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POWER GaN

GaN-Based Switcher ICs Empower Next-Generation Power Products

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COVER STORY

GaN-Based Switcher ICs Empower Next-Generation Power Products

There have been a number of disruptive advances in the power electronics community over the last 20 years. These changes - from switching power supplies to digital power management to AI-driven systems - have moved the industry forward. Up until recently, these advances have mainly been topology and system design. However, in recent years, arguably the most significant disruptive change has been the advent of wide-bandgap semiconductors such as Gallium Nitride (GaN). GaN offers very real benefits over Silicon, including enabling much higher switching frequencies and/or significantly increasing energy efficiency. By all metrics, a GaN device is simply a better switch than Silicon. However, GaN devices have mostly only been available in the form of discrete components, which require considerable effort and finesse to design into systems than would a more integrated solution. In 2019, Power Integrations launched its GaN-based InnoSwitch™3 family of offline CV/CC flyback switcher ICs, delivering up to 95 % efficiency across the full load range, and up to 100 W in enclosed adapter implementations, all without requiring a heatsink. This industry-leading increase in performance is enabled by using an internally-developed high-voltage GaN switch technology. This approach yields overall circuit performance, size and system cost benefits, providing customers with an easy adoption curve: the new GaN devices build on established Silicon products delivering significantly improved performance that can be cost-effectively implemented into existing designs.
More details on page 19.

Cover image supplied by Power Integrations, USA

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Current Sensing Moves In Advanced Embedded Systems

The embedded electronics development community is currently experiencing the biggest changes in our industry since the creation of the integrated circuit. From new software-oriented solutions like Artificial Intelligence, to new hardware topologies, to new semiconductor materials, we are in the middle of a disruptive period of demanding growth. **Khagendra Thapa, VP of Business Development, ACEINNA Inc., Andover, USA**

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A Step Forward to Miniaturize Current Sensing in Power Conversion

Modern power conversion systems must simultaneously become more efficient, smaller and cheaper than previous generation. LEM has used its expertise in this field to create a single chip package, the HMSR. **Stepanie Rollier, Product & MarComs Manager, LEM, Geneva, Switzerland**

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PCB Design for Low-EMI DC/DC Converters

Every switch-mode power supply presents a wide-band noise source. Integrating a DC/DC converter from the car board net into an automotive control unit and still fulfilling the EMC requirements of automotive OEMs is a difficult task. With the view that layout, with its parasitic elements, is part of the circuit, PCB design can be optimized for low EMI in DC/DC converters. The MPQ4431 buck converter from MPS demonstrates that careful component placement and board layout help make it possible to meet the strict EMC limits within the automotive industry. **Jens Hedrich, Senior Field Application Engineer, Monolithic Power Systems, USA**

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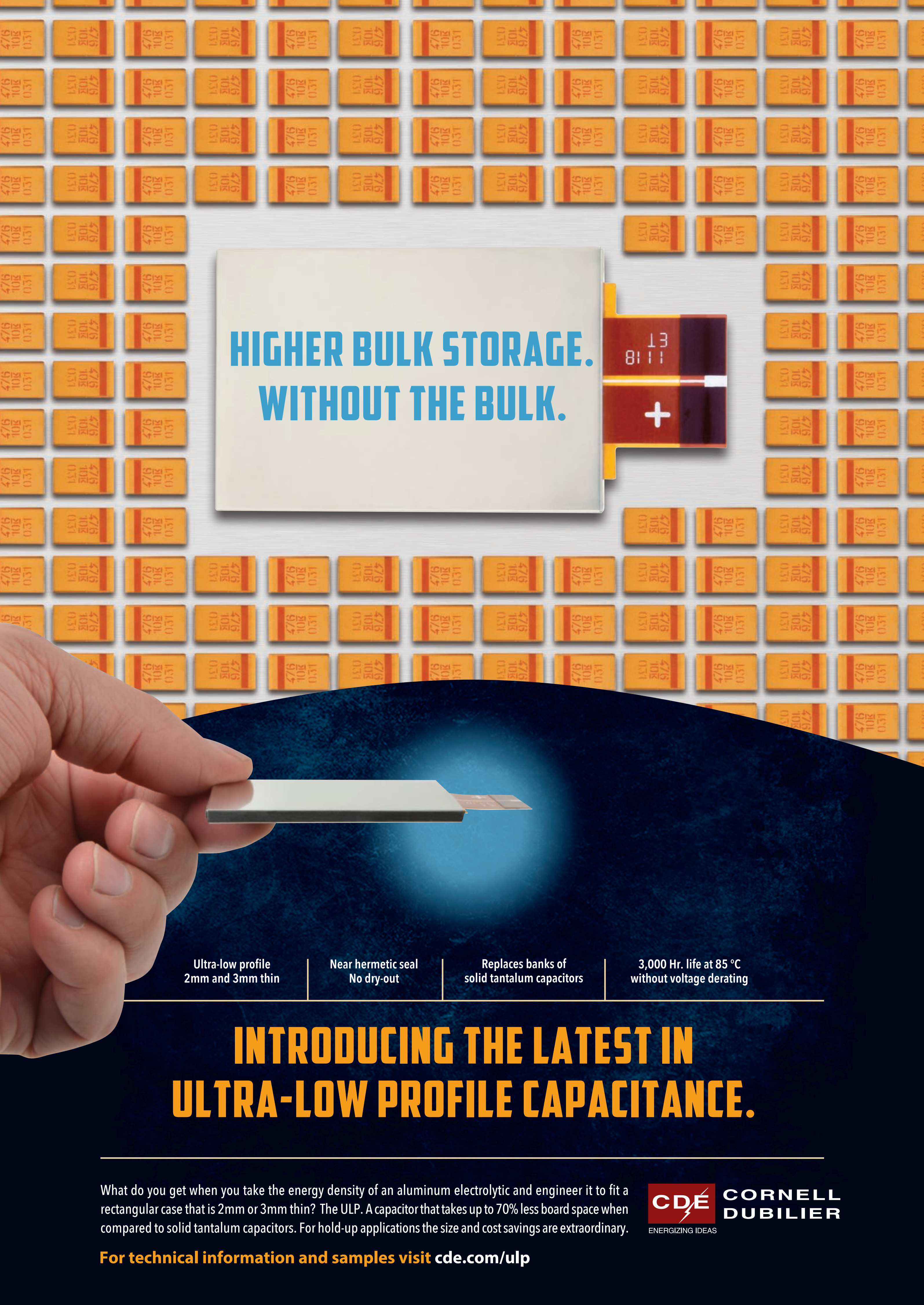
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Changes in the Decade to Come

Energy efficiency is now a strategic initiative in increasingly power-reliant industries such as data centres, electric vehicles, renewable energy systems, industrial motors, and consumer electronics. How businesses choose to generate, store, deliver, and use power will be an important impetus for global change in 2020.

The EV/HEV race has begun. More than $300 billion of EV/HEV investments have been announced by different OEMs, clearly confirming the automotive industry's commitment to governmental carbon reduction targets. The transformation of the automotive supply chain is ongoing. In particular, many questions involve China, which is today the biggest market for electric cars. For EV/HEV components, China has different levels of technology and independency. Regarding battery, China has top suppliers like CATL and BYD. However, the majority of IGBT power modules are still manufactured outside of China. The trend towards increasing the share of Chinese-made products is clear, and some companies have started working to build a local supply chain - for example, BYD built its own IGBT product line and is developing SiC MOSFETs, stated market researcher Yole. Driven by the prosperous EV/HEV market, the market for semiconductor power electronics devices should have a bright future, with value exceeding $3.7 billion in 2024 at a 2018 - 2024 CAGR of 21 %. IGBT modules represent the largest market, which is expected to double in five years. Silicon carbide (SiC) power modules will also grow fast, with a 2018 - 2024 CAGR of roughly 50 %. The implementation of SiC power devices in the Tesla Model 3 EV's traction inverter has created plenty of interest. Indeed, high-power traction inverters represent a huge new business opportunity for suppliers of SiC devices, suitable device packaging solutions, and SiC-based systems. Also, interest in gallium nitride (GaN) has recently revived, mainly as a potential candidate for future EV/HEV 12 – 48 VDC mild hybrid converters and onboard chargers. The evolution of the design of chargers and traction inverters will play a major role in automotive design studios in 2020, and then onto the public roads in the years following. In order to address the long-standing issue of 'range anxiety,' the number of public electric charging stations will continue to grow, with an increasing focus on solar power and plug standardization. Thus the demand for EVs will continue with fuel efficiency pressure and driving range at the center of consumer demands. Designs from major auto manufacturers will focus on increased efficiency, power density and reduced weight with a focus on Chargers and Traction Inverters.

In 2019, GaN Systems witnessed GaN's proliferation also in the consumer electronics space with an abundance of smaller, lighter, and higher power adapters/chargers in the aftermarket. The tiny adapters had everyone's attention as size and weights were decreased by 2X or 3X. Growing momentum for USB-C and USB-PD products which can be used to charge any compatible product. The days of one charger for one piece of electronics will quickly disappear and the days of one charger for all your electronics will begin to dominate. A single adapter/charger that handles every device regardless of varying voltages for a phone (5 V), tablet (12 V), or laptop (19 V). USB-PD will garner increasing commercial interest across industries besides mobile phones and computers with its spec for higher power (100 W) applications. Industrial markets will also demand a new generation of smaller and more powerful chargers for uses in portable test equipment, industrial equipment, medical and supply chain applications.

In 2019, Power Integrations launched its GaN-based InnoSwitch3 family of offline CV/CC flyback switcher ICs, delivering up to 95 % efficiency across the full load range, and up to 100 W in enclosed adapter implementations, all without requiring a heatsink. This increase in performance is enabled by using an internally-developed high-voltage GaN switch technology. Developed specifically for offline power conversion applications, the devices realize the performance benefits promised by wide band-gap technology. Losses in GaN switches are almost entirely due to inter-nodal capacitances, which are much smaller in GaN compared to Silicon MOSFETs due to the reduced size of the switch for a given on-resistance. The new switches give the InSOP-24C-packaged devices the ability to deliver much higher power levels without a heatsink, a benefit which comes from substantially increasing the overall power supply efficiency. A major challenge when using GaN is the difficulty in driving the transistors and protecting them. GaN is so much faster than silicon that even small amounts of parasitic trace inductance and capacitance causes challenges to safe operation. Common issues include high dv/dt frequency oscillation during switching, which creates EMI, lowers efficiency, and some cases can cause destruction voltage stress on the device. Power Integrations resolved the issue by embedding the GaN switch in its switcher ICs, which significantly reduces parasitic inductances and capacitances (see our cover story).

Thus, the journey with SiC and GaN is ongoing. For example, nearly half of the APEC and PCIM 2020 papers are now dealing with wide bandgap technologies and applications. At the PCIM Europe event we will host again a panel discussion with leading industry representatives on GaN – Past, Present & Future. First GaN products have been introduced in 2010, now after ten years it is time to check the status of this industry and to have a look forward.

Enjoy reading!

Achim Scharf
PEE Editor

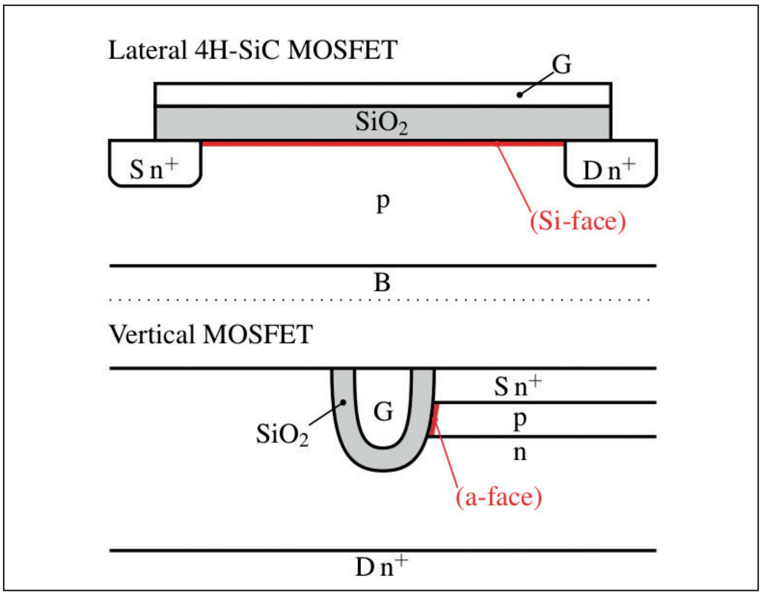
New Research Results in Power Semiconductors

Innovative Devices for an Era of Connected Intelligence – this was the theme of the 2019 IEEE International Electron Devices Meeting in December. It reflected the conference's focus on the processors, memories, 3D architectures, power devices, quantum computing concepts and other technologies needed to drive diverse new applications of electronics technology forward. SiC and GaN (see PEE 6-19) played a major role in the power semiconductor sessions.

To further enhance the efficiency of MOSFETs SiC has emerged as a perfectly suitable substrate material. Even though the performance of 4H-SiC MOSFETs has been substantially improved in the recent past, their reliable operation is still affected by numerous defects located in the proximity of the channel. In contrast to Si devices only little attention has been put on modeling of defects and their impact on the SiC device characteristics so far. The large number of defects present in SiC devices cause a sub-threshold hysteresis of the transfer characteristics and also large drifts of V_{th}. While the former is typically considered a fully reversible effect, the latter accounts for long term drifts of V_{th}, giving rise to the so called bias temperature instability (BTI).

In general the defects can be categorized into interface states, border and oxide traps. From experiments it has been observed that the defect densities strongly depend on processing parameters, e.g. post oxidation annealing (POA), and also on the channel surface termination, which is different for lateral and vertical channel devices.

In this work Infineon Technologies Austria and the TU Wien characterized and simulated charge trapping in lateral SiC MOSFETs. Advanced measurements (eMSM,pMSM,RVS) with long stress and recovery times are conducted on both SiC technologies and fully reproduced through simulations. Simulations rely on the two-state NMP model to describe the charge transitions of the involved border traps. Two electron (shallow and fast) and hole trap bands are identified and used to explain PBTI and NBTI in lateral devices. The shallow traps modeled with similar parameters as in Si/SiO2 suggest an intrinsic charge trapping behavior of SiO_2, which is supported by a comparison with slow V_{th} drifts in vertical devices. Based on this simulations accurate lifetime predictions can be made. While empirical models appear to provide too pessimistic (power law) predictions, these results provide a physics based extrapolation at operating conditions.



Schematic of a (top) lateral 4H – SiC/SiO_2 transistor with Si-face (0001) terminated interface and a (bottom) state-of-the-art vertical channel MOSFET with a-face (1120) terminated interface. The simulation tools are adjusted and used to explain lateral devices, and finally benchmarked with vertical devices.

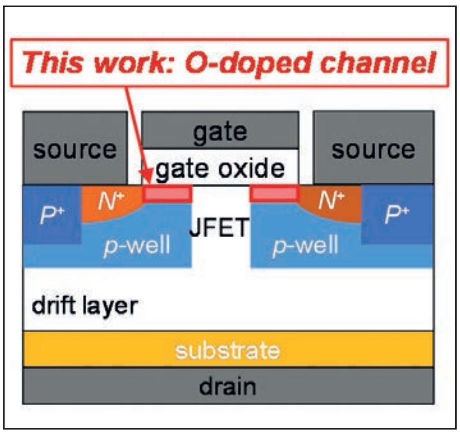
Oxygen-doped SiC gate

Mitsubishi Electric Corporation and the University of Tokyo demonstrated a Si-face 4H-SiC MOSFET with Oxygen (O) doping in the channel region. Compared with a conventional device, the O-doped channel provides lower channel resistance (Rch) and higher threshold voltage (V_{th}), which is expected from the fact that O acts as a deep level donor in 4H-SiC. By applying this novel technique to vertical 4H-SiC MOSFETs, 32 % reduction of specific on resistance at a high V_{th} of 4.5 V was achieved.

In order to evaluate gate oxide reliability, negative bias temperature instability (NBTI) of V_{th} was investigated. The O-doped channel shows a smaller V_{th} shift, and its acceleration coefficient of the time to V_{th} shift is similar to that of a conventional device. Therefore, the O-doped channel is found to be a promising approach to further improve NBTI of 4H-SiC MOSFETs by channel engineering using deep level donors.

The E_{ion} of O in 4H-SiC was evaluated by deep level transient spectroscopy (DLTS) using Schottky barrier diodes and simulation of electrical characteristics of MOS capacitors. Lateral and vertical Si-face 4H-SiC MOSFETs with O-doped channel were fabricated by implanting O in the channel region, and the trade-off between R_{ch} and V_{th} was evaluated. Relatively high concentration of O near the MOS interface was realized by ion implantation, which cannot be achieved by simple thermal oxidation of SiC. After the electrical activation of these impurities, the gate oxide was formed by thermal oxidation followed by nitridation in diluted NO. NBTI was investigated by applying a negative gate voltage stress below – 30 V at 175°C, using lateral MOSFETs.

Since the deep level donors might influence the dynamic characteristics of the MOSFETs, pulsed V_g measurements were carried out in order to estimate Vth during switching operation. Although the V_{th} slightly decreases by applying shorter pulses, no significant difference was found by doping deep level donors, suggesting that doping deep level donors in the channel region have negligible impact on the switching characteristics. Thus this technique is found to be a promising approach to further improve the gate oxide reliability.



Cross section of vertical 4H-SiC MOSFETs with O-doped channel region

Gallium Oxyde achieve breakdown voltage over 2.6 kV

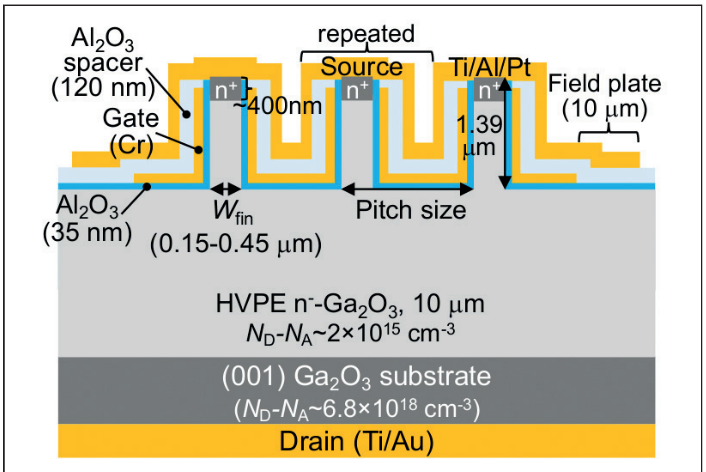
Owing to the availability of high-quality melt-grown substrates, an ultra-high breakdown field of 6-8 MV/cm and a decent electron mobility up to 200 $cm^2/V{\cdot}s$, ß-Ga_2O_3 is an attractive material for the development of cost-effective, high performance power devices. Lateral transistors with a breakdown voltage up to 2.32 kV have already been demonstrated. For high-voltage and high-current applications, vertical devices are generally preferred. To realize normally-off vertical transistors, a submicron fin-channel structure can be utilized without the need for p-type doping. With this device concept, normally-off single-fin Ga_2O_3 vertical 1.6 kVtransistors have been demonstrated by the Cornell University, Ithaca, NY (**www.cornell.edu**).

The epitaxial wafer consists of a 10-µm n^--Ga_2O_3 drift layer grown by halide vapor phase epitaxy on a (001) n^+-Ga^2O_3 substrate. The net doping concentration in the drift layer below the fin region was determined to be ~2×10^{15} cm^{-3} from capacitance-voltage measurements. An n^+ layer was formed on the top surface by Si-implantation at Hosei and activated at 1000°C to facilitate the source ohmic contact.

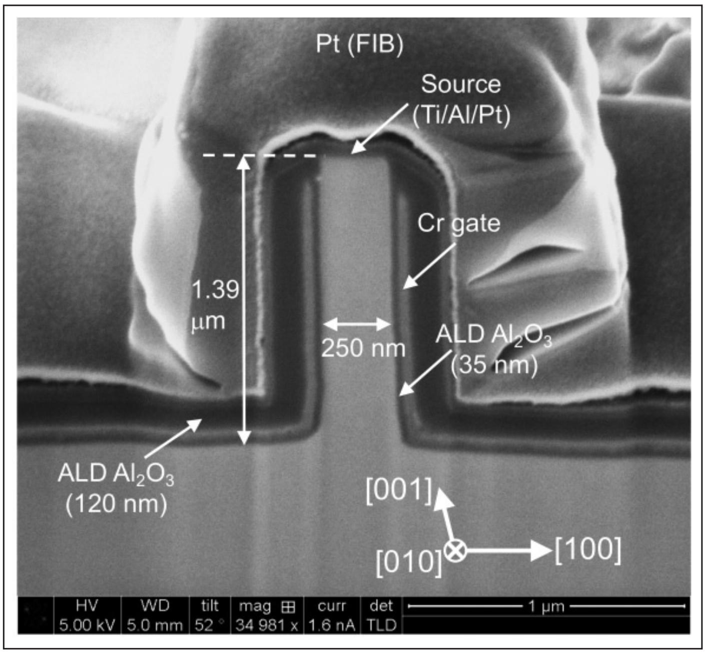
Submicron fin channels were defined by electron beam lithography and formed by dry etching using a BCl_3/Ar mixture. The resultant fin channels have a near vertical sidewall profile. After dry etching, the Cr/Pt etch mask was removed by Cr etchant and the wafer was treated with HF for 23 minutes to remove plasma damage. Next, the drain contact (Ti/Au) was deposited before the deposition of the gate stack, consisting of a 35-nm Al_2O_3 gate dielectric by atomic layer deposition (ALD) and a 50-nm Cr gate by sputtering.

The gate stack and thick ALD Al2O3 spacer was patterned by photoresist planarization and self-aligned etching processes. The source electrode (Ti/Al/Pt) was deposited by sputtering after the spacer formation, simultaneously forming the source-connected field-plate. The devices were tested before and after a PDA at 350°C for 1 minute under N2 to improve the interface quality.

The devices with (100)-like fin-channel sidewalls exhibit the lowest interface trapped charge density and a significantly higher current than other fin orientations. These findings offer important insights on the development of Ga_2O_3 MOSFETs and show great promise of Ga_2O_3 vertical power devices.



Schematic cross-section of the Ga_2O_3 vertical fin transistors with multiple fins. Fin channel widths of 0.15-0.45 ?m and pitch sizes ranging from 1.2 µm to over 2 µm were designed. A source-connected field-plate was implemented



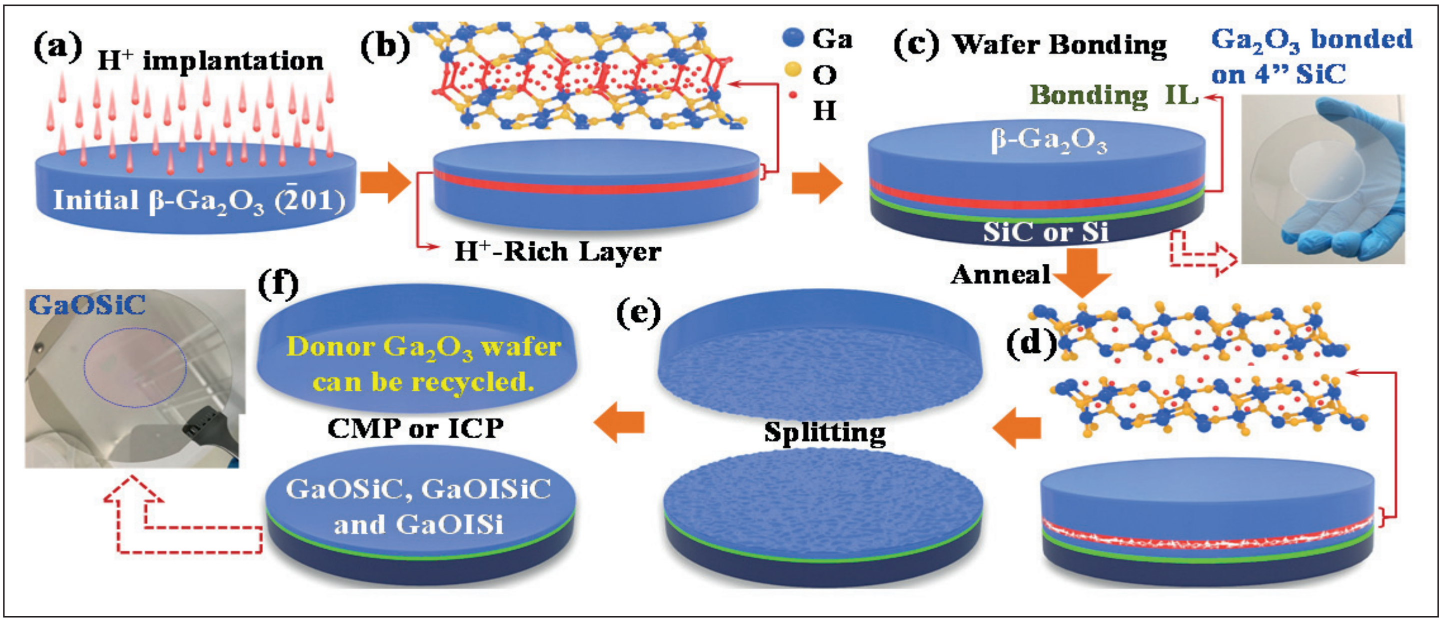
Scanning electron microscopy (SEM) cross-section image of a fin channel with a 0.25-µm fin channel width

Gallium Oxyde MOSFETs on SiC and Si substrates

A 2-inch single-crystalline β-Ga_2O_3 thin film with a wafer-level thickness non-uniformity below ±1.8 % is transferred onto Si and SiC substrates. Three high-quality heterogeneous wafers, the Ga_2O_3-on-SiC (GaOSiC), Ga_2O_3-Al_2O_3-SiC (GaOISiC), and Ga_2O_3-Al_2O_3-Si (GaOISi) are fabricated by the Chinese Academy of Sciences, which have surface RMS roughness below 0.5 nm and the FWHM of XRD rocking curve of 130 arcsec.

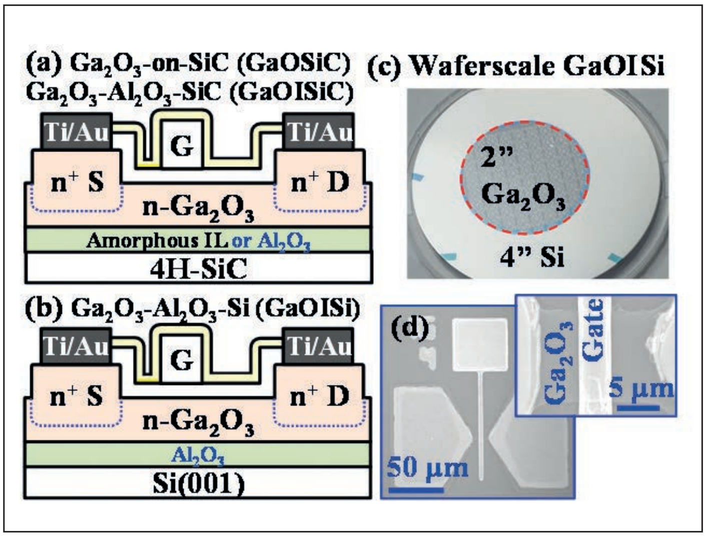
By varying the channel thickness, both enhancement- and depletion-mode MOSFETs are realized on a GaOSiC wafer. As the ambient temperature increases from 300 K to 500 K, little degradation was observed in the on-resistance, forward saturation current, reverse leakage current and breakdown voltage. A breakdown voltage above 600 V is achieved at 500 K with a low dependence on temperature. These results show a significantly improved device thermal stability compared to the reported bulk Ga_2O_3 devices. The technology demonstrated is promising to overcome the fundamental thermal limitation of Ga_2O_3 electronics for high-power applications.

The device threshold voltage (V_{TH}) of the fabricated β-Ga_2O_3 MOSFETs on GaOSiC (or GaOISiC) and GaOISi wafers, respectively. is controlled by the thickness of the recessed-channel (T_{ch}) and the channel doping concentration



ABOVE: Process flow for transferring β-Ga_2O_3 thin film onto SiC (or Si) by ion-cutting. (a – b); implanting H^+ into bulk β-Ga_2O_3 to form a H-rich layer (c); wafer bonding of β-Ga_2O_3 with SiC (or Si) and bonding interfacial layer (IL) can be an amorphous layer or an Al_2O_3 film realized (d) and forming plate-like defects by annealing; splitting (e) and surface smoothing by ICP etching or CMP (f) on fabricated GaOSiC

(Nch) modulated by Si^+-implantation. A 30 nm ALD-Al_2O_3 was used as the gate dielectrics. Ti/Au source/drain (S/D) metals and Pt/Ti/Au gate electrode were deposited by a sputtering system. S/D regions were heavily doped by Si^+-implantation with a dose of 1×10^{16} cm^{-2} and an energy of 10 keV. Because of the high K of the substrates, the GaOISiC and GaOISi MOSFETs demonstrate the excellent and stable I_{ON} /I_{OFF}, R_{on} and I_{ON} on T_{amb} performance as T_{amb} increases to 500 K. **AS**



RIGHT: Schematics of the fabricated (a) GaOSiC and GaOISiC and (b) GaOISi MOSFETs, (c) wafersale GaOISi MOSFETs and (d) SEM image of the device. Inset shows the zoomed-in channel and gate regions

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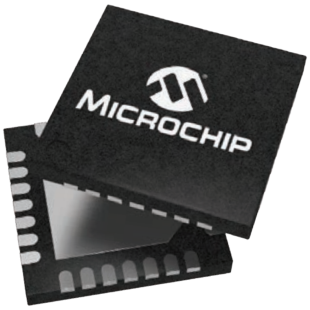

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Automotive H(EV) Market Drives Power Semiconductor Growth

The EV/HEV race has begun. More than $300 billion of EV/HEV investments have been announced by different OEMs, clearly confirming the automotive industry's commitment to governmental carbon reduction targets.

The transformation of the automotive supply chain is ongoing. In particular, many questions involve China, which is today the biggest market for electric cars. "For EV/HEV components, China has different levels of technology and independency. Regarding battery, China has top suppliers like CATL and BYD. However, the majority of IGBT power modules are still manufactured outside of China. The trend towards increasing the share of Chinese-made products is clear, and some companies have started working to build a local supply chain - for example, BYD built its own IGBT product line and is developing SiC MOSFETs", stated Yole analyst Milan Rosina.

In 2018, 1.32 million battery electric vehicles (BEV) were purchased, along with 0.75 million plug-in hybrid electric vehicles (PHEV) - compared to 0.78 million and 0.41 million units in 2017, respectively. This equates to year-over-year growth of 68 % and 84 %, respectively. Moreover, sales of other hybrid cars have also increased. Driven by the prosperous EV/HEV market, the market for semiconductor power electronics devices should have a bright future, with value exceeding $3.7 billion in 2024 at a 2018 - 2024 CAGR of 21 %. IGBT modules represent the largest market, which is expected to double in five years. Silicon carbide (SiC) power modules will also grow fast, with a 2018 - 2024 CAGR of roughly 50 %.

Trends towards higher vehicle power and larger battery capacity have led to a new battery-voltage level in passenger cars of 800 V. Today, the only commercially-available vehicle with an 800 V battery is the Porsche Taycan sport electric vehicle. However, Hyundai plans to launch a new generation of EVs based on its new E-GMP vehicle platform, with 800V technology.

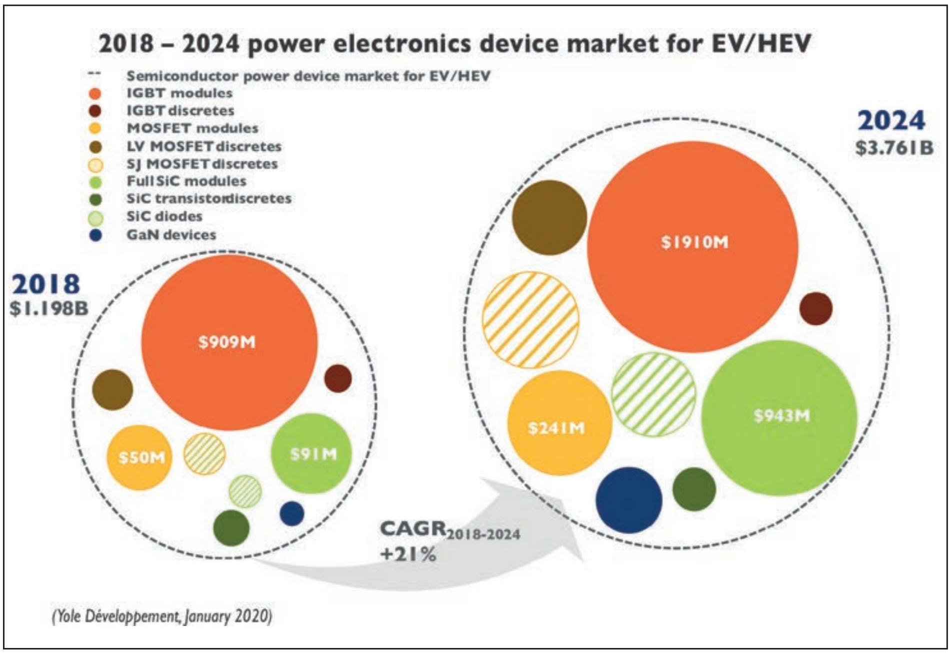
The implementation of SiC power devices in the Tesla Model 3 EV's traction inverter has created plenty of interest. Indeed, high-power traction inverters represent a huge new business opportunity for suppliers of SiC devices, suitable device packaging solutions, and SiC-based systems. Also, interest in gallium nitride (GaN) has recently revived, mainly as a potential candidate for future EV/HEV 12 – 48 VDC converters and onboard chargers.

GaN is attracting lots of attention from various OEMs and Tier1 suppliers, i.e. Valeo and Continental. "Indeed, GaN is very interesting for emerging 48 V DC/DC in mild hybrid electric vehicles and on-board chargers in electrified vehicles. Players like EPC and Transphorm have already obtained AEC qualification, and GaN Systems, which benefits from its BMW i Ventures investment, expects qualification by this year. These device manufacturers are working closely with packaging companies like ASE, AT&S, and Schweizer to enter the OEM supply chain and enjoy increasing volumes starting in 2023 – 2024", according to Yole analyst Ezgi Dogmus.

In just a few years, Infineon and Transphorm have reached the strongest IP position in the patent landscape. Infineon has the strongest IP portfolio to front the growing of GaN power market. Transphorm is a major force in the power GaN IP arena, well ahead of the other GaN pure-players, EPC, GaN Systems, Navitas, Exagan or VisIC. According to Yole, Transphorm today has the dream patent portfolio for all those who want to benefit from strategic advantages in GaN power electronics market. Signals lead us to believe the first 650 V GaN-on-Si FETs from Nexperia announced in November 2019 may use Transphorm's patents.

No matter how GaN providers manufacture power devices, they must consider GaN power patents held by Infineon, Transphorm, Furukawa Electric, Panasonic, Toshiba and Fujitsu. They must also watch other players that are strengthening their IP position such as EPC, Renesas, ON Semi, Toyota, TI, TSMC, Intel, Toyoda Gosei and Sanken. More newcomers of different types are entering the Power GaN patent landscape. Startups include Exagan, Navitas, Cambridge Electronics, GaNPower and Innoscience. New substrate providers include Qromis, AirWater and Zing Semiconductor. Foundries include FMIC, HiWafer, Simgui, Nuvoton, Sinopower and VIS. Integrators include Nissan, Shindengen Electric Manufacturing, Nidec, Kyocera, Hella, Renault, Apple, Midea, Huawei and Velodyne Lidar. China has made an impressive move into Power GaN IP with numerous entrants since 2017.

www.yole.fr



GaN Supports Energy Efficiency Efforts

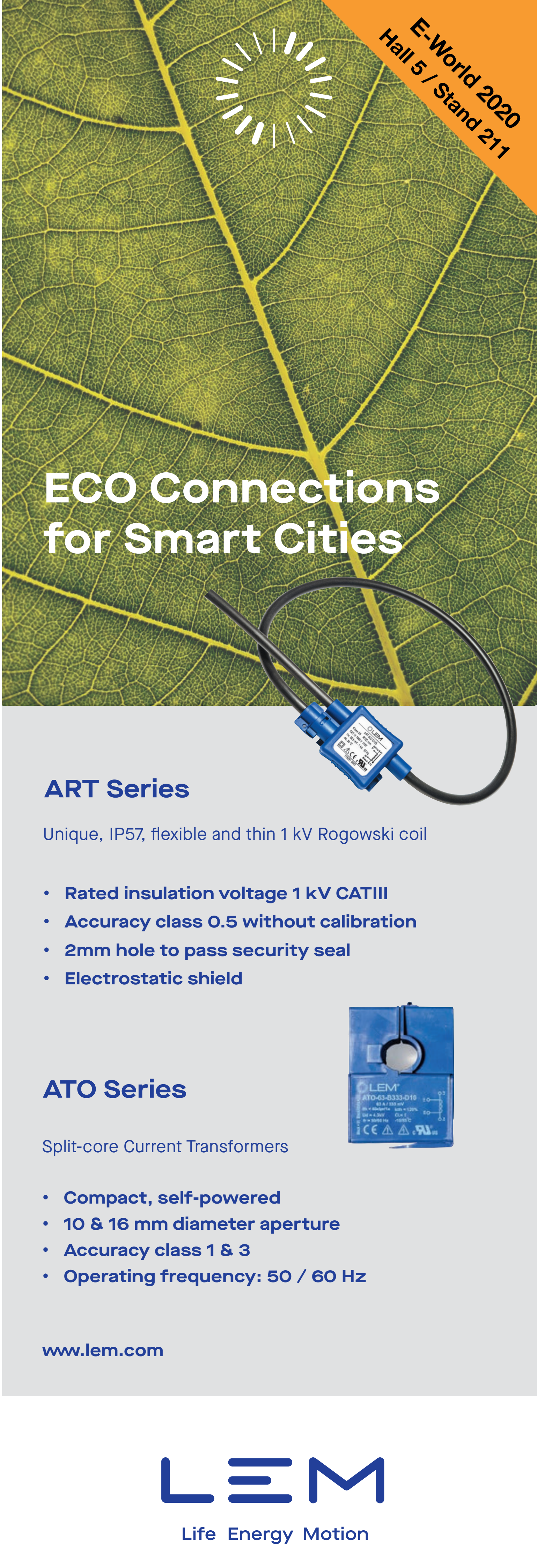
Energy efficiency is now a strategic initiative in increasingly power-reliant industries such as data centers, electric vehicles, renewable energy systems, industrial motors, and consumer electronics. How businesses choose to generate, store, deliver, and use power will be an important impetus for global change in 2020.

Data and energy are the acknowledged fuels for global economic growth. And the demand for both is increasing at unprecedented levels. And those data centers use an astronomical 416 terawatt hours of electricity annually to keep up with that demand. The global demand for electricity has grown by nearly one-third over the past decade. Industry analysts predict that there will be a 57 % increase in global electricity demand by 2050. "Over the past year, in conversations with corporate leaders, we at GaN Systems are more certain than ever before that Silicon has reached its limits in solving critical power systems challenges. GaN is the clear and undisputed solution for driving more robust growth and product innovation, as well as enabling companies to elevate the conversation and engage more deeply in sustainability initiatives", states CEO Jim Witham by predicting the 2020 trends.

In 2019, it became increasingly clear that the near future of transportation revolves around electric vehicles, and in the longer term around autonomous vehicles that are also electric. Today, there are 5.1 million electric vehicles on global roads. Given the amount electricity needed as "fuel" for electric vehicles, the stage is set for a massive unfavorable hit to the global energy grid as 125 million electric vehicles are expected to be on the roads by 2035. The evolution of the design of Chargers and Traction Inverters will play a major role in automotive design studios in 2020, and then onto the public roads in the years following. In order to address the long-standing issue of 'range anxiety,' the number of public electric charging stations will continue to grow, with an increasing focus on solar power and plug standardization. Thus the demand for EVs will continue with fuel efficiency pressure and driving range at the center of consumer demands. Designs from major auto manufacturers will focus on increased efficiency, power density and reduced weight with a focus on Chargers and Traction Inverters. Battery technology will continue to improve and then, combined with lighter weight vehicles, will contribute to increase vehicle range and consumer acceptance. In Autonomous Vehicles we will see technology evolution in Level 2 to Level 3 autonomy and improved safety systems using LiDAR. GaN technology is being used in the design of higher power, longer range detection solutions.

In 2019, the 5G rollout was slower than expected, primarily due to the issues around communications service providers (CSPs) upgrading 4G infrastructure within 5G areas of coverage. Nevertheless, according to Gartner research, 5G services have already begun the U.S., South Korea, and some European countries, including Switzerland, Finland and the UK. In China, 5G commercial services are now available in 50 cities, including Beijing, Shanghai, Guangzhou and Shenzhen, according to Chinese state news agency Xinhua. In Shanghai, nearly 12,000 5G base stations have been activated to support 5G coverage across the city's key outdoor areas. Thus 5G equipment will continue its ramp up throughout the world, requiring greater bandwidth and power in smaller enclosures. GaN power transistors will be the transistor of choice on the rollout of 5G because of power density, energy efficiency, and system size requirements for macro and micro base stations for broadband delivery. GaN RF transistors will play an important part for the power amplifiers of those base stations, and GaN solves the power efficiency and size issues of 5G equipment – in the networks and base stations.

In 2019, renewable energy production has not yet met the mainstream milestone of 24/7 availability. That said, the social attitudes, local policies, and



consumer awareness are in place to push this imperative forward with the urgency that it requires. Across the globe, there needs to be a focused and disciplined mandate to address climate change, pollution, and the unreliability of energy grids. Highly efficient residential and commercial energy storage systems (ESS) using GaN technology will enable distribution, local storage, and on-demand access to renewable energy. Both cost reduction and increasing energy security demands will drive this. The movement from lead acid to lithium ion batteries will lead to declining battery costs and the development of smaller, lightweight, energy-dense batteries that will pair with GaN technology-based converters and inverters to lead the revolution in ESS.

In 2019, we witnessed GaN's proliferation in the consumer electronics space with an abundance of smaller, lighter, and higher power adapters/chargers in the aftermarket. The tiny adapters had everyone's attention as size and weights were decreased by 2X or 3X. Growing momentum for USB-C and USB-PD products which can be used to charge any compatible product. The days of one charger for one piece of electronics will quickly disappear and the days of one charger for all your electronics will begin to dominate. A single adapter/charger that handles every device regardless of varying voltages for a phone (5 V), tablet (12 V), or laptop (19 V). USB-PD will garner increasing commercial interest across industries besides mobile phones and computers with its spec for higher power (100 W) applications. Industrial markets will also demand a new generation of smaller and more powerful chargers for uses in portable test equipment, industrial equipment, medical and supply chain applications.

"At the core of these 2020 trends is the undeniable need for new ways of addressing growing global power consumption and delivery. Power cannot be viewed as an endless resource that comes out of a plug in a wall. There are many questions over the next twelve months and coming years that will arise in regard to electrical power: How do we meet the power demands of all the technology that surrounds us 24/7? And, how do we do that in a way that is both economically and socially responsible? We can not endlessly shift the CO2 emissions and pollution problems across industries, geographies and future generations. Doing so solves nothing on a global level. And we must do so using less materials by making products dramatically smaller and lighter – using less to accomplish the job", Witham underlines. "In 2020, looking at products in the market and next generation products in development using GaN technology, we can clearly see that GaN has become the basic building block of power efficiency proliferating through all the power systems of the world."

www.gansystems.com

More SiC from Cree for STMicroelectronics

An expansion and extension of an existing multi-year, long-term SiC wafer supply agreement to more than $500 million has been announced by the companies recently.

The extended agreement is a doubling in value of the original agreement for the supply of Cree's 150 mm wafers to STMicroelectronics over the next several years. The increased wafer supply enables the semiconductor companies to address the rapidly growing demand for SiC power devices globally, particularly in automotive and industrial applications. "Expanding our long-term wafer supply agreement with Cree will increase the flexibility of our global silicon carbide substrate supply. It will further contribute to securing the required volume of substrate we need to manufacture our silicon carbide-based products as we ramp up production over the next years for the increasing number of programs won at automotive and industrial customers," said Jean-Marc Chery, President and CEO of STMicroelectronics. "Silicon carbide delivers performance enhancements that are critical to electric vehicles and a host of next-generation industrial solutions for solar, energy storage and UPS systems," added Gregg Lowe, CEO of Cree. "The adoption of silicon carbide-based power solutions is rapidly growing across the automotive market as the industry seeks to accelerate its move from internal combustion engines to electric vehicles, enabling greater system efficiencies that result in electric cars with longer range and faster charging, while reducing cost, lowering weight and conserving space. In the industrial market, silicon carbide modules enable smaller, lighter and more cost-effective inverters, converting energy more efficiently to unlock new clean energy applications."

www.st.com, www.cree.com

New SiC Supplier

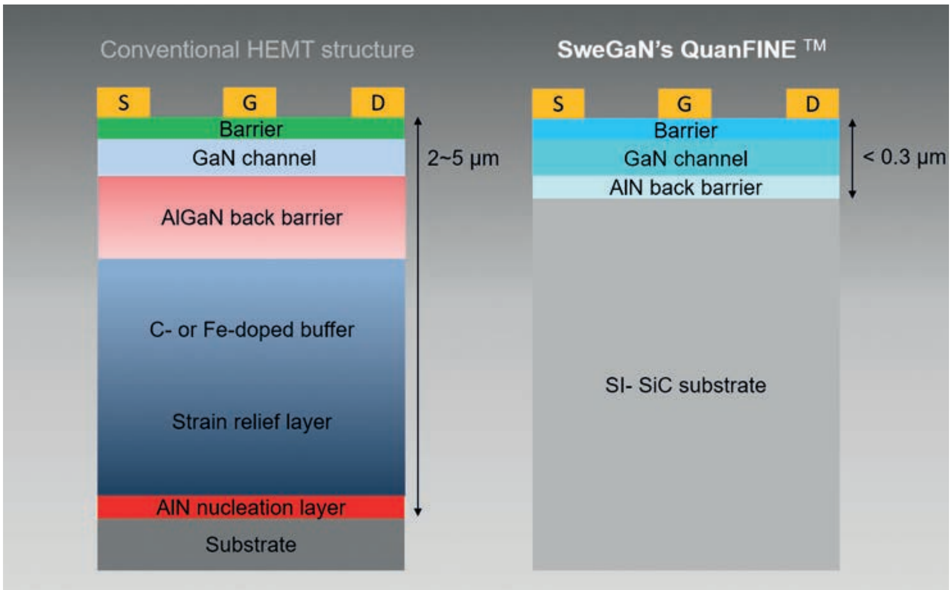
Global Power Technologies Group announced that it has changed its legal company name to SemiQ. The name reflects the company's strategic concentration on designing and manufacturing high quality SiC power semiconductors.

SemiQ is an integrated development and manufacturing company that grows its own SiC epitaxial and is building a redundant supply chain with multiple substrate suppliers, multiple epitaxial suppliers, two wafer fabrication facilities, and multiple packaging and testing facilities. "Our new brand presents SemiQ as one of the most globally innovative and complete silicon carbide semiconductor companies for the commercial power conversion and energy market," stated Michael DiGangi, VP of business development. SemiQ's product line includes SiC power discretes (diodes and MOSFETs), Si and SiC power modules, SiC wafers and die, and SiC epitaxial wafers. The firm also offers custom semiconductor module designs for power system engineers needing modules that accommodate challenging customer-driven power conversion designs and applications. The partially employee-owned company is headquartered are in Lake Forest, California.

www.SemiQ.com

Transmorphic Heteroepitaxy for GaN on SiC

SweGaN AB, a manufacturer of custom-made GaN-on-SiC epitaxial wafers based on unique epitaxal growth technology, collaborated with top scientists from Linköping University in Sweden and IEMN, a French research group dedicated to high power devices, unveiling a revolutionary new epitaxial growth mechanism, Transmorphic Heteroepitaxy, for producing next generation GaN-on-SiC power devices. Key research from a project funded by the EU Horizon 2020 research and innovation programme (grant agreement no. 823260) was an important contribution to the new development. "Not only is this a high-impact innovation, but comes together with a scientific discovery of a novel epitaxial growth mechanism, what we coin transmorphic," said Lars Hultman, professor at Linköping University. "This breakthrough could significantly reduce the power loss for high power devices, which would truly manifest the superiority of GaN power devices over Si super-junction power devices and SiC MOSFETs for 650V rated devices ", added Jr-Tai Chen, CTO at SweGaN AB. Transmorphic Heteroepitaxy - where less than 1 nm-thin atomic interlayers with ordered vacancies are made to sufficiently accommodate the lattice mismatch at the interface between the first epilayer and the substrate - suppresses the formation of structural defects in the beginning of the epitaxy, which enables grain-boundary-free AlN nucleation layers and subsequent high-quality buffer-free GaN-based heterostructures to be realized on SiC substrates. A GaN HEMT heterostructure with a total thickness less than 300 nm grown by the transmorphic epitaxial scheme on a semi-insulating SiC substrate shows a lateral critical breakdown field of ~2 MV/cm and a vertical breakdown voltage of ≥ 3 kV, measured by the senior researchers at IEMN. The critical breakdown field is nearly 3 times higher than that of GaN-on-Si epiwafers grown by the conventional thick-buffer approach. This means that the device ON-resistance has potential to be lower by >1 order magnitude than the value achievable today, according to Baliga's Figure of Merit.



www.swegan.se

More Power for Solar

The installed photovoltaic capacity is growing rapidly worldwide. Photovoltaic systems with a total output of around 600 GW now supply clean and cost-effective electricity – replacing around 600 medium-sized coal-fired power plants. SMA inverters with a total output of 75 gigawatts have been installed in more than 190 countries worldwide. This growth trend is supported with the latest generation of SiC-based solar inverters.

With the Sunny Highpower PEAK3 from SMA, available since 2019, decentralized photovoltaic power plants can be planned flexibly and efficiently up to the megawatt range. The basis for this is the compact design designed for 1500 VDC, which delivers an output of 150 kW per unit. Six power modules EasyPACK 2B and 36 gate drivers of the EiceDRIVER family 1ED20 convert the DCt generated by the solar cells into grid-compatible AC - with an efficiency of over 99 %.

"Silicon carbide enables us to build the inverters compact, powerful and reliable," said Sven Bremicker, Head of Technology Development Center at SMA. "In the Sunny PEAK3, the CoolSiC modules almost double the specific output from 0.97 to 1.76 kW/kg. Due to the compact design, the inverters are much easier to transport and much faster to install." The advantages of a decentralized plant layout can thus be combined with those for central inverters. Expansions are easily possible even after the photovoltaic power plant has been commissioned. Infineon has developed a customer-specific solution for SMA that includes both a classic TRENCHSTOP IGBT and a CoolSiC MOSFET with body diode. The ANPC (Active Neutral-Point Clamped) topology allows system voltages up to 1500 V maximum to be switched with devices designed for 1200 V. The topology thus uses the advantages of SiC, although only some of the switches in the EasyPACK module are based on it. Overall, the use of SiC reduces the complexity in the inverter. This not only increases efficiency, but also makes the system easier to maintain and extends its service life.

"SiC-based power semiconductors are more expensive than Silicon solutions," said Dr. Peter Wawer, President of the Industrial Power Control Division of Infineon. "But thanks to the electrical properties of the material, this is more than offset at system level. Higher switching speeds and efficiency allow transformers, capacitors, heat sinks and ultimately packages to be smaller – and thus save system costs. We are very proud to have convinced with SMA the European market leader in photovoltaic inverters of the advantages and to support volume production with our innovative SiC products." Not only photovoltaic systems profit from these advantages. Demand for SiC-based solutions is also growing in other industrial sectors and for applications such as uninterruptible power supply and charging infrastructure for electric vehicles.

www.sma.de, www.infineon.com

In the Sunny Highpower PEAK3, the CoolSiC™ modules almost double the specific output from 0.97 to 1.76 kW/kg

APEC Opens the Power Conference Year

The 35th APEC 2020 will be held at the Ernest N. Morial Convention Center in New Orleans with expected 6,000+ delegates. The extensive program covers around 500 papers within the Technical Sessions. Workshops, Professional Education, and Exhibitor Seminars complement the event. The Plenary Session addresses issues of immediate and long-term interest. The invited presentations on the Monday, March 16, will open the exhibition.

PSMA and PELS are co-sponsoring a 2 all-day workshop on Capacitors and Power Magnetics already on Saturday March 14. "How to Choose and Define Capacitor Usage for Emerging Applications" - this workshop is designed to bring value to everyone, from newcomers to advanced designers of DC/DC converters, frequency drives, inverters, and other power conversion applications. The 5th "Power Magnetics @ High Frequency" workshop aims to identify the latest improvements in magnetic materials, coil (winding) design, construction and fabrication, evaluation and characterization techniques and modelling and simulation tools. The workshop will target the advancements that are deemed necessary by the participants for power magnetics in order to meet the technical expectations and requirements of new market applications for higher operating frequencies and emerging topologies that are being driven by continuous advances in circuits topologies and semi-conductor devices.

Education and exhibitor seminars

Exhibitor Seminars highlight new products or initiatives that companies in the power electronics industry are developing, along with allowing the opportunity for attendees to interact with other companies in the industry.

The Professional Education Seminars at APEC are three-and-one-half hours in length, can range from broad to narrow in scope, and can vary from introductory to advanced in technical level and they complement the technical papers, the special presentations, and the comprehensive exposition.

Seminars take place in two sessions (morning and afternoon) on Sunday, March 15, and one session on Monday, March 16 (morning only). Subjects include "Fundamentals of Switch-Mode Power Conversion", "High-Frequency Transformers for High-Power Converters", "Full Technology Validation of 600V+ GaN Power Devices", "Soft Switching Technique for SiC MOSFET Three-Phase Power Conversion", "Isolated Gate Driver ICs in Power Electronics Systems", Advanced 3-? Sic/GaN PWM Inverter Concepts for Future Vsd Applications", "Power Electronics Enabled Health-Conscious Battery Management and Fast Charging for E-Transportation", "LLC Calculator – Vector Method as an Application of the Design Oriented Analysis", "Designing Compensators for the Control of Switching Power Supplies", or "High-Efficiency and High-Density Single-Phase PV Inverters with Advanced Topologies, Control and WBG Devices".

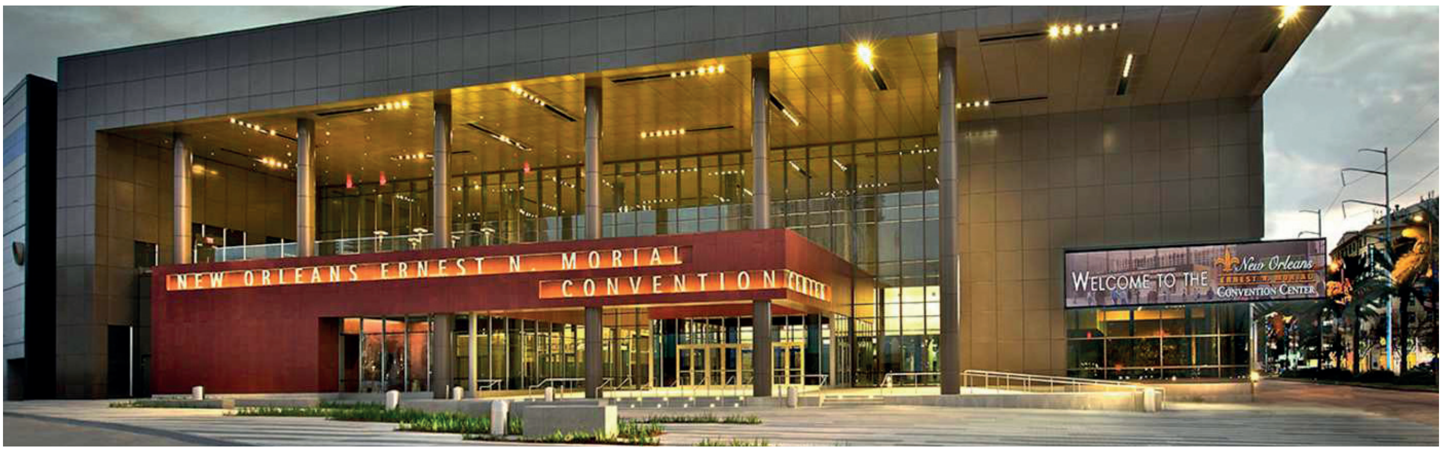
One of the guiding forces behind APEC 2020 is Aung Thet Tu, Director of Marketing & Applications at Infineon Technologies USA. He is on the APEC Steering Committee, has been a long-term co-chair of the Professional Education Seminars, and he will also be co-chairing this year's plenary session.

Plenary session topics

The plenary session opens APEC officially on Monday afternoon. According to Tu, the objective is to provide a view of what the future holds for applied power electronics. "We try to mix the industry viewpoint with the academic viewpoint, because both are equally important for APEC. We try to find a balance between the theoretical and the practical. Sometimes, we achieve both on the same topic. We also try to cover different power electronic fields that are trending in the industry. Attendance-wise, we normally get anywhere from a third to half our total registration. Last year, I think, we had close to 2,000. The plenary is kind of like the opening ceremony of the Olympics."

The first plenary speaker - John Kassakian, Professor, Massachusetts Institute of Technology – will talk about "35 Years of APEC and the Path Forward for Applied Power Electronics". "Power in Automotive: Beyond Just Power" – is the subject of David Dwelley, Vice President and Chief Technology Officer, Maxim Integrated. "Emerging Technologies in Power Electronics" will be introduced by Burak Ozpineci, Group Leader, Power Electronics and Electric Machinery Group, Program Manager, Electric Drive Technologies, Oak Ridge National Laboratory. "Switched Capacitor Power Electronic Converters" will be covered by Robert Pilawa-Podgurski, Professor, University of California Berkeley. Finally, Balu Balakrishnan, CEO, Power Integrations, will focus on "Power Electronics for Consumer Applications".

This year over 500 papers make up APEC's Technical Sessions. The technical program includes papers of broad appeal scheduled for presentation from Tuesday (March 17) morning through Thursday (March 19) afternoon. Papers with a more specialized focus for discussion with the authors will be presented at the dialogue session on the Thursday from 11:15 a.m. - 1:45 p.m. **AS**



Integration of Power Electronics and Mechanics Conference

CIPS 2020, the 11th Conference on Integrated Power Electronics Systems, will be held from March 24 – 26 in Berlin/Germany. In the future, power electronic system development will be driven by energy saving systems, intelligent energy management, power quality, system miniaturization and high reliability. Monolithic and hybrid system integration will include advanced device concepts including wide bandgap devices, new packaging technologies and the overall integration of actuators/drives (mechatronic integration).

Thus CIPS is consequently focused on aspects such as assembly and interconnect technology for power electronic devices and converters, integration of hybrid systems and mechatronic systems with high power density, and systems' and components' operational behavior and reliability. Basic technologies for integrated power electronic systems as well as upcoming new important applications will be presented in interdisciplinary invited papers.

GaN Workshop

A day before CIPS (March 23), a workshop "Circuit Technology for GaN Devices in Power Electronics" in German language will take place in the same hotel as CIPS 2020 (Mercure Hotel MOA Berlin).

GaN components have undergone rapid development in recent years and are becoming more and more established in applied power electronics. Meanwhile, power semiconductor devices from various manufacturers are commercially available in different designs and technologies as well as voltage and current classes and are on their way to application. More and more users are investing in research and development to exploit the potential of fast GaN semiconductor switches for their systems. This raises many questions about suitable transistor technology, optimal circuit topologies, gate driver units and practical implementation, for example with regard to construction and integration techniques or EMC. In addition to the classic hard switching applications, in which the low forward resistances of the GaN components are used, users focus on the high switching frequencies achievable with GaN as well as resonant or quasi-resonant circuits.

CIPS Keynotes

The program covers four keynotes. First is "Power Cycling - Methods, Measurement Accuracy, Comparability", given by Professor for Power Electronics and Electromagnetic Compatibility at the Chemnitz University of Technology. Power cycling capability is a main criterion for the design of power electronics equipment. It is a clear progress that there is now a European standard for power modules. Power electronics evolves to higher power density packages. This leads to systematic measurement errors which have been neglected in the past. They are now of significant influence and should be considered as well. When going from Si to SiC devices, especially SiC MOSFETs, a new test method is suggested. More semiconductor physics related effects have to be taken into account, and not all modifications during ageing of a device can be adjusted to the ageing of the interconnections, as it is practice with Si. A more detailed test documentation is recommended.

The second keynote is entitled "Wide-Bandgap Semiconductor Power Electronics: Overcoming Barriers in Materials to Circuits for a more Electrified Future" to be presented by Dr. Isik C. Kizilyalli currently serves as a Program Director at the Advanced Research Projects Agency – Energy (ARPA-E), Department of Energy. The third keynote will cover "Capacitor-Based Power Converters for High Power Density and Efficiency - the Theoretical Promises and Practical Challenges" by Robert Pilawa-Podgurski, currently an Associate Professor in the Electrical Engineering and Computer Sciences Department at the University of California/USA.

The fourth keynote "Present and Future of Fault Tolerant Drives applied to Transport Applications" will be presented by Prof. Volker Pickert, leader of the Electrical Power Group at Newcastle University/UK. As part of the "electrical revolution" electric drives are increasingly being developed for safety critical applications, where their reliability is several orders of magnitude below the application requirements. This is particularly the case in electrical propulsion and actuation systems in aircraft, leading to intensive research into fault tolerant electric drives. The paper will illustrate some of the most common failure mechanisms and the consequences of such failures. It will then progress to examine architectures which are fault tolerant through partitioning of the drive into a number of independent lanes and examine the penalties of adopting such an approach. The paper will discuss pros and cons of different fault tolerant architectures and suggests future research and development steps that are required to increase the overall safety of electric drives.

www.cips.eu

Program for *CIPS 2020 - 11th International Conference on Integrated Power Electronics Systems*

Tuesday, March 24				
10:00-10:10		*Introduction*		
10:10-10:50		*Keynote*		
10:50-11:50		*Session Power Packages and Modules (1)*	*Session Components to be integrated (1)*	
11:50-13:20	*Lunch Break*			
13:20-14:40		*Session Power Packages and Modules (2)*	*Session Components to be integrated (2)*	
14:40-15:10	*Tea Break*			
15:10-16:30		*Session Power Packages and Modules (3)*	*Session Components to be integrated (3)*	
16:30-17:00	*Break*			
17:00-18:20		*Session Power Packages and Modules (4)*	*Session Components to be integrated (4)*	
18:20-18:30				
19:00-21:30	*Get Together*			
Wednesday, March 25				
08:30-09:10		*Keynote*		
09:10-10:10		*Session Power Packages and Modules/Mechatronic Systems (1)*	*Session General Aspects of Packaging (1)*	
10:10-10:40	*Tea Break*			
10:40-12:20		*Session Power Packages and Modules/Reliability(2)*	*Session Clean Switching, EMC (1)*	
12:20-13:50	*Lunch Break*			
13:50-16:30	*Poster Session + Tea Break*			*Poster Session Clean Switching, EMC,* *Poster Session Components to be Integrated,* *Poster Session General Aspects of Packaging,* *Poster Session Mechatronic Systems and their Applications,* *Poster Session Power Packages and Modules,* *Poster Session Reliability*
16:30-18:00		*Session Reliability (1)*	*Session Clean Switching, EMC (2)*	
19:00-22:00				*Conference Dinner (Departure from the Venue by Bus)*
Thursday, March 26				
08:30-09:10		*Keynote*		
09:10-10:10		*Session Reliability (2)*	*Session General Aspects of Packaging (2)*	
10:10-10:40	*Tea Break*			
10:40-12:00		*Session Reliability (3)*	*Session General Aspects of Packaging (3)*	
12:00-13:20	*Lunch Break*			
13:20-14:10		*Keynote*		
14:10-15:00		*Closing and Awards Ceremony*		

pcim
EUROPE

International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management

PCIM Europe 2020 in Good Shape

With 12,182 visitors, 515 exhibitors, and 804 conference delegates PCIM Europe 2019 closed. This year's event (May 5 – 7) at Nuremberg Fairgrounds will slightly grow, according to the organizer Mesago. The conference program offers more than 300 papers, 28 oral sessions, and three dialog sessions - nearly half of them will deal with wide bandgap devices.

After a slowdown of the power electronics market in 2019 an increase of around ten percent is expected in the running year, mainly caused by e-mobility. Thus PCIM Europe 2020 takes place in a favorable econonic environment.

Half-day seminars

Already on the Sunday (May 3) afternoon Seminars will be given. Jacques Laeuffer from French Dtalents will educate the attendees on "Basics for Electromagnetic Compatibility (EMC) of Power Electronics". Fast semiconductors commutations are required for efficiency of high frequency power converters and drives, together with wide bandwidth of their control electronics. But sudden front edges generate perturbations in control circuits, and on utility power networks. Seminar shows and calculates step by step how perturbations propagate, as Differential Mode (DM) and Common Mode (CM), how to reduce noisy oscillations from the beginning, how to design and implement on PCB robust control electronics, how to calculate and optimize DM and CM filters for EMC standards compliance, how to avoid expensive shielding and improve reliability. Number of practical designs are analytically calculated, and showing numbers for a wide range of powers and frequencies.

EPC (USA) will talk with three speakers (Alex Lidow, Michael de Rooij, John Glaser) on their "2020 Vision for Maximizing GaN FET and IC Performance". GaN power semiconductors have seen increased adoption in many power electronic applications. The performance of GaN FETs continues to evolve and improve and so do the challenges of maximizing their benefits. This tutorial provides engineers the tools and understanding needed to fully utilize the potential of GaN FETs and emerging GaN integrated circuits and teaches how to maximize those advantages.

Seminar 3 on May 3 entitled "Ceramic Capacitors: Characterization and Use as Control Elements" is given by Shmuel Ben-Yaakov, Ben-Gurion University (Israel). Ceramic capacitors are widely used in electronic design and are essential in power electronics systems. Despite the widespread use of these elements, many of their intrinsic parameters are poorly understood or even known. Following an introduction on ferroelectricity and basic parameters of ferroelectric ceramic capacitors, the seminar unveils yet unrecognized features of ceramic capacitors while the control application section focuses on the voltage dependent capacitor's ability to change the resonant frequency of resonant networks and help to better tune WPT systems.

Seminar 4 by Ionel Dan Jitaru, Rompower (USA) covers the "Latest Trends in Magnetic Technologies for High Efficiency and High Power Density". There was a significant progress in semiconductor technology in the last twenty years which pushed the power conversion efficiency from low to middle 80% to low to middle 90% over the last twenty years. During the same time period the progress in magnetic technology was practically negligible. We all were waiting for a "miracle" new core material which will allow us to make the next jump. Though not much publicized, in magnetic technology there were many new technologies but these technologies did capture just fragments of the market due their proprietary nature. Some of these new ideas are in public domain these days but many of the engineers were not exposed to them. The goal of the seminar is to bring some light into the modern magnetic technologies and to teach the engineers how to rethink the magnetic design for high efficiency and high power density.

Full-day tutorials

On the Monday (May 4) four full-day Tutorials are offered. Again Ionel Dan Jitaru from Rompower will educate attendees about "A Novel Soft Switching Technology which can Convert any Hard Switching PWM Topology into a True Soft Switching Topology". The goal of this tutorial is to present a new soft

Leo Lorenz, PCIM General Chairman: "After a slowdown of the power electronics market in 2019 an increase of around ten percent is expected in the running year, mainly caused by e-mobility, one of the focus areas of this year's PCIM Europe" **Photo: Mesago**

With around 800 conference delegates PCIM is Europe largest event in power electronics
Photo: Mesago

switching technology which can be applied to any of the classical hard switching topology and converting them to a "true soft switching" topology. In "true soft switching" technology, the primary switching devices turn on at zero voltage and the secondary switching devices turn off at zero current. There is no ringing or spikes across any of the switching devices in primary or secondary. The new technology uses a self-adjusting current injection solution which ensure that all the switching elements in the secondary turn off at zero current and all the primary switching turn on at zero voltage. Using the methodology familiar topologies such as flyback, boost, two-transistor forward, half bridge and conventional full bridge into "a true soft topology" can be converted. This technology can be also applied to more traditional soft switching technologies such as acti ve clamp forward, asymmetrical half bridge and phase shifted full bridge topology and improve their performances an ensure that the soft switching occurs under any input-output operating conditions. These new soft switching technologies offer an avenue to increase the efficiency and power density in power converters.

Tutorial 2 is entitled "Demystifying GaN HEMT: From Theory to Practice" and will be held by Miroslav Vasic, University of Madrid (Spain) and Shmuel Ben-Yaakov, Ben-Gurion University.

The tutorial covers the two fundamental aspects of modern GaN devices: device theory, and practical design issues. The theoretical section discusses and clarifies the characteristics and fundamental advantages of wide bandgap devices over traditional Si devices, while the application section covers the engineering issues that must be tackled when a GaN based design is performed. The morning session covers the device-material aspects, comparison to, and benefit over, Si devices, as well as a multitude of design examples that implement GaN devices. The afternoon session is engineering oriented and discussed practical issue that need to be considered and tackled in industrial designs that include GaN devices - demonstrated by circuit designs and experimental results.

Tutorial 3 "A New Design Approach for EMC and Faster Power Electronics" complements the mentioned Seminar 1.

Tutorial 4, given by Christian Peter Dick and Jens Onno Krah, both from Cologne University of Applied Sciences (Germany) will talk on "High Performance Control of Power Converters".

Utilizing power electronic based converter technology is a key approach to build energy efficient solutions. Due to the innovation cycles of the semiconductor suppliers the size and the cost of the more and more complex inverter systems is not increasing. However, especially new and fast switching wide bandgap devices (SiC & GaN) are challenging the control hardware. The advanced control architectures are covered by discussing algorithms and possible implementations using µC, DSP and FPGA technology. Robust controller designs with well-defined set up procedures or reliable self-tuning algorithms can help to use these innovations utilizing a reasonable set-up time.

Four keynotes on three days

After the official opening and award ceremony for the young engineers and best paper on the Tuesday morning, May 5, Ahmed Elasser, GE Global Research Center (USA), will give the first keynote on "Battery Energy Storage Systems: Past, Present and Future". In this talk, the speaker will draw on his extensive experience as a key member of the GE Global Research Center Renewable Reservoir team that worked for three years (2017-2019) to conceive, design, prototype, and productize the GE 4 MWh Li-Ion Battery Energy Storage System (BESS) dubbed the Renewable Reservoir. In addition to being a key member of the power electronics team that extensively tested the various power conversion components, the speaker worked closely with the co-located GE Energy Storage Team on the testing of the prototype 1 MWh energy storage boxes, and on the commissioning and energization of a 12 MVA test bed for testing the 4 MWh energy storage boxes. The speaker also worked with GE Solar to design, commission, and energize a solar PV array that is used to charge the batteries. In this talk the speaker will talk about the history of BESS systems from a research and industrial perspective, address the present situation of AC and DC coupled BESS. In particular DC coupled BESS that enables solar and storage integration will be discussed from a practical point of view. Topics like architecture type, dc/dc converters topologies, short circuit testing, integration with solar arrays using dc/dc optimizers, as well as overall safety, reliability, economical benefits, cost, and deployment will also be addressed. Other topics such as container requirements, battery technology, digital tools, unit controller, and grid requirements will also be discussed. Finally, the speaker will address the challenges facing BESS and the various hurdles to its extensive deployment and adoption by utilities and commercial customers. The challenges at the battery, power conversion, and grid level will be highlighted.

On the Wednesday (May6) two keynotes are scheduled - "Electric Cars" by Robert Plikat, who will introduce Audi's first electric drive train, and "The Future of Work". The latter, given by Hanne Caspersen, Senior Innovation Advisor and Speaker at TRENDONE (Germany), will deal with trends of future work. Digital devices now enable us to work from anywhere in the world, access information everywhere and at all times. The education sector also benefits from the new possibilities offered by this form of knowledge transfer. Game-like applications are already teaching nursery school children the basics of programming,while students attend their lectures virtually and adults take part in further training courses at online universities. Besides hyper-specialization and the transfer of artificial intelligence to the world of knowledge work, highly individual work styles will also influence the world of work in the future. For companies, both knowledge of and about their employees will become a competitive factor. Who works when and how well, what kind of teams make most sense and how many new employees do we need – these questions will not be answered by a mere gut feeling in future, but by way of strategic data analysis.

The fourth keynote by Roland Hümpfner, Huawei Technologies (Germany) on the Thursday (May 7) morning is entitled "Innovative Data Centers Power Infrastructure Solutions". Driven by Digitalization the demand for Data Centers will increase significantly in the next few years. The power demand of information and communication technology will grow substantially into the double digit percentage range. High availability Data Centers have a sophisticated power and cooling infrastructure substantially supported by power electronics. Looking into the historical evolution, considering the state of the art and have an outlook in to potential future solutions. Power Usage Effectiveness (PUE) is a traditional measure to evaluate energy efficiency, integration of renewable and providing grid services, sustainability and eco design will be in the future more and more interesting.

More on the PCIM Europe 2020 in our next issue. **AS**

DRIVES & CONTROLS 2020
THE AUTOMATION, POWER TRANSMISSION & MOTION ENGINEERING EVENT
The Digitalisation Forum sponsored by
PILZ
THE SPIRIT OF SAFETY

A platform for knowledge at Drives & Controls Exhibition

The biennial co-located events; *Drives & Controls, Smart Industry Expo, Fluid Power & Systems, Plant & Asset Management,* and *Air-Tech* Exhibitions – are once again set to return to Birmingham's NEC between the 21st -23rd April 2020, alongside MACH 2020.

Located at the heart of the 2020 co-location are **The Digitalisation and Engineering Forums.** With a strong emphasis on technology, **The Engineering Forum** will bring together all aspects of plant and asset management, hydraulics, pneumatics, robotics and automation, energy efficiency, machine safety, drives, motion control, legislation, system strategies and technological developments. Featuring representatives from across industry including government agencies, research bodies, trade associations, and manufacturers.

Chairman of the British Automation and Robot Association (BARA) Mike Wilson, will be discussing how the growth of robotics will generate better ROI and productivity. He will also explain the ongoing practical challenges, continued efforts around education, and investment in robotic technology as a means to help UK manufacturing compete with other major economies.

While Dr. John Ahmet Erkoyuncu, from the Cranfield University will take a look at the importance of condition monitoring as part of a digitalisation Strategy.

In addition, Nikesh Mistry, sector head – Industrial Automation, GAMBICA, will be exploring why demand for automation technology is set to grow throughout the coming year, and how to retain a competitive advantage in the face of these new demands as well as overall automation trends in the UK.

Panel discussions will also be a major feature of the Engineering Forum with issues such as Predictions for manufacturing: Industrial trends for 2020. In light of the changing relationship between the UK and the EU, this panel discussion will offer a lively debate around the direction UK Manufacturing is heading over the next twelve months, as well as the products and initiatives hailed as ways to help transform manufacturing businesses.

The Society of Operations Engineers (SOE) will also be discussing practical ways its members can help inspect, maintain, and manage the machinery and equipment which keeps manufacturers functioning.

Other seminars include presentations by The Association of Electrical and Mechanical Trades (AEMT), who will be looking at ways to manage the condition and energy efficiency of your plant assets, as well as seminars and case studies from the CSA Catapult, British Fluid Power Association, BCAS, Pilz, Primary Engineer, plus many others which will be updated on the show websites.

The Digitalisation Forum

While **The Digitalisation Forum**, **sponsored by Pilz**, will fully reflect the ongoing global transformation to the smart manufacturing era and provide a fascinating insight into the potential plants of the future, covering all aspect of the digital transformation across the manufacturing spectrum. Leading expert will address the vast array of information around 4IR, discussing the practicalities, technologies and issues surrounding transition and implementation of digitalisation in UK manufacturing. Over the course of the three-day seminar programme, visitors will have the opportunity to learn how they can seize the opportunities that exist and promote the benefits of adopting emerging digital technologies through a range of practical case studies, panel discussion and seminars.

Steve Brambley will be presenting papers on getting started on your smart manufacturing journey by discussing IT, cyber security, cloud computing and Industrial Automation and what it all means for Smart Manufacturing.

While Made Smarter will explore the barriers and challenges North West Manufacturers have experienced around bringing technology into their businesses.

Other key issues will also be highlighted. Andrew Hodgson, Strategic Lead - Digitalisation at Siemens, and Vice President of the Manufacturing Technologies Association (MTA), for example will pose the questions, what Digital Twins really mean for the manufacturer, and how can it benefit the design, the production and the service either as a complete unbroken value chain or as a supplying SME in B2C and B2B?

As part of the MTC's significant presence at the co-location of events in 2020, The Manufacturing organisation will highlight the changing manufacturing landscape - challenges and opportunities as well as case studies that will help provide practical steps, which manufacturers can take on the journey to embrace digitalisation.

BCAS, Executive Director, Vanda Jones will also help demystify an often overlooked aspect of digitalisation by highlighting how compressed air systems within the context of the Smart Factory can provide major efficiency gains.

The variety and scope of both Forum programmes for 2020 is extremely exciting, adding real value and will give visitors a genuine opportunity to keep abreast of the latest industry developments.

For further updates and to view the full programme please visit:
www.drives-expo.com
www.smartindustry-expo.com
www.fluidpowersystems-expo.com
www.airtech-expo.com
www.maintenanceuk-expo.com

GaN-Based Switcher ICs Empower Next-Generation Power Products

There have been a number of disruptive advances in the power electronics community over the last 20 years. These changes - from switching power supplies to digital power management to AI-driven systems - have moved the industry forward. Up until recently, these advances have mainly been topology and system design. However, in recent years, arguably the most significant disruptive change has been the advent of wide-bandgap semiconductors such as Gallium Nitride (GaN). **Chris Lee, Power Integrations, San Jose, USA**

GaN offers very real benefits over Silicon, including enabling much higher switching frequencies and/or significantly increasing energy efficiency. By all metrics, a GaN device is simply a better switch than Silicon. However, GaN devices have mostly only been available in the form of discrete components, which require considerable effort and finesse to design into systems than would a more integrated solution.

Incorporating GaN

In 2019, Power Integrations launched its GaN-based InnoSwitch™3 family of offline CV/CC flyback switcher ICs, delivering up to 95 % efficiency across the full load range, and up to 100 W in enclosed adapter implementations, all without requiring a heatsink. This industry-leading increase in performance is enabled by using an internally-developed high-voltage GaN switch technology (Figure 1).

Developed specifically for offline power conversion applications, the devices realize the performance benefits promised by wide band-gap technology. Losses in GaN switches are almost entirely due to inter-nodal capacitances, which are much smaller in GaN compared to silicon MOSFETs due to the reduced size of the switch for a given $R_{DS(ON)}$. Power Integrations calls its advanced GaN Switch technology 'PowiGaN™'. The new switches give the InSOP-24C-packaged devices the ability to deliver much higher power levels without a heatsink, a benefit which comes from substantially increasing the overall power supply efficiency.

A major challenge when using GaN is the difficulty in driving the transistors and protecting them. GaN is so much faster than silicon that even small amounts of parasitic trace inductance and capacitance causes challenges to safe operation. Common issues include high dv/dt frequency oscillation during switching, which creates EMI, lowers efficiency, and some cases can cause destruction voltage stress on the device. Power Integrations resolved the issue by embedding the PowiGaN GaN switch in its highly-integrated switcher ICs, which significantly reduces parasitic inductances and capacitances.

PowiGaN technology

A key advantage to PowiGaN-based products is that they incorporate drivers tailored to the specific GaN-based device, optimizing switching speed to minimize EMI, maximizing efficiency, and effectively eliminating oscillation (as described above). Integrated protection circuitry is able to quickly and accurately detect excess currents and safely shut down the device during fault conditions, and Power Integrations' switching converter ICs include start-up circuitry that eliminates the need for external biasing circuits.

PowiGaN devices also employ lossless current-sense technology, eliminating the need for the external sense resistors seen in discrete implementations. In order to bias the control loop sufficiently to ensure a response fast enough to protect the switch, the value of these resistors can exceed that the GaN switch itself. The operation of PowiGaN-based InnoSwitch3 is indistinguishable from that of legacy Silicon-based devices from the same family, with switching frequency, transformer design, EMI filtering, biasing, and synchronous rectification circuitry remaining the same for both PowiGaN- and Silicon-based parts.

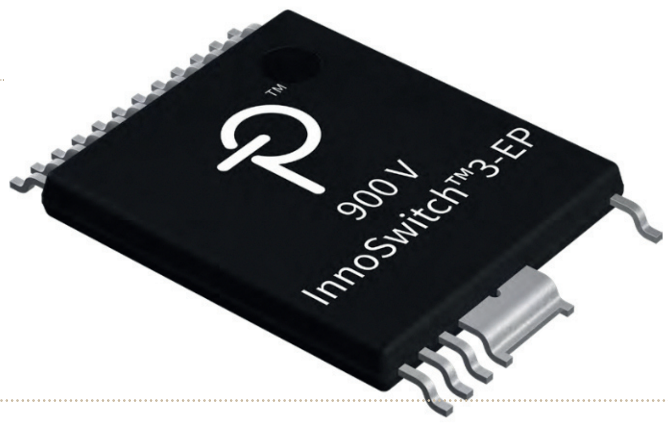


Figure 1: InnoSwitch3 offline CV/CC flyback switcher ICs deliver up to 95% efficiency across the full load range

InnoSwitch and LYTSwitch

Incorporating GaN technology into the InnoSwitch3 and InnoSwitch3-Pro families of flyback power conversion ICs and LYTSwitch™-6 LED driver ICs allows the elimination of heatsinks in chargers, adapters, LED ballasts and other compact or sealed power systems that must rely on convection cooling. Another advantage to InnoSwitch devices is that these ICs also use high speed FluxLink™ communications technology that ensures high regulation accuracy, rapid transient response, and advanced line, load and protection features without the need for optocouplers.

Able to deliver between 30 W and 100 W without a heatsink, the low-profile highly-integrated surface-mount InSOP-24C package is ideal for use in applications that employ PCB cooling. FluxLink feedback technology enables very fast control – virtually eliminating overshoot and undershoot during transient load transitions.

A drop-in solution

Because the operation of the PowiGaN-based InnoSwitch3 is indistinguishable from that of legacy devices from the same family, the new products provide a drop-in replacement for existing InnoSwitch-based circuits, and changes are only necessary to accommodate the higher power of the PowiGaN-based design. PI Expert automated power supply design software supports both MOSFET and PowiGaN-based devices, speeding up the design process by optimizing component selection and generating the full schematic, magnetics, and bill of materials (BoM).

Figure 2 shows the seamless transition between GaN and silicon devices which is demonstrated by the side-by-side comparison

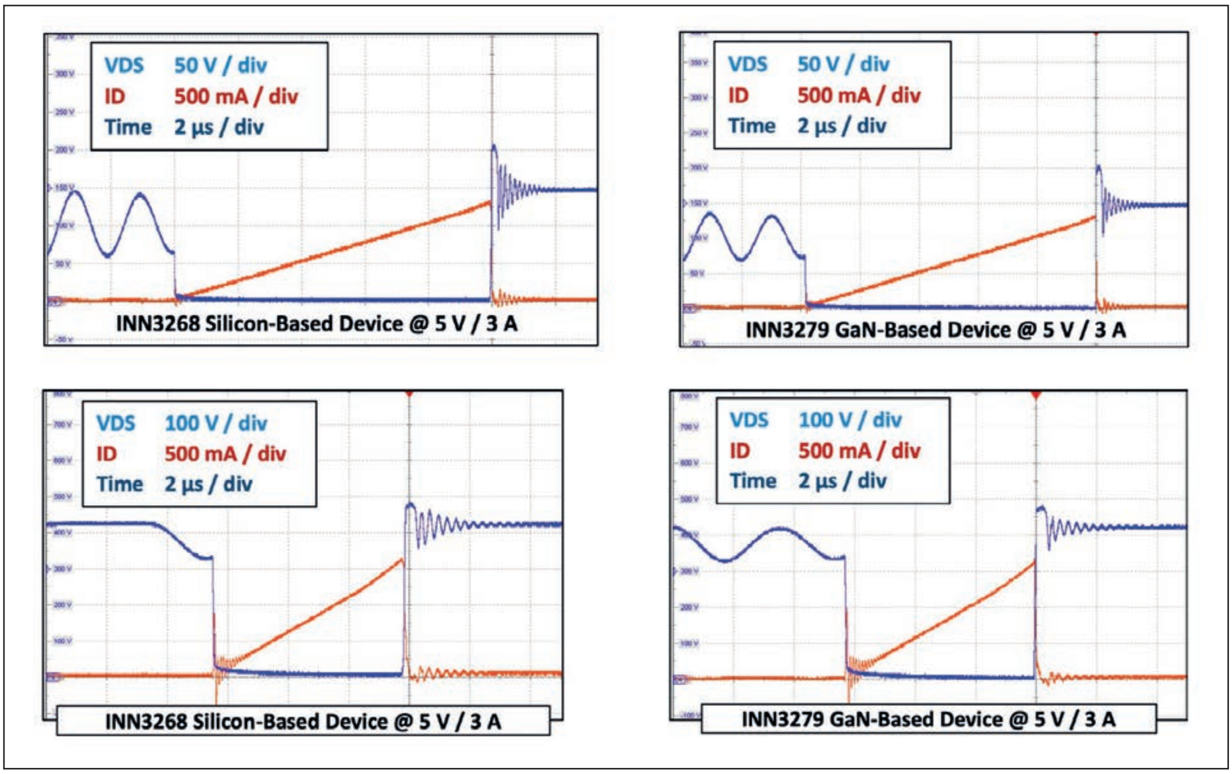


Figure 2: **A comparison of drain-source voltage waveforms during switching for Silicon InnoSwitch3 devices (left) and PowiGaN (right) at 50 V (upper) and 100 V / div (lower) image**

of drain-source voltage waveforms during switching for PowiGaN and Silicon InnoSwitch3 devices. The waveforms are virtually identical, showing the same circuits can be used for Silicon and PowiGaN-based devices. The slope of the transition is the same and produces a similar EMI signature.

Because the efficiency of PowiGaN-based designs is constant across line and load, they are particularly suitable for applications requiring high average efficiency, as well as for adjustable output-voltage designs such as USB PD and for PPS. In USB PD type applications, designs using InnoSwitch3 devices with PowiGaN switches achieve the high efficiency across load vital for eliminating heatsinks in applications with widely varying output conditions.

Reliable and rugged

Specifically designed to operate at the voltage levels seen in off-line flyback power conversion, PowiGaN devices have undergone extensive qualification testing, which includes challenging environmental and highly accelerated life testing, as well as extensive long-term testing in real-world power supply designs, resulting in a field-failure rate of less than 0.2 parts per million (PPM). Product qualification includes additional DOPL and HALT testing to confirm survive ability in worst-case (real-world) conditions (Figure 3).

The company's switcher devices operate across variable mains voltage levels encountered worldwide. In a typical flyback design the worst case voltage stress under normal operation occurs at maximum line voltage (264 V AC for European systems). All InnoSwitch3 family members and LYTSwitch-6 devices monitor the bus voltage via the V pin and will interrupt switching to eliminate VOR and VLE induced voltage-stress on components during line surges.

The existence of two voltage ratings for the PowiGaN switch enable optimization for practical applications, with a VMAX(non-repetitive) rating (750 V) describing the maximum voltage-withstand under transient, swell, and extended surge conditions. This parameter is employed for derating purposes in the power supply design, in the same way as the absolute max BVDss rating for a traditional MOSFET is used.

The maximum continuous voltage parameter describes the stress that may be applied continuously to the GaN switch. For PowiGaN devices this figure is 650 V. Operation above this limit will not damage the device, but extended exposure to higher voltages may cause temporary RDS(ON) shift beyond the limits described in the datasheet. As described, the fast line-over-voltage protection feature will cause the device to cease switching in the event that the line voltage exceeds a user-defined limit, increasing safety margins in fault conditions.

Summary

Power Integration's approach yields overall circuit performance, size and system cost benefits. This has provided customers with an easy adoption curve: the new GaN devices build on established Silicon products delivering significantly improved performance that can be cost-effectively implemented into existing designs.

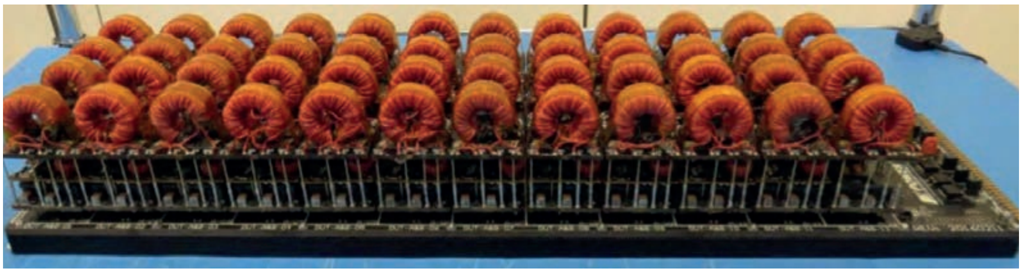


Figure 3: **DOPL stress-test board used for PowiGaN InnoSwitch3 device qualification testing¶**

Current Sensing Moves In Advanced Embedded Systems

The embedded electronics development community is currently experiencing the biggest changes in our industry since the creation of the integrated circuit. From new software-oriented solutions like Artificial Intelligence, to new hardware topologies, to new semiconductor materials, we are in the middle of a disruptive period of demanding growth. **Khagendra Thapa, VP of Business Development, ACEINNA Inc., Andover, USA**

Much of these advances are related to user functionality, like Cloud-based Internet of Things (IoT) solutions that rely on next-generation RF technologies. Other rapidly emerging current sensing applications include Electric Vehicles (EV) and their Advance Driver-Assistance Systems (ADAS) and Autonomous Driving needs, to wide-bandgap power switches based on Silicon Carbide (SiC) and/or Gallium Nitride (GaN) semiconductors. Some of the most important advances in these spaces have been in performance and efficiency, enabling the next generation of electronic solutions to address the challenges and demands of users and the marketplace.

The latest trends in personal electronics put a lot of pressure on the designers of embedded systems. When it comes to consumer and medical wearables, advanced personal electronics, and the internet of things, the smaller, more functional, and longer lasting, the better. Similarly, industrial and automotive applications are pushing boundaries to achieve smaller, more efficient, reliable, and robust solutions. Significant improvement in all of these include reducing parts count, simplifying circuitry, and increasing operational efficiency.

Current-sensing technologies are key to creating the small precision control and protection electronic circuits needed to make the devices of tomorrow serve applications in an efficient and cost-effective manner. There is no precision without feedback, and current sensing can provide the critical performance information an embedded intelligent system needs to manage itself. The size, accuracy and speed of your current-sensing solution will directly impact all of these aspects.

Figure 1: **Current sensing technologies are available for a wide range of applications – from EV cars and ADAS systems to home appliances, telecommunications and server farms**

AMR current sensing

A single-chip solution, the ACEINNA Anisotropic Magnetoresistive (AMR) technology based, isolated current sensor does not require additional components other than a decoupling capacitor. Compared to the other methods of current sensing, an AMR sensor provides a compact and high-performance solution. For example, the problem with using a shunt resistor is that it is inherently not isolated. A current transformer is bulkier than an AMR based current sensor and it only works with AC. Compared to using a Hall-effect sensor, AMR technology offers a bandwidth of 1.5 MHz, and has a lower offset and noise.

Benefits of AMR

Delivering better performance than a shunt register or transformer, AMR technology can respond to both DC and AC bi-directional current, with a bandwidth of 1.5 MHz and a lower offset and less noise than Hall-effect-based solutions.

Offering better accuracy, higher bandwidth with lower phase shift, and a very fast output step response, an AMR based current sensor is an accurate and compact solution for very critical measurements to protect and control power systems.

Within the sensor, the current flows through a U-bend in the lead frame, where it generates a forward or reverse field measured by two current sensors in the device. By measuring the field from both current directions, the device cancels out the external fields and magnetic anomalies which might be present. This

Desired Feature	Aceinna AMR	Hall IC / Hall IC based Modules	Current Transformer	Sense Resistor
Accuracy	✓	✗	✓/✗*	✓/✗*
DC - >1MHz 3dB BW	✓	✗	✗	✓
Isolated	✓	✓	✓	✗
Small Size	✓	✓/✗**	✗	✗

*Current Transformer and Sense Resistor applications require design trade-offs regarding complexity and customization. Accuracy will depend upon the components selected and the quality of the design.
**Hall Effect IC based sensor modules (such as those with Ferrite cores) are not small.

Figure 2: Advantages of AMR based Current Sensing versus other types of current sensing technologies

allows a horizontally-sensing AMR chip to ignore external fields generated from other nearby components on the board.

Electric vehicles

There is a tremendous amount of attention being paid to EVs right now. Much of the focus is on improving the efficiency of the powertrain, motors and On-board/Off-board charging systems as well as the performance of the battery pack, as they are all directly related to vehicle range and charging efficiency. The proper application of current-sensing technology in these application areas can deliver significant advantages.

Since the motors are where the power is being spent, any improvement there will cascade benefits throughout the system, from increasing EV range to reducing thermal management needs. When it comes to driving motors, the switching frequencies and control mechanisms are critical.

Effective motor control requires accurate performance measurement, and for that you need effective current sensors. For condition monitoring of motors for predictive maintenance, fast current sensors help to measure and monitor motor ripple currents to determine lifetime and performance parameters. On the protection side, the current sensor helps support safety by improving the control, accuracy, and reliability of a motor drive.

Many EV power electronics and charging systems are migrating to advanced wide-bandgap semiconductors like Silicon Carbide (SiC) and Gallium Nitride (GaN), as the benefits provided include higher efficiency and the ability to increase the switching frequency. A significant benefit of faster switching is the ability to shrink the size of the passives and magnetics in a circuit, with direct size and weight benefits.

However, when a circuit is switching faster, the ability to measure the performance parameters must be able to keep up, demanding real-time information from a fast and accurate current sensor. Monitoring the circuit in real-time enables advanced functionality like dynamic control of the power switching and motor drive frequency, as well as reliable and fast fault detection.

In the related area of electric trains, industrial machines, traction and robotics, we are starting to see the use of reluctance motors, a winding-free design that generates torque through magnetic reluctance. Available in synchronous, variable, switched and variable-stepping configurations, reluctance motors can deliver high power density at low cost.

The problems with reluctance motors include high torque ripple at low speed, and the resulting noise. In addition, because of the extremely high temperatures involved, reluctance motors are usually deployed with a separate harness and control system. Advanced solutions using SiC semiconductors and high bandwidth AMR sensors can take more heat, enabling size, weight, and complexity reductions of the overall

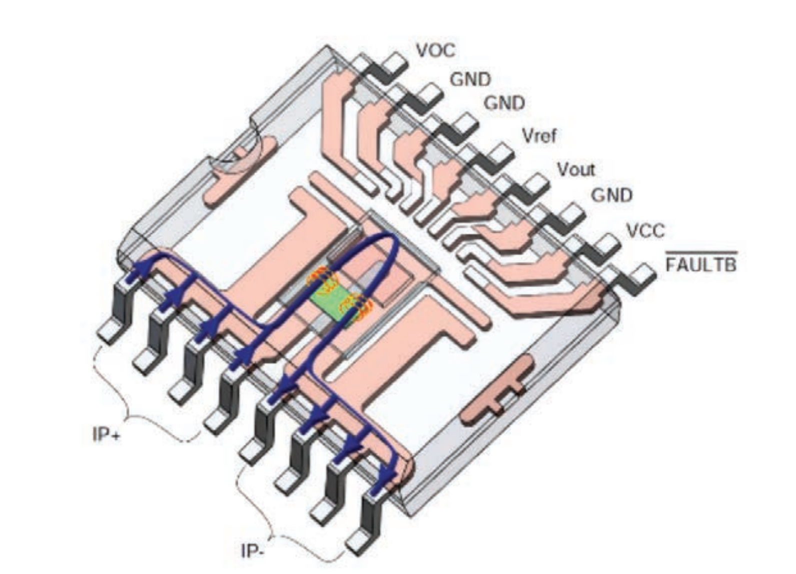


Figure 3: ACEINNA Current Sensors use a U-bend with two AMR sensors to cancel out external fields

system, providing cascading benefits.

Constructed without copper coils in the rotor, reluctance motors can be lighter than comparable electric motors.

However, the required control system is very complex, because if you don't accurately control the current, which is related to torque, you'll get a torque ripple and that generates noise issues. Advanced fast current sensing improves control of the ripple current, which provides lower noise and a more reliable solution.

It's important to bring up the protection side again because in high-power systems, you might want to switch the whole power stage off in 1.5 µs. If you look at that shutdown time budget, your step response needs to be less than 500 ns, and that's going to become more stringent as we migrate into higher power and frequency levels.

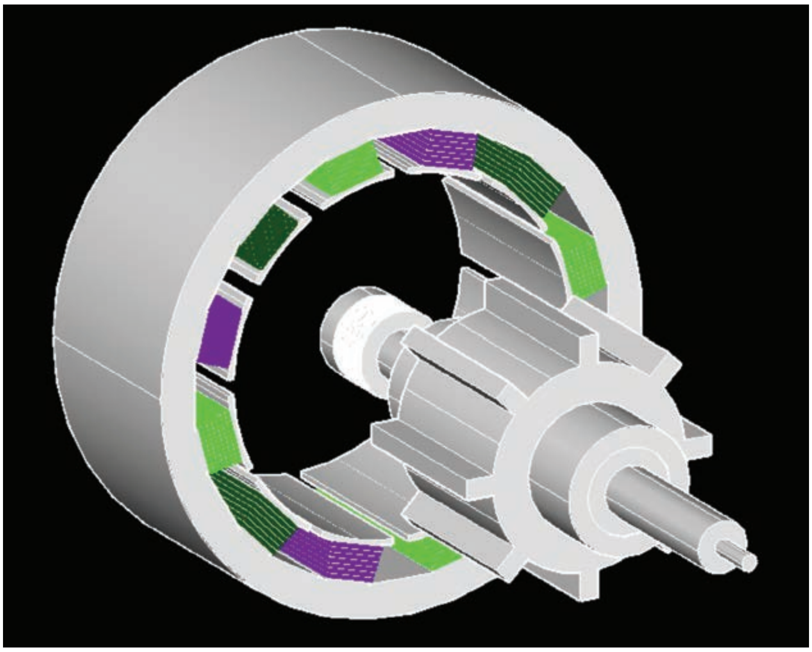


Figure 4: Variable switched reluctance motors can deliver high power density

Power factor correction

Used to reduce the lagging power factor in inductive loads, Power Factor Correction (PFC) compensates for the phase difference between voltage and current, for when the power factor drops, the system becomes less efficient.

To get 1 kW of real power at a 0.2 power factor, 5 kVA of apparent power needs to be transferred (1 kW ÷ 0.2 = 5 kVA). This obviously can severely impact the performance in the case of inductive loads such as motors, refrigerators and HVAC systems, Inverters, uninterruptible power supplies (UPS), and similar application spaces.

Fast turn-on and -off time, fast reverse recovery and lower ON resistance of wide bandgap SiC and GaN based power switches are allowing effective use of Totem Pole architecture to improve efficiency of PFC and reduce the number of components used. These benefits help power systems to achieve higher efficiency 80+ Gold and Titanium certifications.

For example, when it comes to ripple currents in the PFC in a Totem Pole, to measure current cycle-by-cycle to calculate the pulse-width modulation (PWM) duty ratio, you need to have a high bandwidth for the ability to match the circuit's switching frequency. Let's say if your PFC switching frequency is being pushed to 65, 140, 200, 300 kilohertz, you ideally want 10 times the bandwidth of the switching frequency for the current sensor.

Smart manufacturing

When it comes to smart manufacturing and the smart factory, it's really about automation and data exchange. In a system where powered devices are connected to an intelligent infrastructure and the internet, you'll also need power conversion. Power monitoring and management are critical to the optimal operation of a smart assembly process, with everything being measured in real-time.

There are various locations in an automated system where an AMR current sensor can be deployed to take advantage of its accuracy, bandwidth, and step response. If you have a highly accurate sensor, then you can optimize your process and increase efficiency and productivity.

This performance advantage can be further leveraged by using AMR current sensing to determine how much the processor is being used, especially for applications involving AI, the Cloud, and data storage. AMR current sensors can also enable the use of power tracking for performance monitoring's sake, optimization of processor loading and thermal management.

Looking forward

Whether it is for advanced EVs, entire smart factories, UPS, inverters or motor drive, efficient and cost-effective power management is key to optimal performance. In applications from driving motors or powering 5G telecom, you want to be operating much faster and more effectively. Advanced current sensing enables a higher level of control, with a higher efficiency, at higher frequencies and temperatures.

The next generation of embedded devices must be able to serve the latest application spaces in the most efficient and cost-effective manner. Using AMR-based current sensing solutions to ensure that the electronics are performing at their best will pay off in cascading benefits throughout the entire system.

There is no precision without feedback. Precise fast current feedback enables the highest levels of efficient and safe operation in an advanced powered circuit.

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A Step Forward to Miniaturize Current Sensing in Power Conversion

Modern power conversion systems must simultaneously become more efficient, smaller and cheaper than previous generation. LEM has used its expertise in this field to create a single chip package, the HMSR.

Stepanie Rollier, Product & MarComs Manager, LEM, Geneva, Switzerland

The traditional way to measure current is to use Open Loop Hall effect sensors. The magnetic field created by a current is captured by a magnetic core and measured by a hall element. More recently, dedicated ASICs helped to increase the overall accuracy of the system using advanced compensation techniques.

LEM first moved into miniaturization with the LTSR product in the previous decade. At that time, the best way to ensure optimum performances was to use Closed Loop Hall effect technology in combination with a special Closed Loop ASIC. The evolution of ASICs technology enabled the development of Open Loop Hall effect sensors that were capable of approaching the level of performance that Closed Loop technology delivered (see Figure 1).

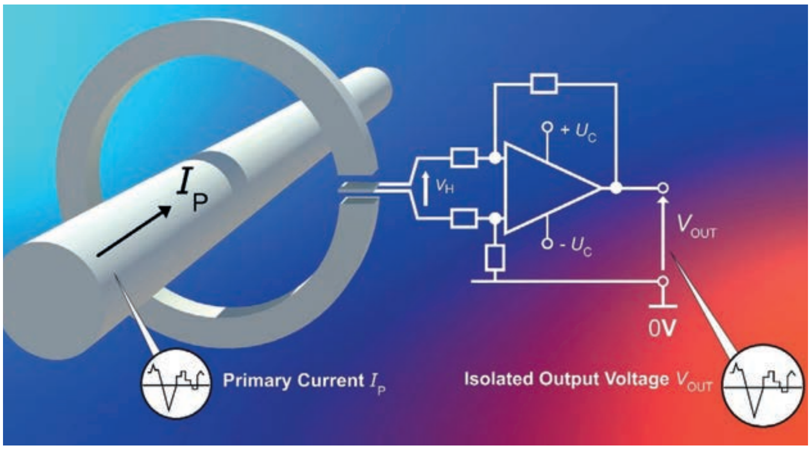

Figure 1: **Open loop technology principle using a traditional Hall effect chip or a dedicated ASIC**

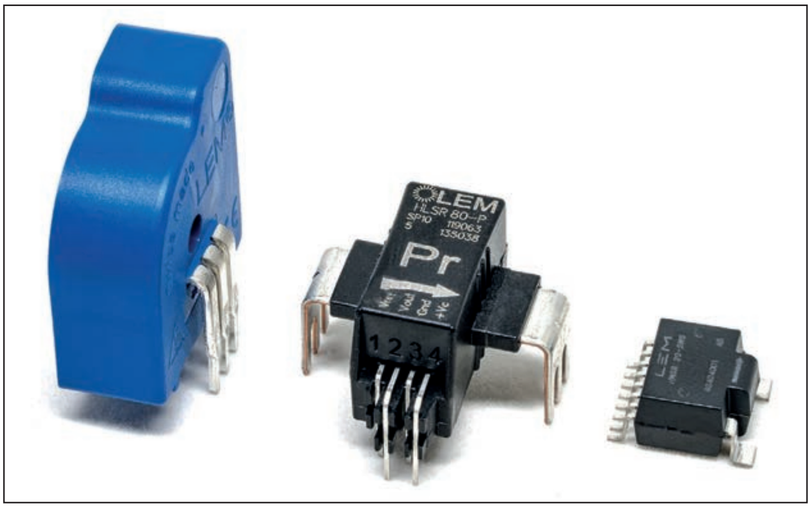

Figure 2: **Evolution of the current sensor's size over the decades**

Not only did Open Loop technology make it easier to reduce the size of components but it also brought the cost improvements that the market demanded, thanks to it having a simpler structure and lower power consumption. This decade has seen the development of the HLSR series which not only delivers high performance in terms of offset and drift but also excellent response time – and all in a package small enough for PCBA-type applications with only a few mm height. LEM has used the extensive know-how and design expertise that it has accumulated over many years to create the HMSR, a state-of-the-art current sensor which satisfies the continuous market requirements of cost reduction, performance improvements and miniaturization (see Figure 2).

Ferrite and ASIC improve performance

With this new series, LEM is expanding its miniature, current sensors range for AC and DC isolated current measurement. The new HMSR models (Figure 3) are easy to use because they include a low-resistance primary conductor (which minimizes power losses), a miniature ferrite and a proprietary ASIC to allow direct current measurement and consistent insulation performance.

This new product category already includes six different nominal currents – 6 A, 8 A, 10 A, 15 A, 20 A and 30 A – with a measurement span of 2.5 times the nominal current available in a SOIC 16 "like" footprint package. Standard models provide an analogue voltage output with different sensitivity levels available, with 5V power supply versions achieving an output voltage of 800 mV at I_{PN}.

Built-in are two OCD (over current detection) units which separate the control application path to the safety loop. These

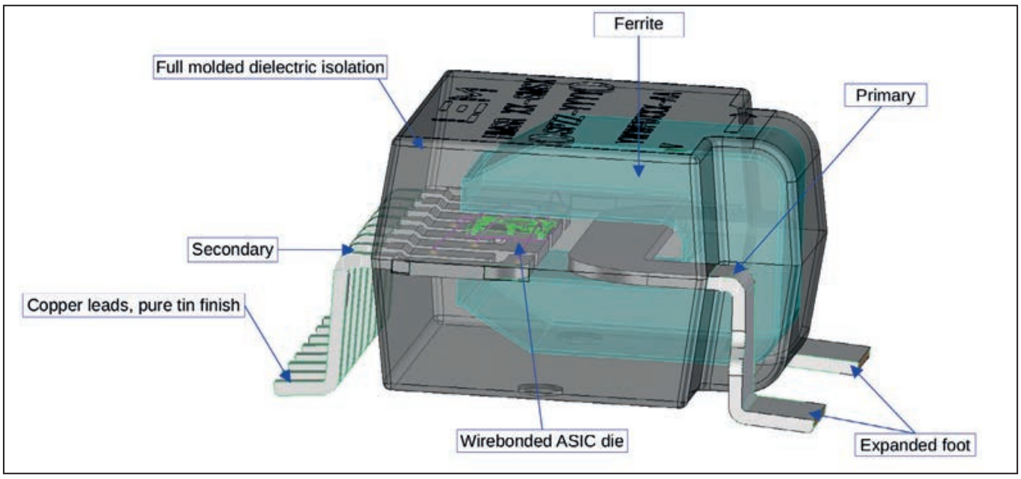

Figure 3: HMSR current sensor

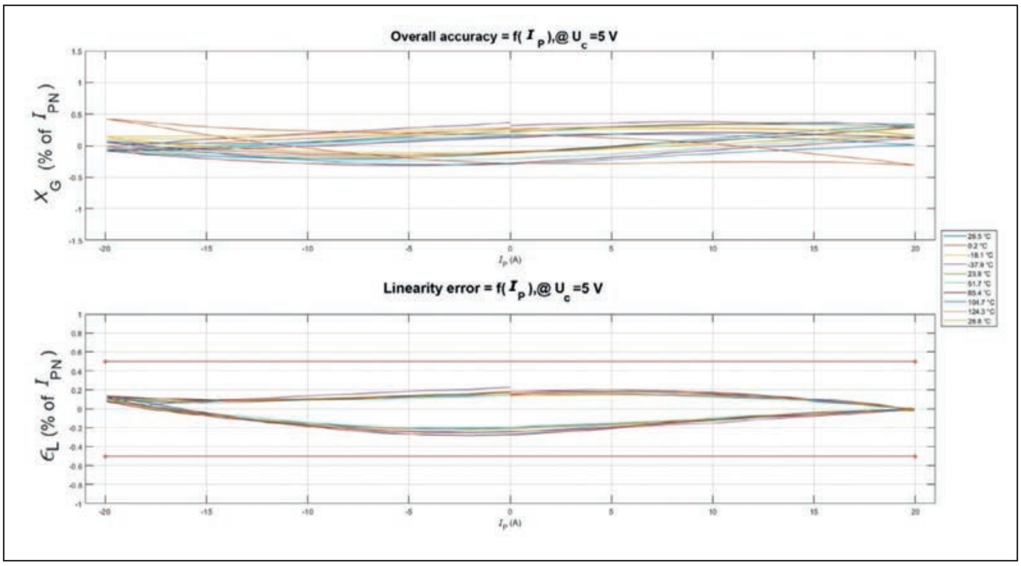

Figure 4: Typical overall accuracy and linearity for HMSR 20-SMS model from -40°C to +125°C)

OCDs are on two dedicated pins – one set internally at 2.93 x I_{PN} as threshold and one externally whose threshold can be adjusted by the user.

However, HMSR sensors should not be seen as simple Open Loop Hall effect ASIC-based transducers. The HMSR unique primary conductor allows overload punctual currents and a high level of insulation. All this is combined with a ferrite-based magnetic circuit to provide high immunity against the external inhomogeneous fields found in power electronics applications. This enables the HMSR to be used in environments with high levels of disturbance. The ferrite used in the HMSR is also a key factor in achieving a high-frequency bandwidth of 270 kHz (-3dB) and makes it possible to achieve good rejection against external fields.

These dedicated ASIC designs combine field-proven techniques such as spinning, programmable internal temperature compensation (EEPROM) for improved gain and offset drifts. The result is high levels of accuracy across a range of temperatures, from -40°C to +125°C with a typical value of 0.5 % of I_{PN} (the HMSR 20-SMS model). Power conversion applications such as solar inverter or drives demand high efficiency levels and these can be reached only if the control loop is accurate.

The accuracy over temperature figures have been greatly improved on the HMSR in comparison to the previous generation of products. The graph below shows the low level of typical overall error across a measured current with the HMSR 20-SMS, as well as very good linearity on a wide temperature range (-40°C to +125°C).

However, such accuracy is not enough if it isn't backed by a fast response time. To this end, the deployment of a fast IGBT, like SiC-based technology, increases the possibility of working with a faster switching frequency – the HMSR is proven to be ready for such demanding technology with a response time below 2 μS.

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For demanding applications

In multiple applications, HMSR sensors can be mounted directly onto a printed circuit board as SO16 SMD devices, reducing manufacturing costs and providing much needed space-saving for restricted environments. At just 6 mm high, the HMSR offers significant space-saving in applications, for example placing it under the heatsink over intelligent power modules (IPMs) as sketched in Figure 5.

Another area where the HMSR will deliver significant benefits in terms of current measurement is in solar applications.

In particular, the maximum power point tracker (MPPT), an important asset in solar energy conversion, is a collection of components that maximize the power generated from a photovoltaic (PV) panel. It does this by regulating current and

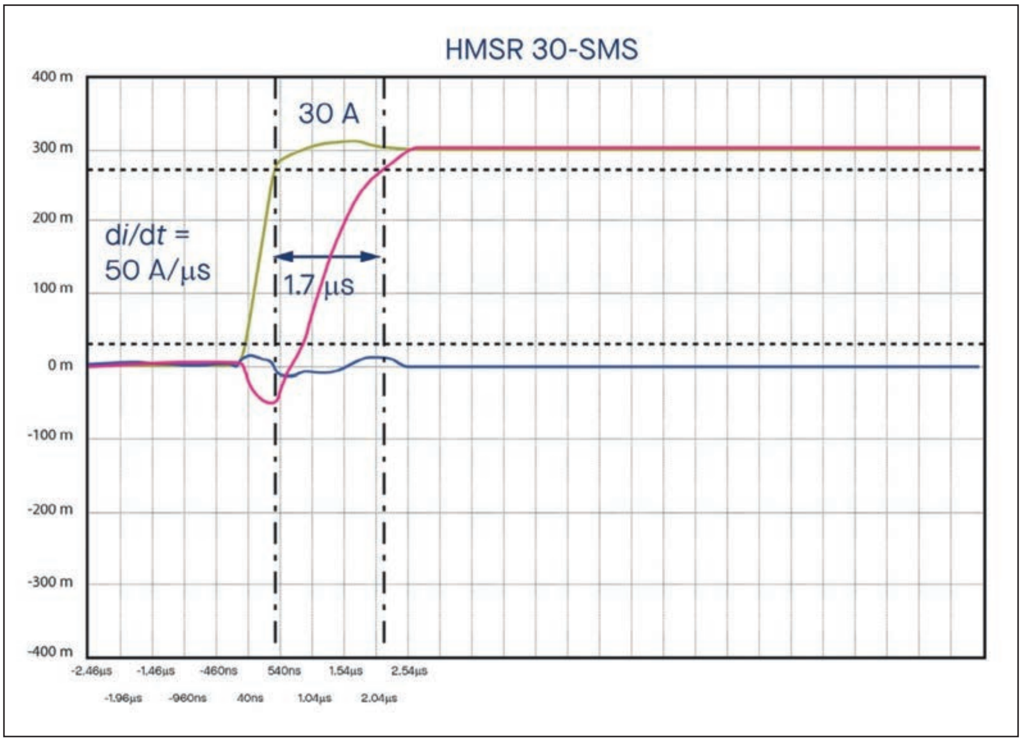

Figure 5: HMSR response time

voltage depending on temperature, sunshine and total resistance of the system. The control system permanently analyzes the system output after injecting a small perturbation (using the perturb and observe method). The MPPT then analyzes the resulting power (by sensing voltage and current) and deducts the parameter to change in order to reach the MPP (maximum power point). The MPPT then changes the pulse width modulation (PWM) to adapt the voltage of the DC/DC converter (see Figures 6 and 7).

The greater the accuracy and lower the noise, the better the performance from the MPPT will be. The HMSR provides a highly accurate and very low-noise signal which allows the system to operate to its optimal level. String current monitoring makes it possible to compare several strings and to detect issues such as faulty wiring, dirt on the panels and shadows created by growing trees. Here, the accuracy of the HMSR will enable strings to be compared. In addition, the DC/DC converter used in the MPPT uses high-frequency regulation (around 80 kHz), creating high dV/dt which is harmful for electronic components. Thanks to its ruggedized design, the HMSR offers significant resistance to such a noisy environment. This immunity can easily be checked by applying dV/dt through the sensor and observing the output reaction.

Of course, isolation requirements could be an issue for the adoption of IC packages when it comes to choosing a current sensor. For example, in the solar industry power plants are often used with higher DC voltages, up to 1500 V in order to increase the DC/AC power ratios. This increases the isolation needed for a current converter.

The long internal distance between primary and secondary sides helps to isolate the primary bar with the rest of the IC, giving a very high level of isolation guaranteed at 4.95 kVRMS (at an AC insulation test voltage of 50 Hz, 1 min). This level will be guaranteed for 100 % of the shipped products that are tested during production assembly. The special footprint of the HMSR allows 8 mm

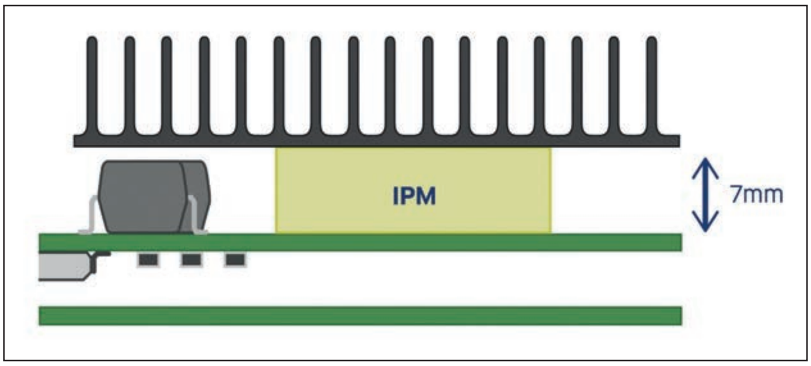

Figure 6: HMSR mounted with IPM

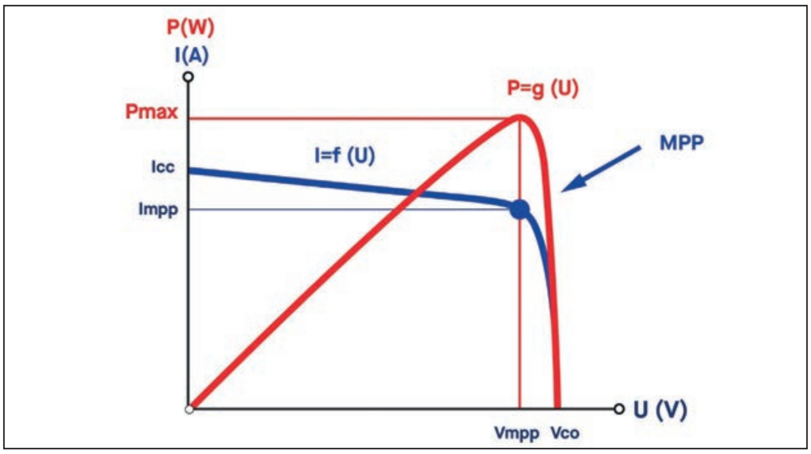

Figure 7: Maximum power point tracking

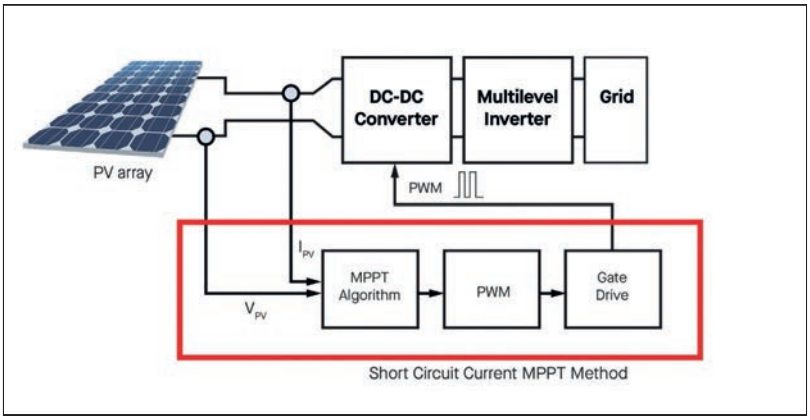

Figure 8: MPPT architecture

creepage and clearance distances on the landing pad.

A higher comparative tracking index (CTI) means a lower minimum creepage distance is needed and with a CTI of > 600, according to the IEC 62109-1 (Safety of power converters for use in photovoltaic power systems), the working voltage for the HMSR reaches 1600 V, which means it is suited to such high-constraint applications. Another key requirement in the solar industry is that equipment needs to be surge tolerant up to 20 kA to offer effective lightning protection. With the HMSR placed directly on to the string inputs that are subject to lightning, components will be extremely robust against such powerful current surges. The HMSR has been designed and tested to this level according to the standard 8/20 µS surge test profile (see Figure 8).

A HMSR evaluation board makes it possible to prototype and test quickly the extraordinary performances of this new generation of sensors.

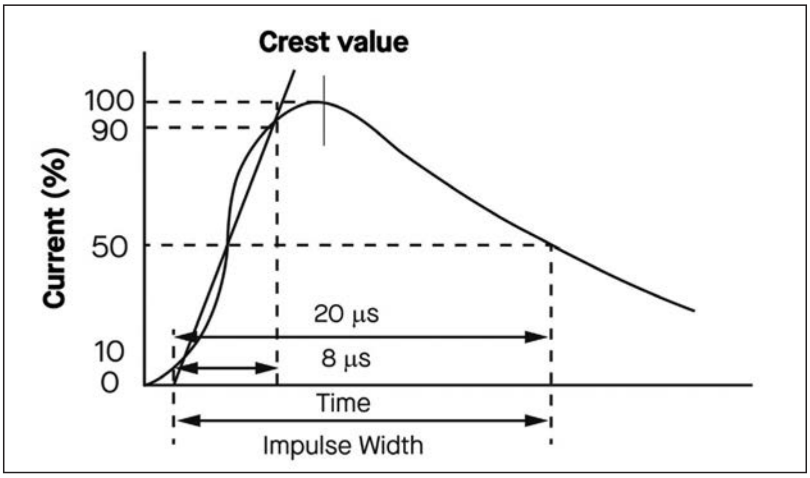

Figure 9: Typical overcurrent surge profile in solar applications

PCB Design for Low-EMI DC/DC Converters

Every switch-mode power supply presents a wide-band noise source. Integrating a DC/DC converter from the car board net into an automotive control unit and still fulfilling the EMC requirements of automotive OEMs is a difficult task. With the view that layout, with its parasitic elements, is part of the circuit, PCB design can be optimized for low EMI in DC/DC converters. The MPQ4431 buck converter from MPS demonstrates that careful component placement and board layout help make it possible to meet the strict EMC limits within the automotive industry. **Jens Hedrich, Senior Field Application Engineer, Monolithic Power Systems, USA**

Typically, noise from the DC/DC converter and other high-speed circuits radiates via connected cables that provide an effective antenna path. To block this potential radiation path, filter circuitry is required at each cable connection point. This filtering is only effective if no H- or E-fields from the noise source couple into the filter components or cables.

In close-field environments, the amplitude of the fields falls by 1 over distance squared ($1/d^2$). Therefore, a certain minimum distance is required between the noise source, filter components, and connector.

Unfortunately, PCB size and connector positions for the cables are usually pre-defined by mechanical constraints. Additionally, the maximum component height may be very limited in certain areas of the PCB, and two-sided assembly may not be possible. These conditions necessitate careful component placement and PCB layout, especially when working within highly regulated industries such as automotive manufacturing.

Real estate planning

To avoid directly coupling the E- and H-fields of the DC/DC converter into connectors and cables, the circuit must be placed as far from the PCB connection points as possible (see Figure 1).

Only distance or additional shielding can reduce the field strength at the EMC filters, connector and cable to the necessary low levels. Shielding can replace distance!

It is best to use a two-side assembled PCB with at least four layers, where the DC/DC circuit and filter components are placed on opposite sides of the board. At least one inner layer should be solid GND to minimize cross-coupling from the noise source into the filter circuits.

In systems where the DC/DC circuit must be placed very close to the connector, effective shielding must be considered early in the design process. Thermally necessary heatsinks can sometimes be utilized for shielding. Ideally, the inductor, the DC/DC IC with power MOSFETs, and its decoupling capacitors are all located under the shield.

PCB layout guidelines

In a step-down converter, the main field sources are:

- High di/dt loop (hot loop), formed by the two power switches and CIN, which radiates wide-band magnetic fields
- SW node between power FETs and the inductor, with strong E-field radiation
- The inductor, which radiates E-fields and H-fields

AC-magnetic fields are shielded by solid metal areas that allow the induction of eddy currents. Due to its high conductivity, copper is very effective. Any conductor in the path of the potential difference that returns to a fixed potential on the PCB will effectively shield E-field radiation.

Any high di/dt loop radiates H-fields proportional to the loop area and current amplitude. Place the input capacitor close

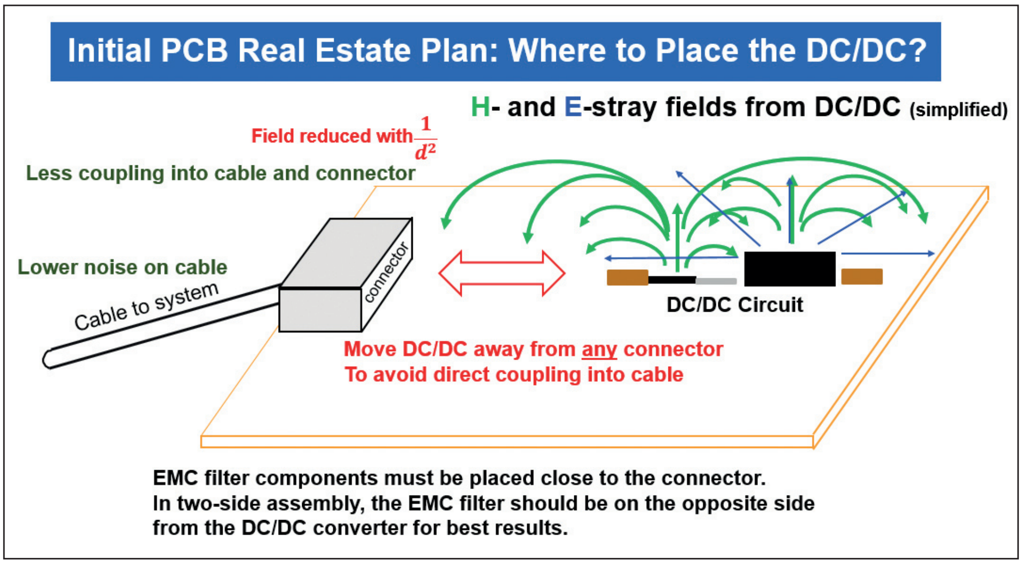

Figure 1: Place noise source in maximum distance from connector and cable

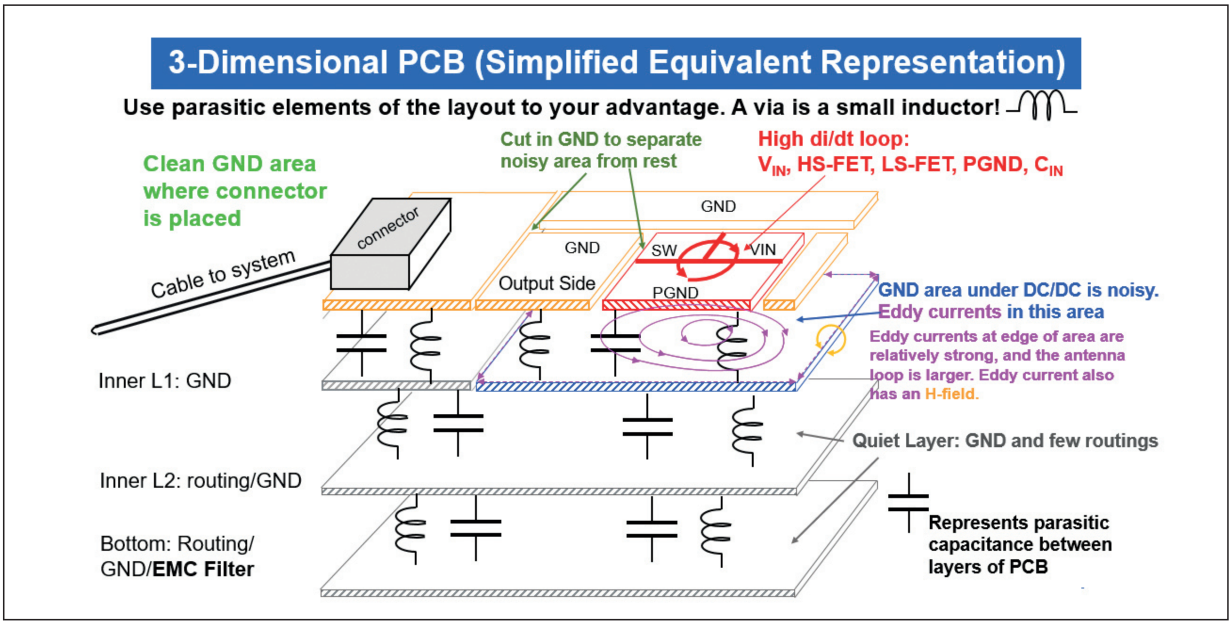

Figure 2: **3-Dimensional PCB view – layout is part of the circuit**

to the two power switches with a low-impedance connection to minimize the antenna loop area.

To further reduce the magnetic fields from this loop, place two sets of capacitors symmetrically at the power switches. Ideally, the peak currents in both loops will be half of the original, reducing the H-field by 6 dB. The orientation of the two loops is opposite, which further reduces the radiated H-field (see Henry W. Ott, Electromagnetic Compatibility Engineering, John Wiley, 2009).

There should be a solid GND area in the layer under the DC/DC circuit, spaced with a distance of less than 100 µm. In this copper area, the high di/dt currents flowing through the circuit components and PCB traces induce eddy currents. The eddy currents run opposite to the original currents on the component side, and their magnetic fields cancel the original field. This works best if the eddy current can mirror-image the high di/dt loop current from the component side with minimal distance. This reduces H-field radiation from the component side of the PCB. In an ideal case (super-conduction, zero distance, and perfect matching of both loop shapes), it would be canceled by the H-fields from the eddy currents.

Since the GND copper area under the DC/DC circuit has impedance, the high di/dt eddy currents create potential differences and make the area noisy. This noisy GND area must be separated from the system GND area, especially from any GND reference for filters and connectors. In a multi-layer PCB, these are separated by shaping the individual layers and by the impedance of the connecting vias between them. A 3-dimensional view of the multi-layer PCB illustrates this concept (see Figure 2).

On the top layer, the input capacitor (C_{IN}) and the two power FETs join a V_{IN} area and a PGND area (shown in red) that are connected to inner layers through vias. For the VIN path, the component after the vias must be an inductive element (e.g. a 1 µH to 2 µH coil). The high di/dt current from the switch transition is then forced to flow only in C_{IN}, and not across the PCB.

The PGND area is not directly connected to any other GND on the component side, only through vias to the PGND area under the DC/DC block (shown in blue). The goal is to keep high-frequency currents on the component side, separating the noise from the

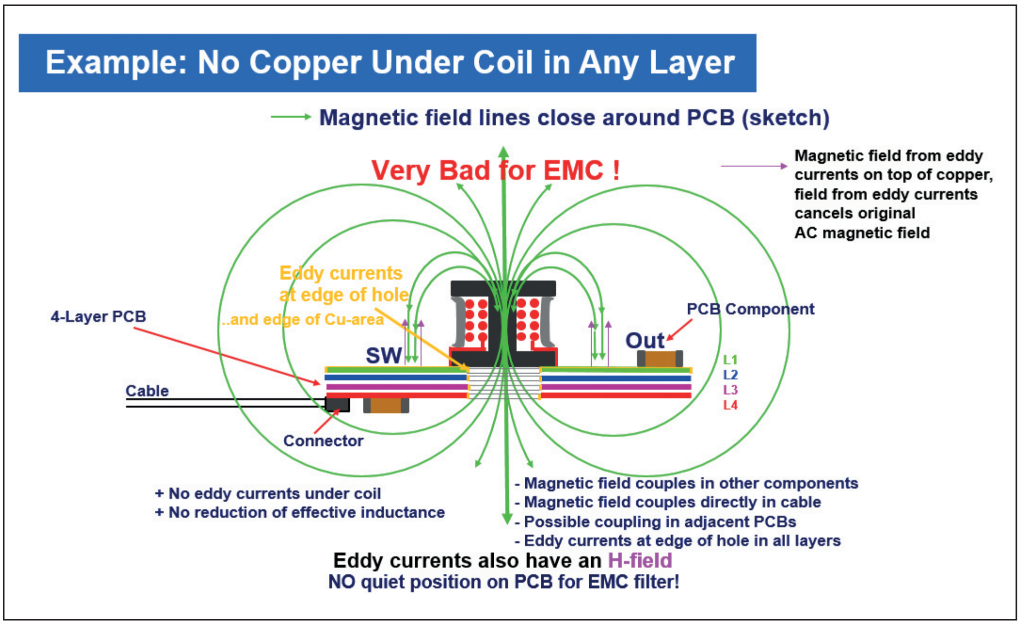

Figure 3: **4-Layer PCB with no copper under the coil**

"outside world." At least one layer should be solid GND for the full size of the PCB to provide a low-impedance system reference. Remember, layout is part of the circuit.

Should copper be placed under the inductor?

Some PCB layout tools have a pre-setting that does not allow copper under an inductor core. Views on this topic range from no copper at all to copper directly under the coil on the component side of PCB.

Figure 3 shows a sketch of the magnetic fields around the coil with no copper under the coil in any layer of a 4-layer PCB. The strong magnetic field lines from the coil are present on the bottom side of the PCB and close around the PCB, effectively coupling into any connected cable. Filter components on the PCB are bypassed through the air. This makes it very difficult, if not impossible, to meet automotive OEM EMC levels. Figure 4 shows the PCB layout with copper directly under the coil on the component side.

This provides an area for eddy currents to cancel the magnetic field already on the outside of the PCB. Inner Layer 2 and Bottom Layer are clean. EMC filter components can be effectively placed on the bottom side. The magnetic field of the eddy currents somewhat reduces the effective inductance of the coil (typically less than 5 %). The eddy currents also create some losses in the GND copper. Another small disadvantage of copper directly under the inductor core is an increased parasitic capacitance from the winding to GND. However, in most designs this effect is not dominant as the capacitance is very low.

PCB layout example

The MPQ443x family are 40 V synchronous buck converters with low operating quiescent current and output currents from 1 A to 3.5 A, ideal for automotive and industrial applications.

On the top side of the PCB, the MPQ4430 IC (U1) has symmetric CIN sets (C1A-C1D). The GND of these capacitors is directly connected to the IC PGND pins, which is the source of the bottom FETs. This local GND area is very noisy. On the component side, this GND area is not directly connected to any other GND area. The only connection is through vias to the GND area in the layer under the DC/DC circuit. In this configuration, the high di/dt current from the power stage stays on the component side. The highest current density is on the inner edges of the traces, between V_{IN} and PGND, shown in the green ellipse of the example (see Figure 5).

V_{IN} is connected to Layer 3 by vias. Due to the vias' inductance, the high-frequency part of the input current remains on the top side. CIN9 damps this V_{IN} node at the IC,

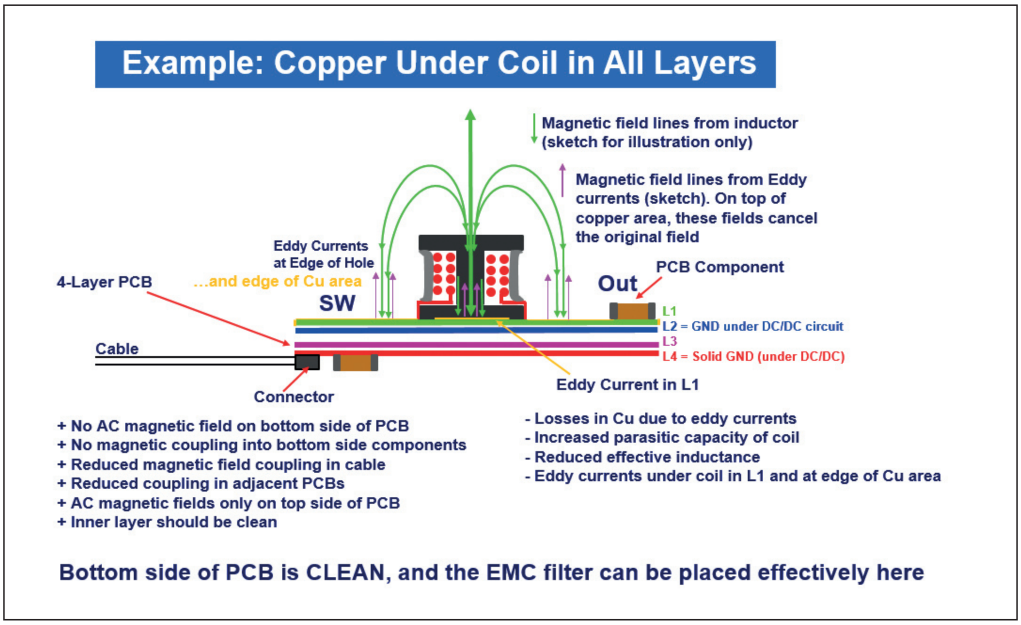

Figure 4: Effects of copper under coil in PCB

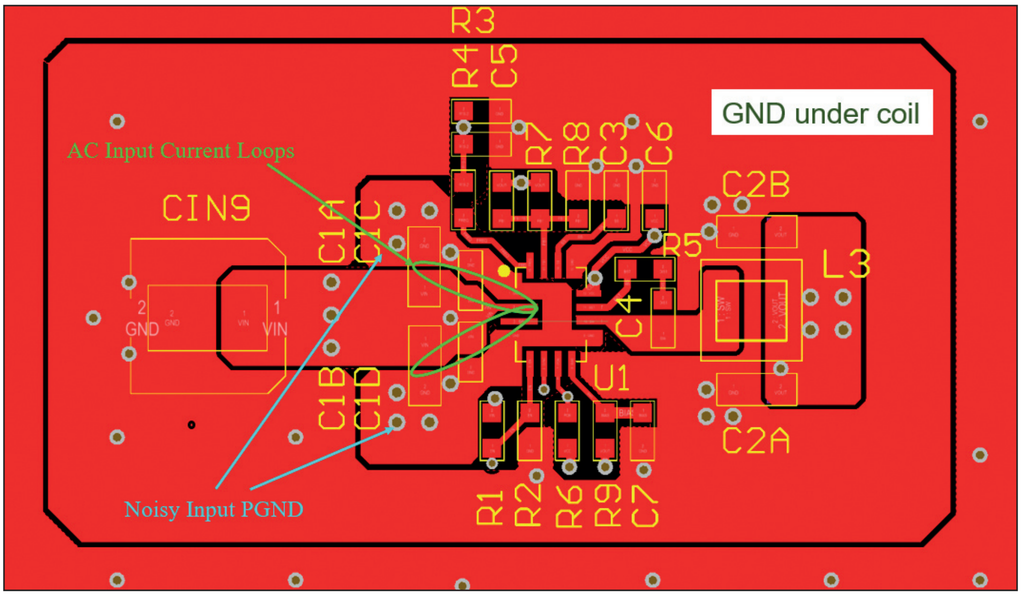

Figure 5: MPQ4430 PCB top-side layout

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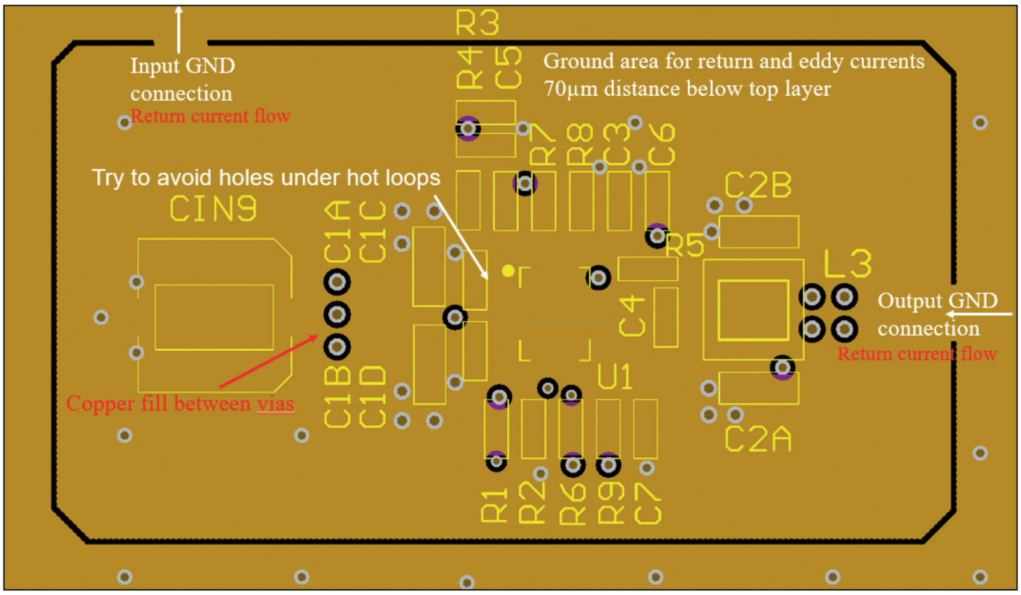


Figure 6: Inner Layer 1 recommended PCB layout

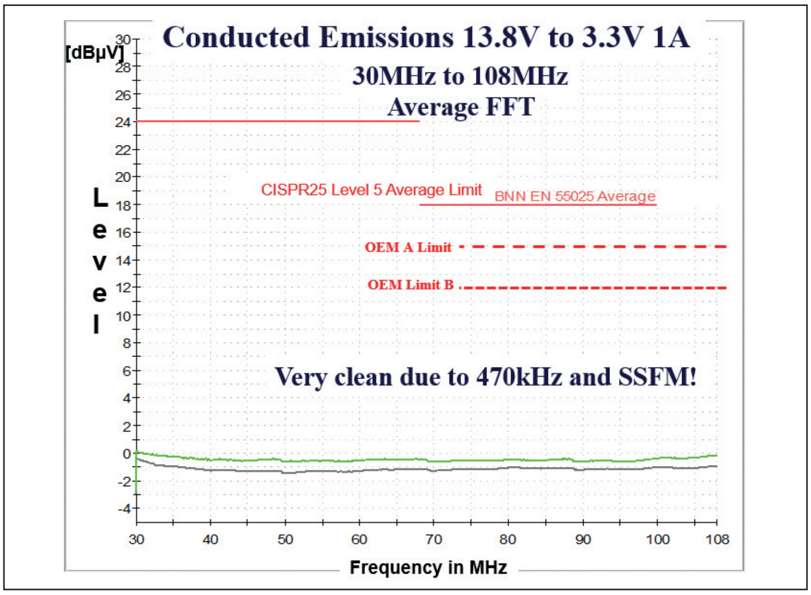
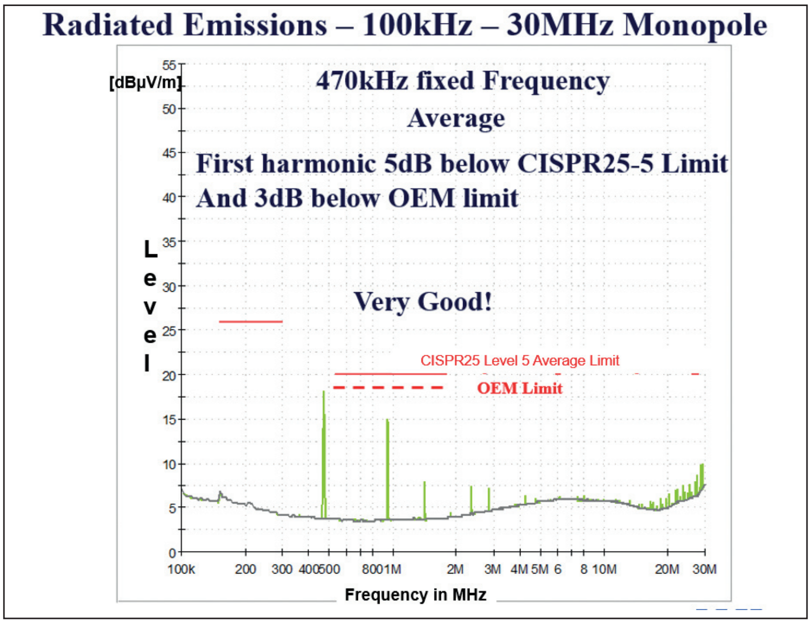


Figure 7: CE test results, 30 MHz to 108 MHz



but as it is 6 mm high and cathode-connected to GND, it also blocks part of the E-field radiation from the SW node and coil.

The cut around the DC/DC block on the top side keeps all high-frequency current within this area. Without the cut, a fraction of the hot loop currents would still flow at the corner of the PCB, making the area noisy.

The high dV/dt SW node is connected to the inductor, which is typically large and radiates E-field. For most inductors, the E-field radiation is lower if the start-of-winding is connected to the SW node.

One trick to reduce E-field radiation from the coil is to place the output capacitors (C2A & C2B) on both sides of the coil. This works best if the capacitors are as high as or higher than the coil. In general, a smaller-sized, lower-profile inductor typically provides better EMC performance than a larger, higher coil.

Inner Layer 1 of the EMC-optimized board is GND. It should be placed 70 µm under the top side (see Figure 6). This GND area is noisy. A cutout in the GND area around the DC/DC block prevents residual currents from flowing at the edges of the layer under the connector and filter components. The cut should have two narrow openings exactly where V_{IN} and V_{OUT} are routed to the DC/DC circuit in the layer underneath, providing a defined local return path.

Measured results

With f_{SW} = 470kHz and spread spectrum frequency modulation (SSFM), the CE test result from 30 MHz to 108 MHz is about 0 dBµV, only a few dB above system noise (see Figure 7). The MPQ4431 switching at 470 kHz with a 0805 2.2µH inductor and two 0805 output capacitors passed a low-frequency RE monopole test without additional shielding or SSFM (see Figure 8).

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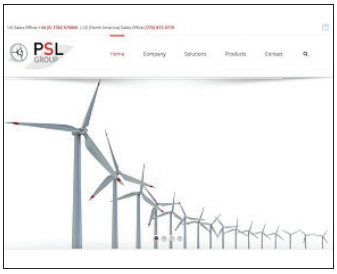

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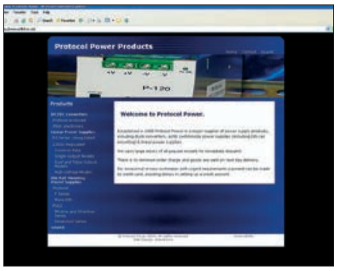

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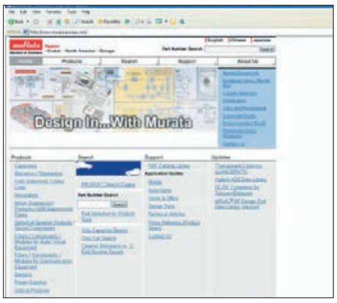

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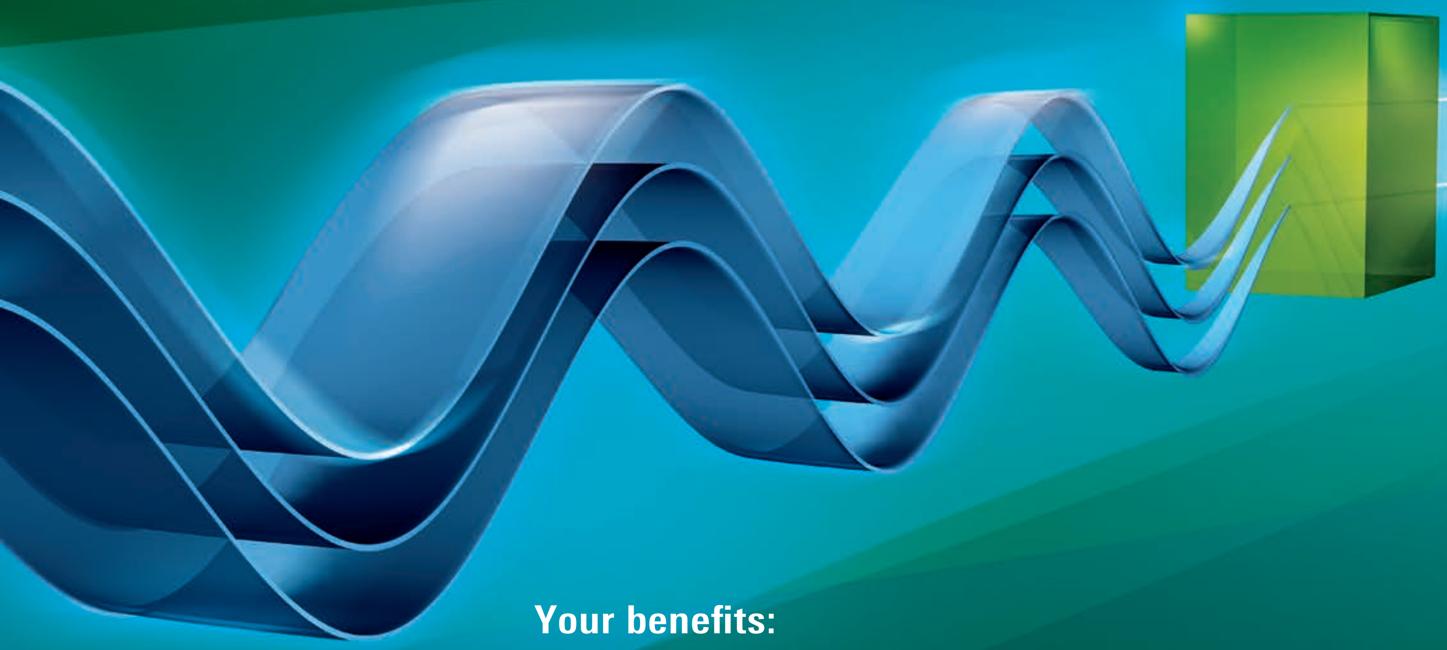

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