solutions for BEVs: from now to 2030
Robert Lassartesses, Renault, F
This keynote will describe different charging solutions which are already available for a long-distance drive with a BEV (battery electrical vehicle) today as well as the trends for the future. Pro and contra will be shown. The today trend is to increase the battery and the fix charger power. However, this trend limits the mass market for BEVs. The keynote will show some of these limits on the car point of view (battery cost/packaging/weight, uncertainty on specific material availability and environmental consideration). Game changer as charging during driving could solve these mass market car roadblocks. Charging during driving transfers an important investment part from BEV to infrastructure by reducing battery size or in other words transfers investment from the BEVs owners to the public. If we consider that 5000 euros could be saved by reducing the needed battery size and if we consider 30 % EVs to be sold each year, it would represent 3 billion euros investment each year for road infrastructure only for a country like France. In any case, hundreds of billions will be needed though the world to equip the road in coherence with the high number of BEV expected from now to 2030. To insure profit, each investment needs to be secure for a least 10 years. A very good long term common understanding in the system BEV+ charging infrastructure roadmap is needed between partners to insure BEV success. Even today, if the mainstream of the EV industry invests in huge numbers of powerful fix charger (right now from 43 kW AC to DC 350 kW), many solutions could arrive aside the mainstreams to insure possible lack of fix chargers in dedicated areas or specific timeslots (winter vacations...

Keynote: The Smart Future of Power Electronics and its Applications
Hans Krattenmacher, SEW-Eurodrive, D
Power electronic components have been used for decades in devices in the field of electric drives e.g. inverters, power supplies etc. One of the most important devices is the conventional frequency inverter which is employed in countless applications of the conveyor technology, materials handling technology as well as the field of machine automation. The technology and therefore the power electronics have been adjusted, improved, optimized and perfected to fit the applications throughout the years. However the application itself hardly changed as the main focus lied on making it faster, more efficient and more robust.
The scope of Industry 4.0 possibly brings fundamental changes to the manufacturers of these plant automation technologies leading to completely different tasks, ways of thinking and requirements and therefore different solutions.
The traditional stationary materials handling technology, in which many gearmotors and electronic components are built into, will be replaced by mobile materials handling systems. Based on this knowledge it can be concluded that the product in its current form will no longer be needed in the solutions of tomorrow.
The production philosophy for the future SMART Factory will be organized and operated in a completely new way. Power Electronics will remain an enabling technology however the converter technology will become "SMART". SEW as a trendsetter for the future SMART Factory which will be demonstrated as an example. This keynote aims to outline how this fundamental change of the well-known applications in the field of intralogistics as well as materials handling technology may look and what consequences it will lead to.

Keynote: Evolution in Topologies as a Result of New Devices and Enabling Technologies
Ionel Dan Jitaru, Rompower, USA
The topic that new topologies may be needed as the progress in semiconductor industry and other enabling technologies are emerging, has been raised with different occasions. In order to make a prediction of such developments we need to look into the evolution of the basic topologies in the last thirty years and analyze the impact introduced by the new semiconductor devices, magnetic technologies and control ICs. Though in the last thirty years no more topologies were introduced, we did noticed a clear shift in the ?preferred topologies? used by engineers in power conversion. That

shift did occur mostly due to the progress in semiconductor devices. Another key role was played by the type of applications in power electronics which changed some of the specifications and favored some topologies over others. Recently the availability of digital control has opened the door to intelligent power processing, and allowed us, for example, to take a conventional topology and convert it in ?soft switching topology? without any changes in the hardware. This presentation will look at the progress of some topologies over the years such as flyback topology, forward derived topologies including the two transistors forward, half and full bridge topologies and the changes made in order to further improve the performances. Though some of the ?old? topologies were not fundamentally changed, modifications did occur for performance enhancement. As an example, the flyback topology evolved over the years initially through the magnetic optimization, and further through control methodology, wherein in the latest flyback topology the energy contained in all the parasitic elements in harvested and the performances greatly improved, achieving soft switching in primary and secondary with minimum hardware changes. The same does apply for the half bridge and full bridge topology, wherein the latest generation of half bridge and full bridge topologies do have soft switching both in primary and secondary across the synchronous rectifiers and this is done mostly through the intelligent power processing, possible today due to the digital control. Even in the case of two transistor forward topology, one of the most popular topology over many years, has recently benefited by some key improvements. The latest two transistor forward topology achieves soft switching both in primary and secondary, with minor hardware changes and through intelligent control. The same evolution is achieved also in the traditional boost converter, which evolved in the latest applications in PFC wherein the efficiency went above 99% mostly due to the GaNs and intelligent control. Though the basic boost topology remained the same, some modifications were introduced to improve the performances and convert it into a true soft switching topology. After scanning the improvements in the last 30 years in power conversion it is concluded that the traditional topologies were not replaced but they evolved especially in the last ten years due to the introduction of new devices and the availability of intelligent power processing through digital control. The paper will be highlighted with design examples of such improvements of the basic topologies over the years.

Manuscripts which were handed in late

A Scaled PIN Diode SPICE Model for Power System Optimization
Mehrdad Baghaie Yazdi, James Victory, ON Semiconductor, D; Dongsoo Kim, ON Semiconductor Korea, ROK