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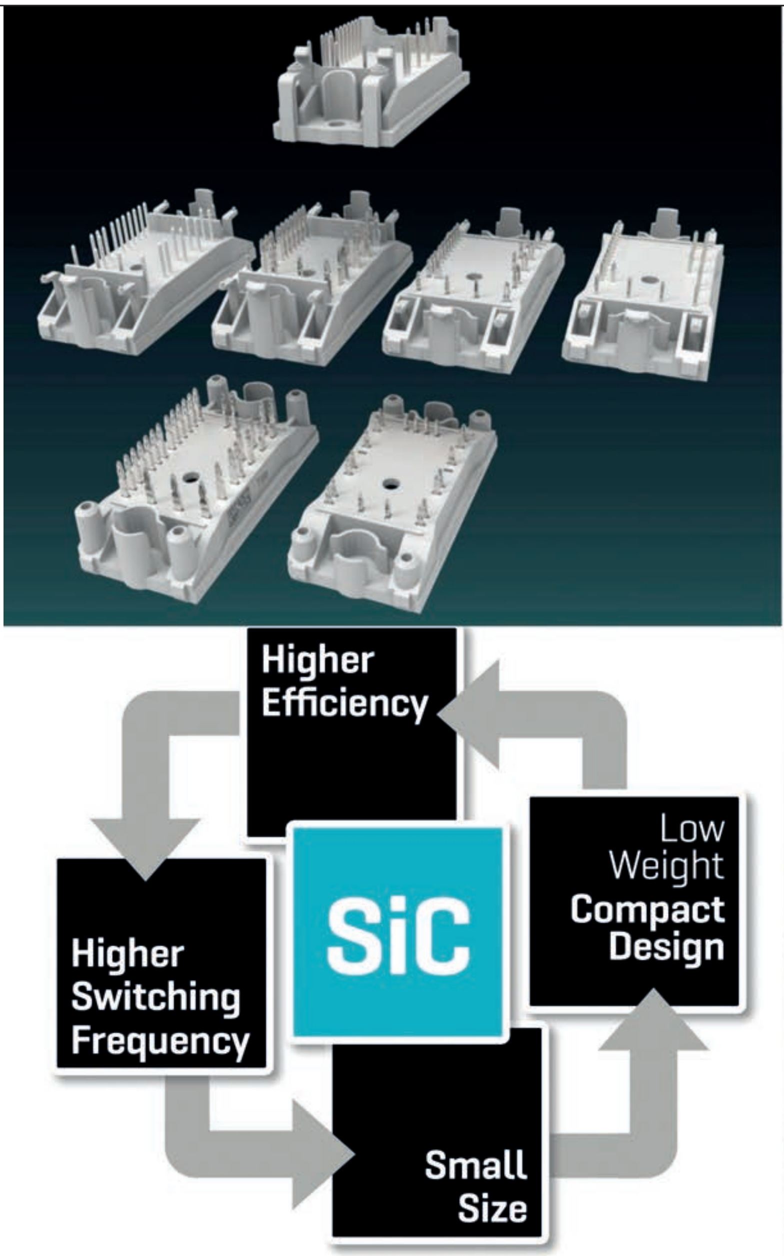
PCIM EUROPE 2018 REVIEW

Automotive Goes SiC



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COVER STORY

Automotive Goes SiC

Power semiconductor module maker Vincotech recently has joined the Charging Interface Initiative e. V., an association set up by Germany's automotive luminaries to entrench the Combined Charging System (CCS) as the definitive technology for battery-powered electric vehicles. CharIN's founding members include Audi, BMW, Daimler, Porsche, Volkswagen and a host of other illustrious enterprises. Vincotech already offers power modules for companies that build innovative stationary chargers for EVs, such as the charger shown at PCIM Europe. Engineers tasked to build better devices and applications want power modules that boost efficiency and performance. Yet they also need compact solutions that shrink the component footprint. Vincotech's SiC-based power modules for charging stations, solar inverters and other applications square that circle. These modules not only deliver better switching performance; they also enable customers to design smaller, lighter systems. The company draws on multiple qualified suppliers for its SiC MOSFETs and SiC diodes. More details on page 23.

Photo: AS

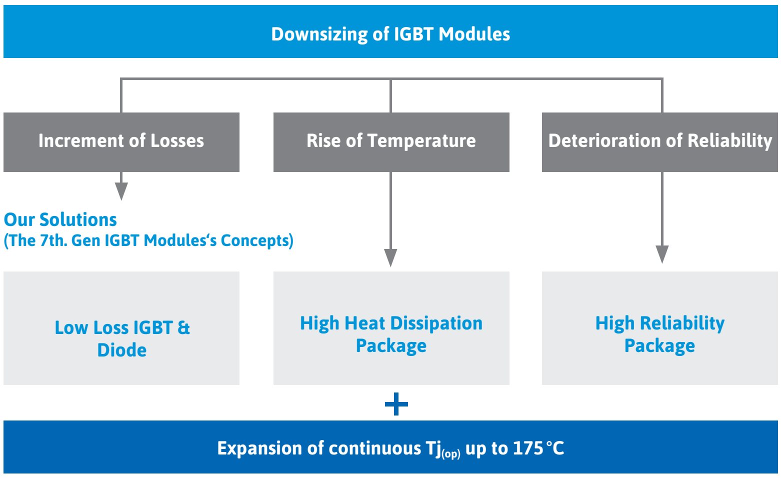
7th Generation X-Series

Top Class in Power Density and Reliability

series 7G

MAIN FEATURES

- 7G IGBT & FWD
- New internal layout
- Higher reliability
- Improved silicone gel
- Solder or Mini press-fit pins
- Advanced bond wire design
- High thermal conductive ceramic substrate
- Package material with CTI > 600
- V_{iso} = 4 kV
- Lower V_{cesat}
- Lower Voltage Overshoot
- Lower Oscillation / Lower EMC issue
- A variety from low to high power packages are available



Automotive Looks for Wide Bandgap Technologies

As many global governments aim to reduce air pollution and lower dependence on vehicles burning fossil fuels, power semiconductors and particularly Silicon Carbide devices are on the rise. China, India, France, Great Britain and Norway have already announced plans to ban cars with internal combustion engines in the coming decades, replacing them with cleaner vehicles. The prospects for electrified vehicles generally, and for wide band-gap semiconductors specifically, are therefore very good. Prospects for continuing strong growth in the SiC industry are high, fuelled predominantly by increasing sales of hybrid and electric vehicles. Market penetration is also growing, particularly in China, with Schottky barrier diodes, MOSFETs, junction gate field-effect transistors (JFETs) and other SiC discretes already appearing in mass-produced automotive DC/DC converters and on-board battery chargers. It looks increasingly likely that powertrain main inverters using SiC MOSFETs instead of Si IGBTs, will start to appear on the market in three to five years. As there are many more devices used in main inverters, than in DC/DC converters and on-board chargers, the required quantity will also rapidly rise, market researchers expect.

Semiconductor vendors such as ROHM confirm this trend towards xEV in the years to come and thus will react in order to catch up with the increasing demand for SiC MOSFETs. The company expects the global SiC market to exceed the $1 billion mark by 2021. The largest share is accounted for by power supply applications, such as power conditioners, battery chargers for electric vehicles and the power grid. However, main inverter of electric vehicles also represent a significant part of the market potential for SiC components. Also Wolfspeed claims to be at the forefront of enabling this change in the automotive industry with new technologies, such as new SiC MOSFET portfolio, that help foster the adoption of electric vehicles. The power industry is on a tipping point by moving towards SiC, fuelled particularly by the automotive industry. If this change occurs the future market for WBG devices will be pretty big. One indicator – automotive companies recently have announced to invest over $100 billion in EVs and thus the SiC demand will grow and therefore the SiC market could be even greater than $10 billion in 2027. The story of Bipolar vs. CMOS could be continued in Si vs. SiC.

Thus SiC MOSFETs are considered as the most promising semiconductor devices for future traction inverter applications. At the PCIM conference Daimler discussed the potential and challenges of a three-phase voltage-source-inverter based on trench SiC MOSFETs in Infineon's new SiC HybridPack under automotive constraints, considering the complete drivetrain. Based on the results, a significant efficiency improvement for an electric vehicle application is possible, confirmed by measurements. The power module as a part of the traction inverter contributes significantly to the efficiency and functionality of the system. For enabling easy design in a well-established form factor, scalability, a lifetime as given today by IGBT modules, robust functionality, reliable switching behaviour, and an adequate thermal setup are important. With the example of the CoolSiC Hybridpack Drive power module family a power capability of 220 % compared to the IGBT version is enabled.

The biggest inhibitor to massive growth for SiC components could be GaN components. The first automotive AEC-Q101 qualified GaN transistor was launched in 2017 by Transphorm, and GaN devices manufactured on GaN-on-Si epiwafers boast considerably lower costs. They are also easier to manufacture than anything produced on SiC wafers. For these reasons, GaN transistors could become the preferred choice in inverters in the late 2020s, ahead of more expensive SiC MOSFETs.

The most interesting story for GaN power devices in recent years has been the arrival of GaN system ICs, GaN transistors co-packaged with Si gate driver ICs, or monolithic, all GaN ICs. Once their performance is optimized for mobile phone and laptop chargers and other high-volume applications, usage may become prevalent in wider applications. In contrast, commercial GaN power diode development never really started, because they would not offer significant benefits over Si devices, and developing them proved too costly to be viable. SiC Schottky diodes already work well for that purpose and a have a good pricing roadmap.

Winner of the PCIM Best Paper Award 2018, co-sponsored by Power Electronics Europe, was Arne Hendrik Wienhausen, RWTH Aachen, Germany, for the work "Highly Integrated Two-Phase SiC Boost Converter with 3D Printed Fluid Coolers and 3D Printed Inductor Bobbins". With the use of Selective Laser Melting (SLM) new 3D printed cooling structures for power converters can be realized. In this paper, a highly integrated two-phase interleaved bidirectional boost converter using discrete SiC-MOSFETs and 3D printed fluid coolers as well as 3D printed inductor bobbins was designed. The converter operates at a high switching frequency of 400 kHz and features a high power density of 32.6 kW/l while delivering 15 kW of output power.

These remarks confirm the increasing interest in wide band-gap technology. And what comes next?

Enjoy reading this issue!

Achim Scharf
PEE Editor

Ørsted Signs Contract for World's Biggest Offshore Wind Farm

Ørsted has placed a multi-million pound turbine order with Siemens Gamesa Renewable Energy (SGRE) for its massive Hornsea 2 offshore wind farm. When operational in 2022, Hornsea Project 2 will overtake its sister project, Hornsea Project 1, to become the largest offshore wind farm in the world. It will have a capacity of 1,386 MW which means it will be capable of supplying well over 1.3 million homes with clean electricity. This is SGRE's largest ever wind turbine order. They will provide all 165 8MW turbines, with the majority of the turbine blades to be manufactured at the SGRE facility in Greenport, Hull. The project will use the first ever 81 m blades to be manufactured in the UK, as big as an Airbus' 380 total wingspan, and when assembled the turbines will have a rotor diameter of 167 m, the largest available on the market. "With our East Coast Hub in construction in Grimsby and the SGRE facility in Hull, it's clear to see the Humber area really is creating a world-leading cluster in offshore wind. The SGRE investment in the Hull facility has brought hundreds of jobs to the area, and we feel proud to have supported that through our leading contracts with SGRE", commented Duncan Clark, Program Director for Hornsea Projects.

www.orsted.co.uk


First blades from UK Hornsea 2 offshore wind farm installed at Race Bank

Improving Reliability of Power Electronics

The need to reduce climate change is prevalent, with global recognition of its impact resulting in many targets being put into place to ensure that dramatic changes in our energy usage occur. The EU has devised the 2020 package with reductions based on 1990 levels. The package includes a 20 % cut in greenhouse gas emissions, 20 % of energy from renewable sources and a 20 % improvement in efficiency by 2020. "Some countries also have their own targets; for example, the UK is looking to achieve an 80 % reduction in greenhouse gas emissions by 2050. As a consequence, the dominance of energy derived from fossil fuels is no longer considered appropriate in some quarters. In a technological age where energy is so important to our everyday lives, it is imperative that we focus on increasing our energy efficiency across all industries", notes Jade Bridges, Global Technical Support Manager of UK-based Electrolube.

Power electronics provide the efficient conversion of electrical energy, typically involving a change to the voltage or current level and/or frequency. The design of these electronics is clearly the most important factor, but in order for these electronics to work and achieve maximum efficiency under a variety of conditions, the use of thermal management materials and protective products may be the vital step towards achieving these targets to fully maximize the efficiency and reliability of power electronics.

There are two key areas where such substances can be used; at component level and device level. At component level, we are typically referring to thermal management. Components, such as a resistor, will generate more heat when more power is applied, however, if this heat is not properly dissipated, the operating temperature of the component will increase to such a point that it may eventually fail. A thermal interface material (TIM) can be used to improve the conduction of heat through to a heat sink. During this process, heat is radiated to the surrounding environment by means of convection. The use of TIMs improves the efficiency of heat transfer and by helping to reduce the operating temperature of particular components, or the PCB as a whole, the efficiency of the device is also improved, consequently reducing energy usage. TIMs can also provide a good compromise of increased performance without the negative impacts of increased board weight or size. This provides PCB designers with additional thermal management options for thermal back planes or heavy board traces, for example.

Some examples of where Electrolube products have been used for power electronics applications include TIMs for IGBTs in power distribution products, gap filling and TIM applications to transfer heat from components to the outer metal casing in a variety of automotive devices, such as battery chargers, and the use of TIMs for heat dissipation within drivers for LED billboards. All of these applications provide their own challenges. IGBTs have a large surface area and are subject to thermal cycling, generating a pump-out/shear effect through changes and variances of CTEs. Pump-out can represent a significant challenge but can be mitigated via a product specifically designed to resist pump-out of the thermal interface layer from the bond line hence ensuring minimal degradation of effective heat dissipation. Gap filling applications in the automotive sector are subject to many different environments, as well as the effects of vibration. None of these applications faced

continuous and stable environmental conditions, which leads to the protection of power electronics to increase reliability.

A finished unit or PCB will operate under standard ambient conditions, however, there are always external factors such as condensation, corrosive gases, salt mist, airborne contamination and thermal changes, which will impact the working life of the device. Products such as conformal coatings and encapsulation resins are used to protect PCBs from these external influences, in turn, increasing both reliability and lifetime. Power electronics push performance expectations further in terms of efficiency and every detail is important, including the protection of electrical contacts and connectors using contact lubricants to ensure stable electrical transfer.

A couple of examples where Electrolube products are used within power electronics to improve device lifetime and reliability, include conformal coatings for power control units within digital substations and resins for encapsulating solar inverters. Both of these applications had their own challenges; the solar inverter also required heat dissipation through the encapsulation resin, maintaining the operating temperature of components within the desired ranges. The coating for power control units needed to offer protection against moisture and corrosive gases, but also required quick and easy application on complicated PCB designs where connectors could not be masked. A thorough understanding of the environmental conditions is therefore imperative to the successful choice of protection compound. "Power electronics is clearly a rapidly expanding and vitally important market. If we are to achieve our goals for a more energy efficient future, we must focus our attention to the small details, some of which may seem insignificant at first, but ultimately, will allow power electronics to function in the vast array of applications in which they may be utilized. It is the crucial understanding of application conditions which will allow the use of thermal management and environmental protection products to increase the efficiency and reliability of power electronic devices", Bridges concludes. At SMT Hybrid Packaging 2018 in Nuremberg Electrolube showcased new resin and thermal management products for the electronics, LED and automotive industries.

www.electrolube.com

"Our thermal management and environmental protection products increase the efficiency and reliability of power electronic devices", states Electrolube's Jade Bridges

Growing Support for Solid-State Batteries

Volkswagen announced its partnership with QuantumScape end of June. This announcement confirms the growing interest of EV/HEV makers in solid-state battery technology.

Today, there is no commercially-available bulk solid-state battery. Over the last several years, numerous different players have made announcements regarding the readiness of prototype cells and expected commercialization starts, only to see these ultimately be cancelled or postponed. And despite decades of development, many technology challenges remain unsolved. First research activities in solid-state battery technology date to the late 1950s. Solid-state battery technology has found applications in the form of microbatteries as a micro-power source for sensors. Unfortunately, materials and manufacturing methods used for microbattery's fabrication are extremely difficult to translate into bulk-size battery manufacture on a cost-effective basis. According to Yole's analysis, the current momentum for growing interest in solid-state batteries is the strong application-pull of game-changing battery industry players: the EV/HEV makers. Indeed, established automotive players including Toyota, Volkswagen, BMW, etc. and newcomers such as Dyson, Fisker, plan to commercialize EV/HEV with a battery that will be safer, lighter, and longer-running than conventional Li-ion battery.

A growing number of players involved in solid-state battery development is another reason for increased momentum, as is a variety of newly established solid-state battery consortiums.

Numerous industry players and R&D players from different areas are combining their efforts, each bringing a piece of technology know-how. As an example, 23 companies take part in the Japanese Libtec consortium. "Sharing know-how from the four main technology areas is crucial for bringing solid-state battery to commercialization," explains Dr. Milan Rosina, Senior Analyst at Yole. These areas include solid-state electrolyte technology – equipment – battery cell – automotive. Regarding solid-state battery technology development, there are many technology bricks involved, including electrolyte material screening, ionic conductivity enhancement, electrolyte/electrode interface stability, lithium metal anode, separator coating, cell and pack manufacturing methods, BMS , and battery pack design. Yole's analysts identified more than 100 companies and R&D players involved in solid-state battery development. "For an emerging technology, it might be surprising to see that only 14 of 68 industrial companies identified are startup companies", comments Rosina. "These start-ups, including Ionic Materials, NEI Corporation, QuantumScape, are positioned mainly in electrolyte material screening and development." Actually, R&D activities are rapidly developing within 54 big companies. These companies are mainly car makers including Toyota, BMW, Volkswagen, Renault-Nissan-Mitsubishi Alliance, and Hyundai. Toyota, with a strong solid-state development history and 200+ engineers working on solid-state battery technology, is considered a leader here. Other players include conventional Li-ion battery cell manufacturers (i.e. Samsung SDI, LG Chem, A123 Systems), battery separator technology solutions suppliers (Asahi Kasei), and materials suppliers (Solvay, Umicore).

www.yole.fr

Electrifying Vehicle Technologies

In January 2018, car manufacturer Ford announced that it will boost its investment in electric vehicles to £8bn in the next five years, doubling its previous commitment. This investment has been reciprocated by General Motors, Toyota and Volkswagen which have made similar pledges as both consumer confidence and sales build in electric vehicles.

"Despite appearing to be a modern phenomenon, the first electric vehicle took to the road in 1832 and in 1899, outselling all other available options, including steam and gasoline powered vehicles. Since 1935, with the invention of the internal combustion engines, gasoline-powered vehicles have become the popular choice. This changed in 2016, which saw a record in the sale of electric vehicles worldwide, with 750,000 cars sold", said Simone Bruckner, director at UK-based power resistor manufacturer Cressall.

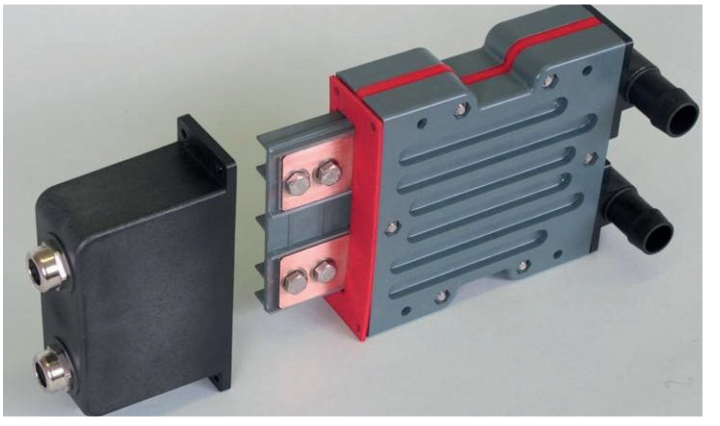
Consumers previously experienced three major obstacles according to a National Renewable Energy Laboratory (NREL) report published in 2016. First is the perceived prohibitive cost, which is rapidly falling as technology advances and can be partially offset by government bursaries and schemes. Similarly, many drivers worry about a lack of charging points, but this is becoming less of a concern as Poppy Welch, head of the Go Ultra Low scheme explains. "Since the introduction of government's plug-in car grant in 2011, registrations of electric cars have grown dramatically from 1,089, to last year's volume of 36,673." In Europe, there are now nearly as many charging points as there are gas stations. The last major concern is range. Vehicles would need to travel 300 miles on a single charge for the majority of recipients to consider a purchase, which is close to being achieved due to improvements in battery technology.

Complementary to research into alternative battery technologies including cobalt, range can be extended by retaining energy lost through braking. Traditional friction brakes convert the kinetic energy from the car's motion to heat, where it is lost. However, regenerative brakes have the ability to recapture this energy by charging the battery. Regenerative braking may be able to capture half of the 80 % of energy lost through traditional friction braking and put it back to work by heating the cabin.

Despite the many benefits of regenerative braking, it could present problems when the battery is fully charged or due to an electrical fault. Cressall's water-cooled EV2 resistor can discharge excess energy captured through regenerative braking in these situations. The EV2 can also provide cabin heating, of particular importance during winter or in colder countries. Instead of using dedicated resistance only for heating, which is an additional component and draws a lot of current from the battery, the EV2 resistor can allow the transfer of heat into the cabin through cooling or heating water in much the same way as in internal combustion cars.

"Electric vehicle technology is continually developing through improvements in battery technology, regenerative braking and charging stations and this is only set to continue in order to meet the increased demand for electric vehicles. Although electric cars became unpopular after 1900, there is little doubt that 2018 will more than make up for it", Bruckner concluded.

www.cressall.com



Cressal's EV2 resistor can allow the transfer of heat into the EV cabin through cooling or heating water

PV Booms Around the World

The year 2017 marked a milestone for the photovoltaics industry. For the first time, the solar capacity installed around the world exceeded 100 GW. And industry experts anticipated at recent Intersolar fair deployment to reach as much as 110 GW this year. Asia has become the most dynamic photovoltaics market. Last year, the continent's share of global sales reached around 70 %, driven primarily by developments in China, India and Japan. The second-largest share has meanwhile been taken by the USA.

Research institutes and manufacturers are working on making solar cells and modules even more efficient while at the same time reducing costs. The Fraunhofer Institute for Solar Energy Systems in Freiburg recently set the world record for multicrystalline silicon at 22.3 %, besting its own previous performance. The Chinese manufacturer Jinko Solar has increased the efficiency of monocrystalline PERC solar cells to 22.78 %. US-based First Solar also reached a new efficiency milestone of more than 17 % with the new Series 6 thin-film module and its active layer of Cadmium Telluride (CdTe). In turn pricing for photovoltaic modules are decreasing constantly.

As the markets grow, they are also becoming self-sustaining. They are no longer driven by subsidies, but instead by the improved competitiveness of photovoltaics. This can be attributed to the decreasing price of solar modules, which has fallen by over 80 % in the last 15 years. In Germany, for example, the average price in tenders for solar parks fell below 4 euro cents per kWh in February for the first time. In Chile, Dubai, Peru and Saudi Arabia, solar power has already been offered at less than 2.5 euro cents per kWh in tenders for large PV parks. According to the International Renewable Energy Agency (IRENA), electricity production costs for large solar installations have fallen by 73 % worldwide since 2010. The market researchers at Bloomberg New Energy Finance have found that solar power is already at least as cheap as coal in Australia, Germany, Italy, Spain and the USA. They expect to see more attractive prices in Brazil, China, Great Britain, India and Mexico as well by 2021.

Photovoltaics are experiencing a second wind in Europe: In 2018, experts expect deployment to exceed 10 GW for the first time in years. Last year the European solar market already recorded annual growth of 28 percent, based on deployment of 8.61 GW. This development is being driven by tenders and power purchase agreements, where photovoltaics scores points thanks to its low cost. The upswing is also fueled by the advantages of consuming self-generated solar power. Over 30 % growth has been forecast for 2018 – alongside Germany, most notably in France, Italy, the Netherlands and Spain. Larger PV plants with a capacity of just under 4 GW, among other developments, are planned in Spain before the end of 2019. Behind these advances is the growing success of photovoltaics as an economical alternative to wind power in public tenders. Sunny days are on the horizon for France, where solar power installations with a capacity of roughly 20 GW are to be set up by 2023. Alongside large-scale PV plants, France also supports smaller installations and on-site consumption via public tenders.

Since the upturn in renewable energies, electricity supply has been undergoing a global transformation. Electricity which is generated locally and renewably should be distributed intelligently, stored efficiently and consumed sensibly – whether in private homes, the public grid or transportation. As energy from renewable sources is not always uniformly available, there is a need for intelligent infrastructure, innovative energy storage systems and sector coupling – that is, connecting the electricity, heating and mobility sectors. In Germany, the combination of photovoltaics and e-mobility is especially profitable for photovoltaic installations with a capacity of 10 kW or less, as they are not subject to the EEG levy for self-consumption. As a result, the self-generated solar power costs less than half as much as electricity purchased from providers. It makes more sense to consume as much of the self-generated solar power as possible, and if necessary to store it temporarily, than to feed it into the grid at no particular profit. Electric car developments continue to move forward. In the future, it will be possible to channel solar power from an electric car back into the house or feed it into the grid via a bidirectional connection. In this way, the electric car can take on the role of a battery storage system. When integrated into the electricity balancing market as part of a swarm storage system, it can help to stabilize the grid.

In addition to efficiency currently approaching the 99 %, inverters are gaining entirely new innovative potential all along the energy supply chain. Digitalization is opening up new fields of use and business models for manufacturers. For example, inverters with an integrated charging function can refuel electric vehicles up to two and a half times faster than traditional charge controllers, while at the same time cutting installation costs by removing the need for additional cables and fuses. The growing digital capabilities of inverters are also being applied in the heating sector, where they are used to control heating elements for hot water production in boilers and buffer tanks, which can be run on excess solar power. And modern PV and battery inverters even fulfill the need for solutions that contribute more to the stability of the grid. Thanks to their energy management qualities, they can supply power as and when it is needed.

www.intersolar.de

Intersolar 2018 in Munich reflected the still growing interest in renewable energies

Global Electric Vehicle Patenting to Reach 7,500 in 2018

PatSnap, a provider of (R&D) analytics, has recently launched its EV IP Report 2018, which analyses PatSnap's global dataset related to innovation in EVs. The report found a significant increase in global EV innovation over the past ten years, and predicts that there will be an expected 7,500 patent applications in 2018 – rising to 8,500 in 2020.

Looking at the IP data of modern innovators in the EV industry reveals signals about how this market, its players, and their technologies, are evolving. Nearly two thirds of EV patent families have a first-filing in the USA (44 %) or China (19 %). Based on this activity, China and USA could strategically be key geographic locations for organizations to establish their patent footprint. Excluding filings with the European Patent Office (9.3 %), the UK is Europe's top destination for EV patenting with 2.3 % of initial patent filings. Luxembourg and Ireland have the highest relative specialisation in EV innovation globally, meaning that these could be important locations for bargain partnerships in licensing, open innovation and other opportunities not reflected in patent data.

The top five EV patenting companies include Hyundai, Toyota, Kia Motors, Hitachi and General Motors. Activity has both grown and decreased amongst top applicants in recent years, suggesting that there is still scope for emerging organizations to establish and maintain leading positions. Experienced automotive companies are remaining diverse in their patenting activity while electronics companies tend to focus on fuel cells, batteries and power transfer technologies.

Top technology areas for EV related patents are: Electric propulsion with power supplied within the vehicle (14.92 %); Manufacturing of secondary cells (9.52 %); Arrangements for charging/depolarising batteries (9.15 %); Arrangement of diverse prime movers for propulsion (7.38 %); and Conjoint control of different vehicle sub-units (6.93 %).

Looking specifically at unexpected key players in EV innovation, Bosch, Samsung and Sony hold nearly 900 relevant patents between them, meaning that each of these companies hold relevant intangible assets that put them in a strong position to enter the EV market in future. Qualcomm owns the most valuable patent in this area - US20130300358A1 - "wireless power transfer for appliances and equipments"- which relates to wireless charging. Due to the far-reaching scope of this technology, this patent is estimated to be worth over $43.4million, up $6 million in estimated value since December 2017.

www.patsnap.com

Turning Heat to Electrical Power

Dillenburg-based Isabellenhuette is now transferring its already 1903 invented Half Heusler metallurgy compound into reality for regenerating waste heat into electrical power. PEE was given the opportunity to take a first look on the pilot line featuring an investment of € 1 million.

Transport, notably automotive, and process industries, in particular metallurgy, glass and chemicals, are today responsible for a large amount of waste heat above 140°C, estimated to reach 5 000 GWh/year, worldwide. Directly generating electricity from waste heat by means of thermoelectric generators could therefore significantly reduce the global carbon footprint of these activities. However, thermoelectric materials have not yet found their way into mass markets due to lack of sustainable sources of materials for production, progress to be made on the required material performance and an industrial production capacity.

Radioisotope thermoelectric generators were developed already in the 1980's for the Voyager spacecrafts, Voyager 1 and Voyager 2. Conversion of the decay heat of the plutonium to electrical power used 312 SiGe thermoelectric couples which supplied the spacecraft with 470 W at launch.

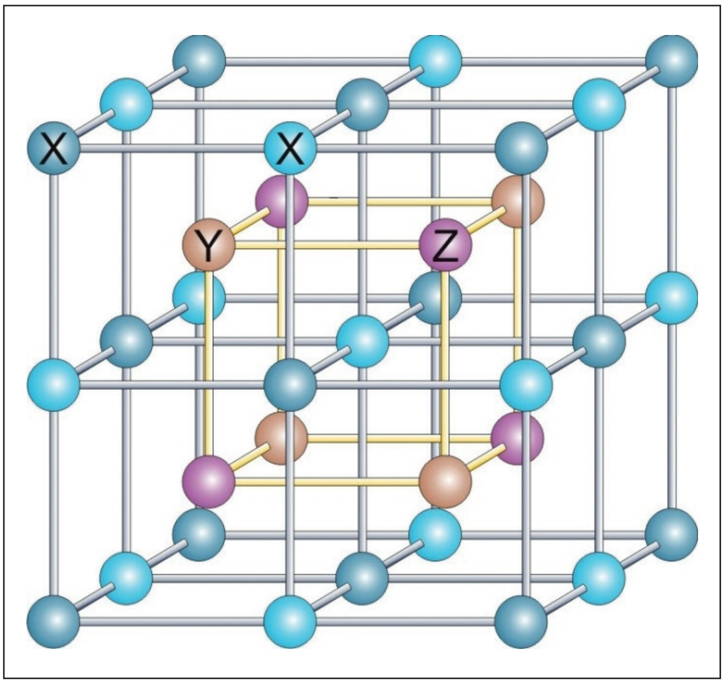
NASA chose to use a nuclear power source because solar power alternatives did not meet the full range of the mission's requirements. Only the radioisotope power system [the RTG] allows full-time communication with the rover during its atmospheric entry, descent and landing regardless of the landing site. And the nuclear powered rover can go farther, travel to more places, last longer, and power and heat a larger and more capable scientific payload compared to the solar power alternatives. Also the Curiosity rover that has been exploring Mars since August 2012 is supplied with thermoelectric power, and the Mars 2020 mission will obtain its electrical power from a radioisotope power system called a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). A MMRTG converts the heat created by naturally decaying plutonium-238 into electricity that can be used to run a spacecraft and its science instruments.

Radioisotope power systems enable or enhance missions where sunlight is infrequent, obscured by dust, or dimmed by distance, making other sources of power impractical or insufficient. But this technology is not usable for civil applications such as transportation or power plants since it relies on radioactivity.

Half Heusler effect discovered in 1903

Now German Isabellenhuette has explored a safer way to recover waste heat i. e. of combustion engines by using its already 1903 discovered Heusler Compounds. The term is named after a German mining engineer and chemist Friedrich Heusler, who was one of the Isabellenhuette managing directors and studied such a compound in 1903. The thermoelectric material was newly discovered by scientists 15 years ago.

Heusler compounds are magnetic intermetallics with face-centered cubic crystal structure and a composition of XYZ (half-Heuslers) or X2YZ (full-Heuslers), where X and Y are transition metals and Z is in the p-block. Many of these compounds exhibit properties relevant to spintronics, such as magnetoresistance, variations of the Hall effect, ferro-, antiferro-, and ferrimagnetism, half- and semimetallicity, semiconductivity with spin filter ability, superconductivity, and topological band structure. Their magnetism results from a double-exchange mechanism between neighboring magnetic ions. Manganese, which sits at the body centers of the cubic structure, was the magnetic ion in the first Heusler compound discovered.



In the case of the full Heusler compounds with formula X2YZ (e. g., Co2MnSi) two of them are occupied by X-atoms (L21 structure), for the half-Heusler compounds XYZ one fcc sublattice remains unoccupied (C1b structure) Source: Wikipedia

It contained two parts copper, one part manganese, and one part tin (Cu_2MnSn). Its magnetism varies considerably with heat treatment and composition. Room-temperature saturation induction is around 8,000 gauss, which exceeds that of the element nickel (around 6100 gauss) but is smaller than that of iron (around 21500 gauss).

In 1934, Bradley and Rogers showed that the room-temperature ferromagnetic phase was a fully ordered structure of the L21 type. This has a primitive cubic lattice of copper atoms with alternate cells body-centered by manganese and aluminium. The molten alloy has a solidus temperature of about 910°C. As it is cooled below this temperature, it transforms into disordered, solid, body-centered cubic beta-phase. Below 750°C, a B2 ordered lattice forms with a primitive cubic copper lattice, which is body-centered by a disordered manganese-aluminium sublattice. Cooling below 610°C causes further ordering of the manganese and aluminium sub-lattice to the L21 form. In non-stoichiometric alloys, the temperatures of ordering decrease, and the range of anealing temperatures, where the alloy does not form microprecipitates, becomes smaller than for the stoichiometric material.

From science to technology

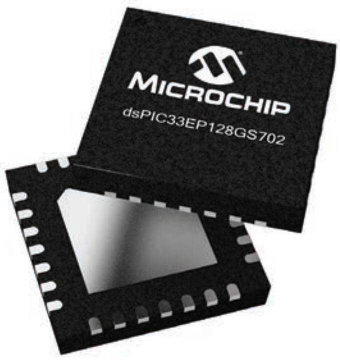
Isabellenhuette with its over 900 employees is one of the world's leading manufacturers of electrical resistance and thermoelectric materials for temperature measurement and passive components in the automotive, electrical and electronics industries. Precision measurement systems set the industry benchmark for current, voltage and temperature sensing in cars and trucks, hybrid and electric vehicles, as well as industrial and renewable energy generating systems. The company has been working since 2009 on the synthesis of thermoelectric Half Heusler compounds with a melt-metallurgical manufacturing process. Since 2015 Isabellenhuette is working on the development of thermoelectric modules based on Half Heusler material and brought its experience in an EU project INTEGRAL (waste heat to power) comprising European research and industrial partners. The project has received funding from the European Union's Horizon 2020 research and innovation program.

INTEGRAL covers industries, small enterprises, research centres with various expertise required for the success of the project such as experts in thermoelectric generators for automotive heat recovery from Valeo (France); Experts in industry heat waste from Elkem (Norway) and autonomous temperature control in industry with ArcelorMittal (Spain); Nanostructured Material production by

Digital Power Designs Made Easier

Products, Tools, Software and Reference Designs

Microchip's digital power design suite includes the Digital Compensation Design Tool (DCDT), MPLAB® Code Configurator (MCC), Microchip compensator libraries and design examples.



These four components of the digital power design suite provide the tools and required guidance for developing complete digital power designs. Once the initial simulation model of your design is ready, the DCDT can be used to analyze the design and the feedback transfer function, and to generate compensator coefficients. Device initialization code can be generated with the help of MCC; and the final firmware can be created with some help from the code examples and the code generated from MCC and the DCDT.

Key Features

- Digital Compensation Design Tool to analyze your design
- Libraries and design examples to jump start your development
- Feature-rich dsPIC33EP "GS" family of DSCs

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Isabellenhuette's R&D director Dr. Jan Marien explaining parts of the Half Heusler pilot production line **Photo: AS**

high energy ball milling with MBN Nanomateralia (Italy); Silicon thermoelectric ring design and production with Hotblock On Board (France); Cast silicon thermoelectric modules with strip-legs design and production with RGS Development (The Netherlands); Thermoelectric material customisation for thermal and electrical conductivity with Cidetec (Spain); Thermoelectric generators prototyping line, as well as material shaping and tuning, and in-line process control with the POUDR'INNOV 2.0 Powder Metallurgy Platform at CEA Liten (France); Sintering and off-line ageing and characterisation with Fraunhofer IKTS (Germany); new material life cycle analysis and cost targeting with Efficient Innovation (France); and Half Heusler cubic-legs design and production with Isabellenhütte (Germany).

The aim of the INTEGRAL project is to upscale a new generation of thermoelectric technology, using existing and growing pilot industry lines, in order to address mass markets (transport, process industries), and to produce advanced functional materials with customized electrical and thermal conductivities. The INTEGRAL project is unique since it gathers leading companies developing these materials in Europe. Furthermore, the large-scale manufacturing processes to be developed for producing nanostructured materials within the project cut across multiple sectors to find a wide range of applications outside thermoelectrics, i.e. where customization of electrical or thermal properties of sintered or casted materials is needed. Finally, a technology transfer will be performed towards the commercialization of a new generation of advanced multifunctional materials with a circular economy vision.

The current EU project INTEGRAL is now focusing on the construction of three pilot productions. The goal of the established pilot lines is to produce thermoelectric material in large quantities. Already at the project halfway point in May 2018, Isabellenhuette was able to demonstrate the complete production process for material batches of 10 kg with its production line.

From technology to products

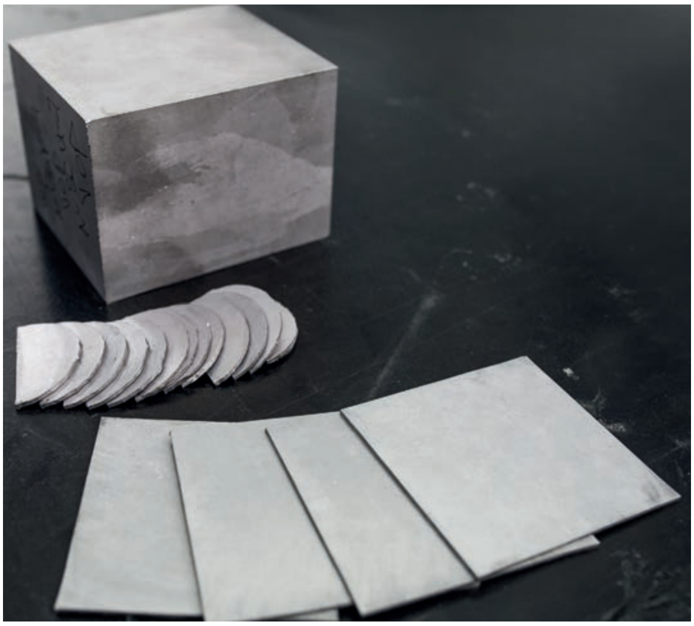
A 150 m^2 production hall was built for this purpose at the company headquarters in Dillenburg, Hesse. Six scientists and technicians are currently working on this topic. Ten kg of thermoelectric material are currently being melted there per production run and processed further into functional components. This quantity is to be increased to 50 kg by the end of the project in December 2019. Theoretically, a production volume of up to 500 kg per production run is possible with the system. This corresponds to an annual production of 25 tons.

With 60 to 70 grams of Half Heusler material, a vehicle with a thermoelectric generator (TEG) installed achieves an efficiency of up to 5 % from the waste heat. This energy is converted into electricity and fed into the on-board electrical system. The effect: The fuel consumption is reduced and the CO_2 emissions are reduced per vehicle by up to 4 %.

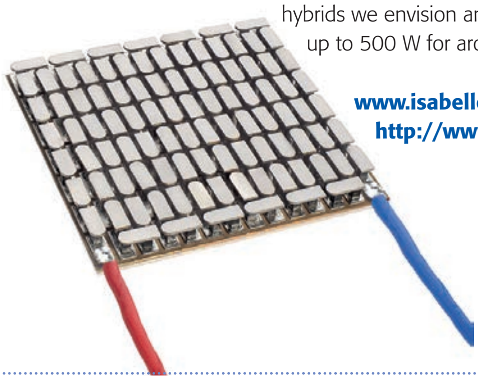
The relevance of this technology is obvious. Automotive manufacturers will face strict environmental requirements in the future. This is why every gram of CO_2 saved matters. The waste heat conversion is also competitive from an economic point of view. The production process realized as part of the EU project generally makes it possible to achieve the market-demanded cost target of EUR 0.50/watt under mass production conditions. A half-Heusler-based thermoelectric generator that, for example, generates 400 watts of electrical energy, would cost about EUR 200.

In this context Isabellenhuette is exploring its Half Heusler compound for recuperation of waste heat into electrical energy by using the temperature (600°C) of the exhaust gas stream against a cold plate (the cooler). The exchanger feature a cubic-legs design and is processed in the automated pilot line for up to 30,000 modules annually. Module size is 150 mm x 100 mm, 1 cm? of module size will harvest around 1 W of electrical power. "Fifty percent of system cost for such an energy harvester consist of the thermal modules, and thirty percent of these are the miniature cubic legs. So far the modules were built more or less manually, but with our newly automated production line we are able to cut cost significantly. We have already synthesized 10 kg of appropriate Half Heusler material in an oven taking around two days, later we will exceed the capacity to 25 kg. The material will then be sawed, sliced and polished. The tiny cubic-legs are then assembled via pick-and-place machine onto the substrate, which is mounted onto the cold plate", said R&D director Dr. Jan Marien. "Typical applications are automobiles, where electrical power is generated within the exhaust gas stream at temperatures around 600°C. Particularly for mild hybrids we envision an additional recuperation of up to 500 W for around 50 Cent/W." **AS**

www.isabellenhuette.de, http://www.integral-h2020.eu/



LEFT: 10 kg Half Heusler brick and processed wafers



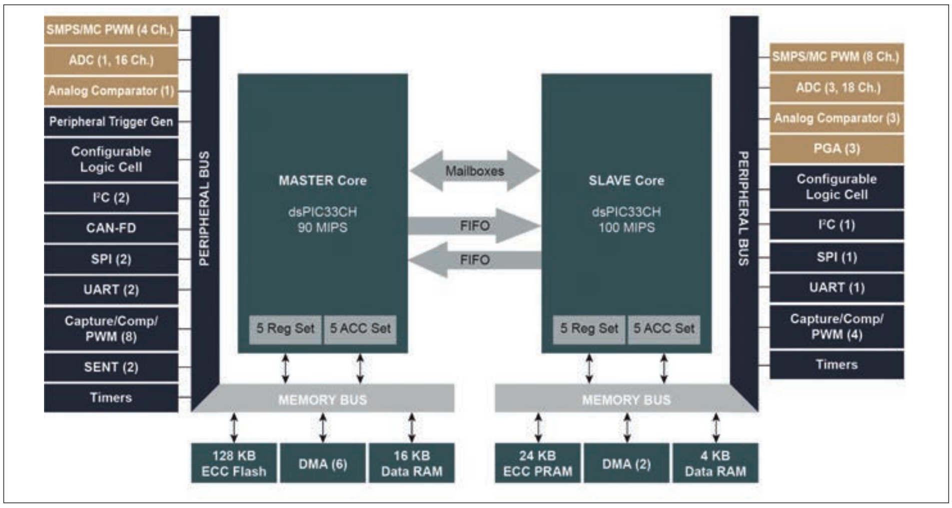
LEFT: Final Half Heusler thermoelectric generator module

Dual-Core Digital Signal Controller Enables Separate code Design for Digital Power and Drives

Microchip Technology announces a new Digital Signal Controller (DSC) with two dsPIC DSC cores in a single chip for high-end embedded control applications. The dsPIC33CH has one core designed to function as a master while the other is designed as a slave. The slave core is useful for executing dedicated, time-critical control code while the master core is busy running the user interface, system monitoring and communications functions, customized for the end application such as digital power or drives.

The dsPIC33CH family is housed in a small 5 x 5 mm package and includes features such as CAN-FD communications. Memory sizes range from 64 to 128 KB of Flash. To reduce system costs and board size, advanced peripherals are available to each core including high-speed ADCs, DACs with waveform generation, analogue comparators, analogue programmable gain amplifiers and high-resolution PWM hardware. Having two cores, with dedicated peripherals, allows the cores to be programmed to monitor each other for functional safety reasons.

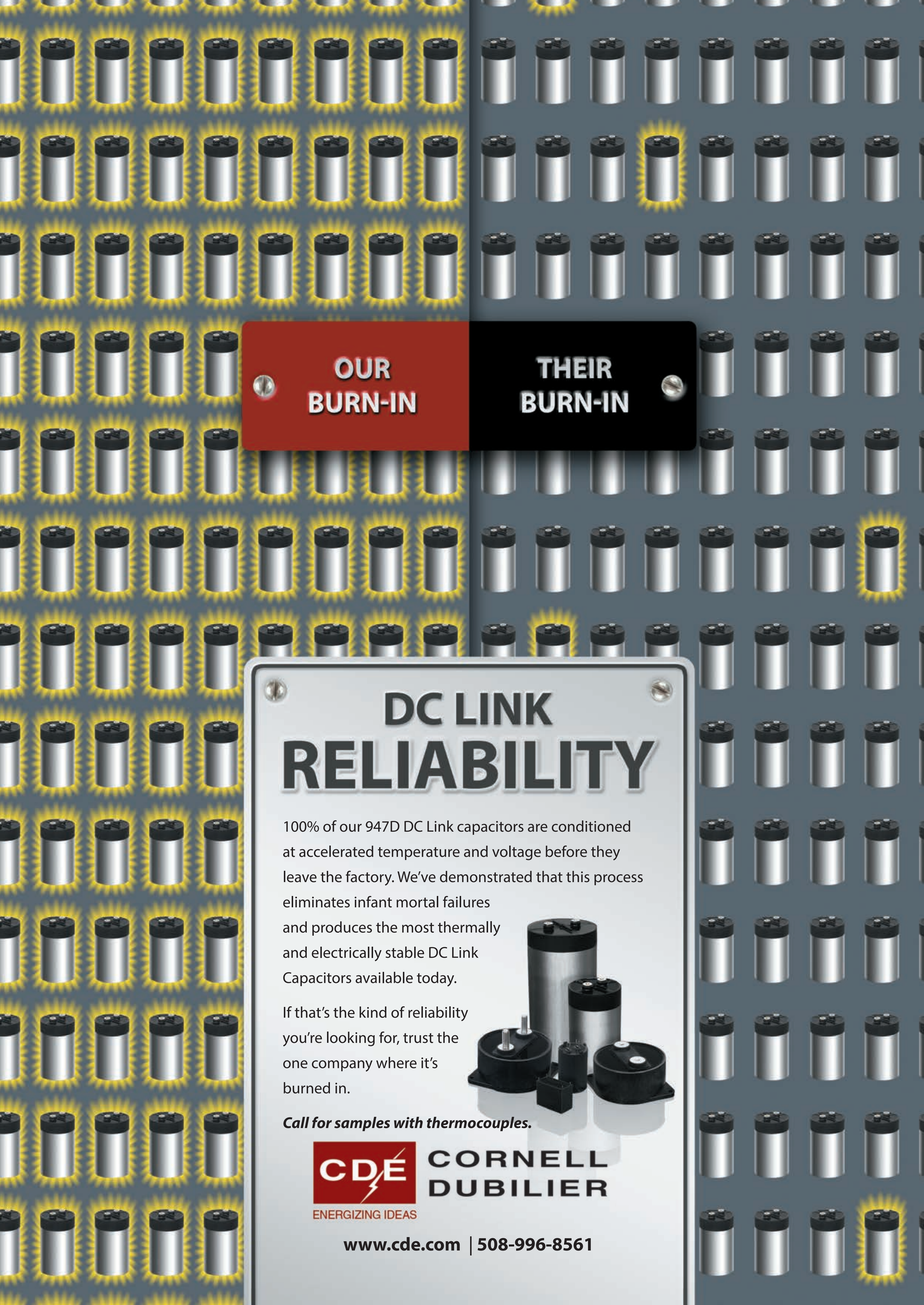
The dsPIC33CH is designed specifically to facilitate independent code development for each core by separate design teams and allows integration when they are brought together in one chip. The Master core will execute the code from Program Flash Memory (PFM) and the Slave core will operate from Program RAM Memory (PRAM). Distributing the overall workload across two DSC cores in a single device enables higher power density through higher switching frequencies, leading to smaller components. The dsPIC33CH family was designed for live updating of the system, which is especially important for power supplies where firmware updates must be made with zero downtime.



Dual-core DSP block diagram

The Master core and Slave core can operate independently, and can be programmed and debugged separately during the application development. Both processor (Master and Slave) subsystems have their own interrupt controllers, clock generators, ICD, port logic, I/O MUXes and PPS. The device is equivalent to having two

Microchip's new dual-core DSP serves many application fields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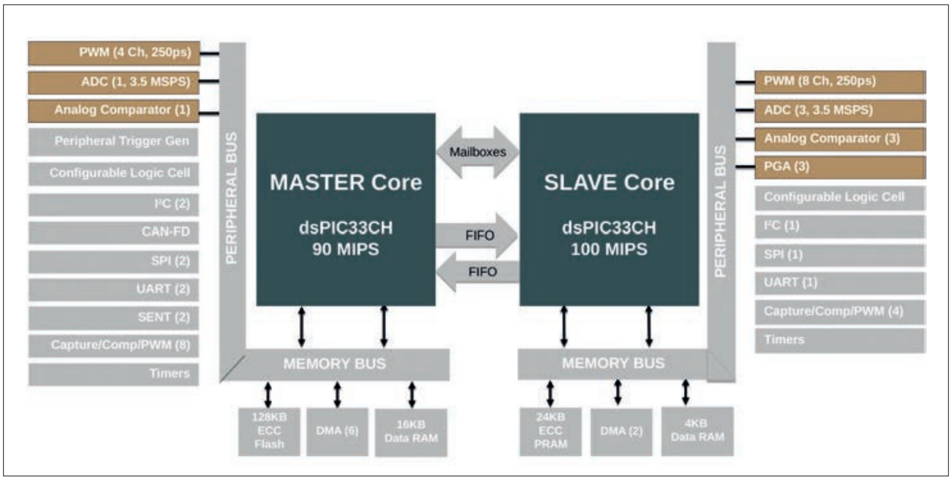


Dual-core DSP PWM and analog peripherals

complete dsPIC® DSCs on a single die.

Once the code development is complete, the Master Flash will be programmed with the Master code, as well as the Slave code. After a Power-on Reset (POR), the Slave code from Master Flash will be loaded to the PRAM (program memory of the Slave) and the Slave can execute the code independently of the Master. The Master and Slave can communicate with each other using the Master Slave Interface (MSI) peripheral, and can exchange data between them.

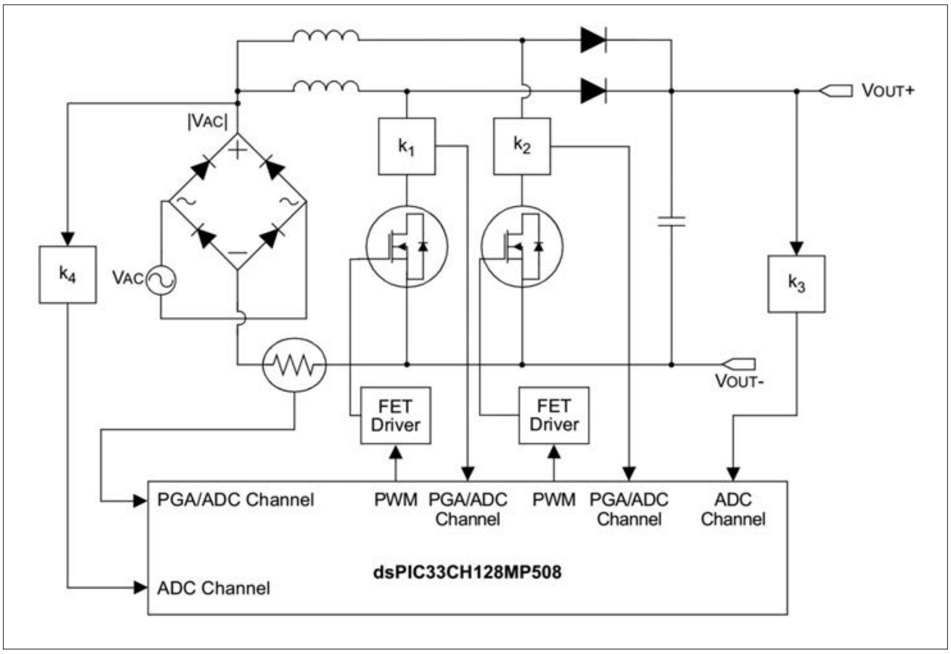
The integrated PWM stage features 250 ps PWM resolution with up to 12 PWM channels with four channels for Master and eight channels for the Slave controller.

Targeted applications

In Power Factor Correction (PFC) targeted applications are Interleaved PFC, Critical Conduction PFC, Bridgeless PFC. For DC/DC Converters Buck, Boost, Forward, Flyback, Push-Pull; Half/Full-Bridge or Phase-Shift Full-Bridge and Resonant Converters are envisioned. For DC/AC applications Half/Full-Bridge Inverters and Resonant Inverters are typical. Motor Control includes BLDC, PMSM, SR and ACIM.

In Digital Power applications the slave core closes the control loop in firmware by running latency- critical compensator algorithms, while the master core cuns PMBus stack and system-level functions. For a 3-Pole 3-Zero compensator algorithm commonly used the new dsPIC33CH core offers nearly 2x performance increase compared to the previous generation due to context-selected accumulators & status registers, new instructions and 100 MHz clock instead of 70 MHz. And the 100-MHz clock results in SMPS switching frequencies above 2 MHz, ideally for GaN devices in the power stage.

In Motor Control applications the slave core provides speed and torque control by executing time-sensitive control algorithms, while the master core runs functional safety routines, such as the Controller Area Network Flexible Data rate (CAN-FD stack), and other system-level functions. In an automotive fan or pump, the slave core is dedicated to managing time-critical speed and torque control while the master manages the CAN-FD communications, system monitoring and diagnostics. The two cores work seamlessly together, enabling advanced



Dual-core DSP interleaved PFC application example

algorithms to improve efficiency and responsiveness. In addition, each of the new cores in dsPIC33CH devices has been designed to provide more performance than current dsPIC DSC cores through more context-selected registers to improve interrupt responsiveness; new instructions to accelerate DSP performance; and faster instruction execution.

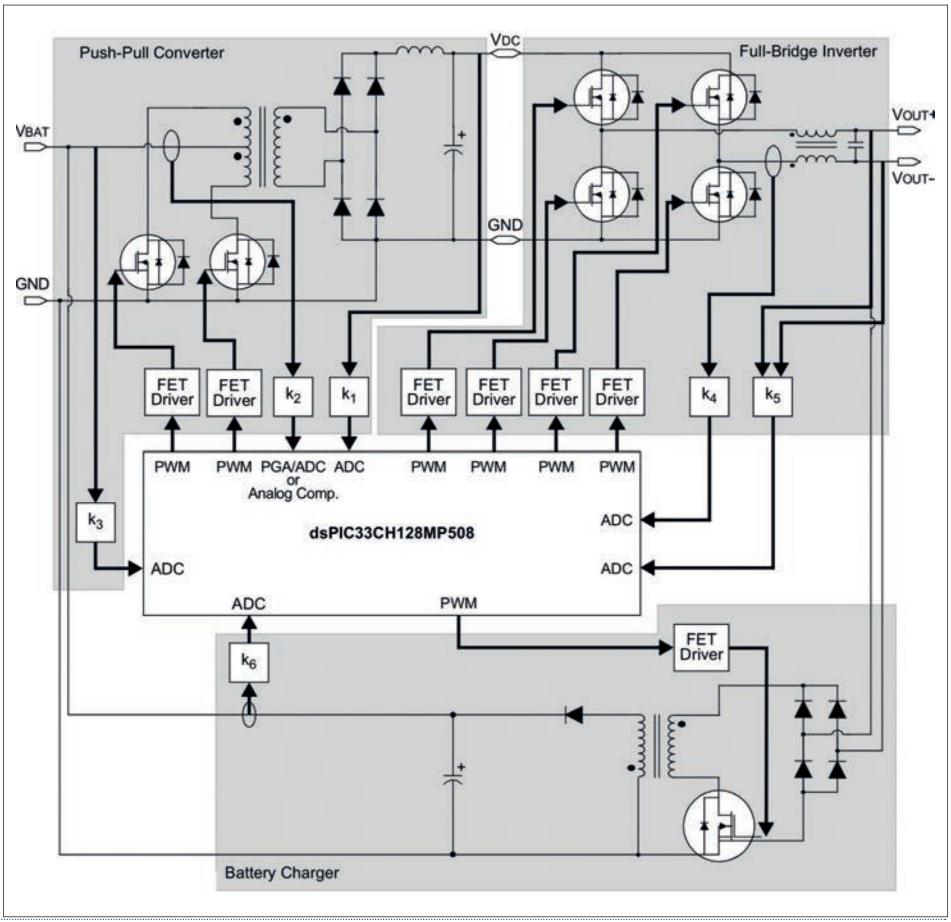
Fast prototyping

The $35 dsPIC33CH Curiosity Board (DM330028) enables customers to rapidly create prototypes. The dsPIC33CH Plug-in Module (PIM) for motor-control platforms (MA330039) is available for MCLV-2 and MCHV-2/3 systems and is priced at $25. The $25 dsPIC33CH PIM for general-purpose platforms (MA330040) is now available for the Explorer 16/32 development board (DM240001-2).

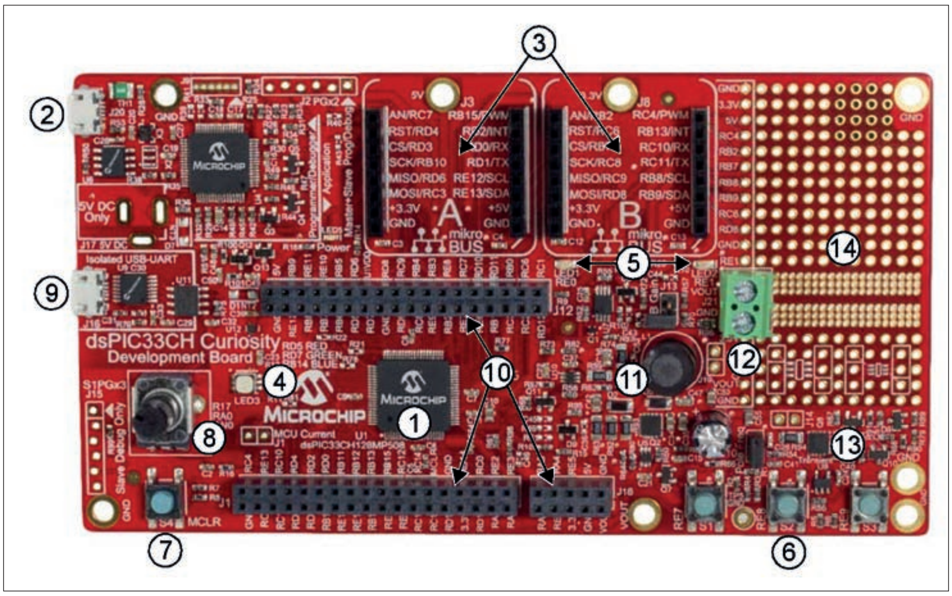
The shown Curiosity Board contains 1. dsPIC33CH128MP508 dual core, 16-bit DSP target device; 2. Integrated PICkit™-On-Board (PKOB) programmer/debugger; 3. 2x mikroBUS™ interfaces for hardware expansion; 4. 1x Red/Green/Blue (RGB) LED; 5. 2x general purpose red indicator LEDs; 6. 3x general purpose push buttons; 7. 1x MCLR reset push button; 8. 10k potentiometer; 9. Galvanically isolated USB-UART interface, capable of up to 460,800 baud; 10. female, 100 mil pitch, I/O pin access headers for probing and connecting to all target microcontroller GPIO pins; 11. Configurable Switch Mode Power Supply (SMPS) test circuit that can be operated in Buck, Boost, or Buck-Boost modes, using either Voltage mode or Peak Current mode control; 12. Converter output voltage screw terminal; 13. Configurable load step transient generator; and 14. General purpose through-hole and SMT prototyping area.

The Curiosity Development Board is intended to be primarily powered from the PKOB USB micro-B connector J20. Power is not sourced through USB connector J16, as it is part of the isolated USB-UART interface. Polyfuse TH1 is rated for 500 mA to enforce the USB current restrictions and to help protect the board, or host, from damage in the event of unintended short circuits or SMPS output overloads. When operating the board from USB power, approximately 300 mA is available to the SMPS circuit, as about 200 mA of the total should be reserved for use by the other non-SMPS circuitry on the board (ex: primarily U1, U4, U11, R17, LED5, etc.).

An external DC wall cube may optionally be connected if a DC barrel jack is installed in the unpopulated footprint J17. If an external wall cube is used, it should be well regulated and rated for 5.0V, ≤ 1.5A, with center pin positive. Compared to operating from USB power, powering the board with an external wall cube enables more power to be sourced by the SMPS



Dual-core DSP off-line UPS application example



Curiosity Development Board showing extensive hardware

circuit on the board. It is not necessary to use an external power supply for standard operation at lower current levels (e.g., SMPS circuit output load power of about <1.2W).

When the board is powered through J17, the polyfuse TH1 is bypassed, and therefore, it is recommended to use a wall cube with internal short circuit and overload protection (≤ 1.5A) to minimize the risk of circuit damage in the event of unintended short circuits.

The board has a PICkit-On-Board (PKOB) programmer/debugger circuit, which can be used to program and debug both the Master and Slave cores in the dsPIC33CH128MP508 target device (U1). Alternatively, an external programmer/debugger tool can be connected to the board via the 6-pin inline connector J2, using a male-male 100 mil pitch 6-pin header.

During simultaneous "dual debug" of both the Master and Slave cores, two debugger tools are required. During simultaneous dual debug operation, the PKOB circuit can be used to debug the Master core, while an external programmer/debugger tool should be connected via the 6-pin 100 mil pitch connector J15 using a male-male header. Two programmer/debugger tools are only required when performing dual core simultaneous debug operations. When programming or debugging only a single core (either Master or Slave) at a time, the on-board PKOB circuit is sufficient.

The PKOB circuit should automatically enumerate and be recognized by the MPLAB X IDE v4.10 or later, when the Curiosity Board is connected to the host via the USB micro-B connector J20. No custom USB driver installation is necessary as the PKOB circuit relies on standard OS provided HID drivers, and therefore, driver installation should be fully automatic. When plugged in, the PKOB programmer/debugger tool can be selected from the MPLAB X project properties page.

www.microchip.com/dsPIC33CH

Solving the Challenges of EV Adoption by Rethinking Component Design

Although a traditionally slow-moving market in terms of customer adoption, recent commitments by a variety of stakeholders - including Swedish manufacturer Volvo, who has committed to going all electric by 2019, and the UK Government, who has introduced a new industrial strategy - means that the market recorded a 63 % increase in sales in 2016 and is expected to exceed one million units for 2017.

The market shows no signs of stalling any time soon either. According to the UK BNEF report, by 2040, 54 % of new car sales and 33 per cent of the global car fleet will be electric, driven predominantly by regulatory changes, falling prices of lithium-ion batteries, increased EV commitments from automakers, more competitively priced EVs across all classes of vehicle, and the increased role of "intelligent mobility."

Barriers for adoption

Despite the burgeoning growth of the electric vehicle market, there are still some important questions that need to be answered surrounding component design, battery technology and charging infrastructure before the market is well positioned to offer a truly viable alternative to the combustion vehicles. Solving these challenges requires a fundamental change in the role of power quality in electric vehicles, according to a white paper from REO UK.

With the shift away from lithium-ion batteries using liquid electrolytes to solid state ones that pack a higher energy density into a smaller package, the issue of safety and range will become negligible. The bigger issue with batteries is the cost. Bloomberg Technology calculates that, to truly compete with petrol and diesel vehicles, the cost of EV batteries needs to fall to around $100/kWh, something that is not expected to happen until 2026.

The next barrier to the adoption of EVs is the charging infrastructure. There simply isn't a sufficient one in place. The adoption problem will only truly be solved when buyers can overcome their range anxiety, and that will only be possible when charging points are widely available. Where a typical car can achieve anywhere up to 800 km on a full tank of fuel, a decade ago the average range for an EV was 120 km and the norm today is around 190 km. There are exceptions with some newer models, such as the new Nissan LEAF and Tesla Model 3 capable of up to 400 and 500 km respectively.

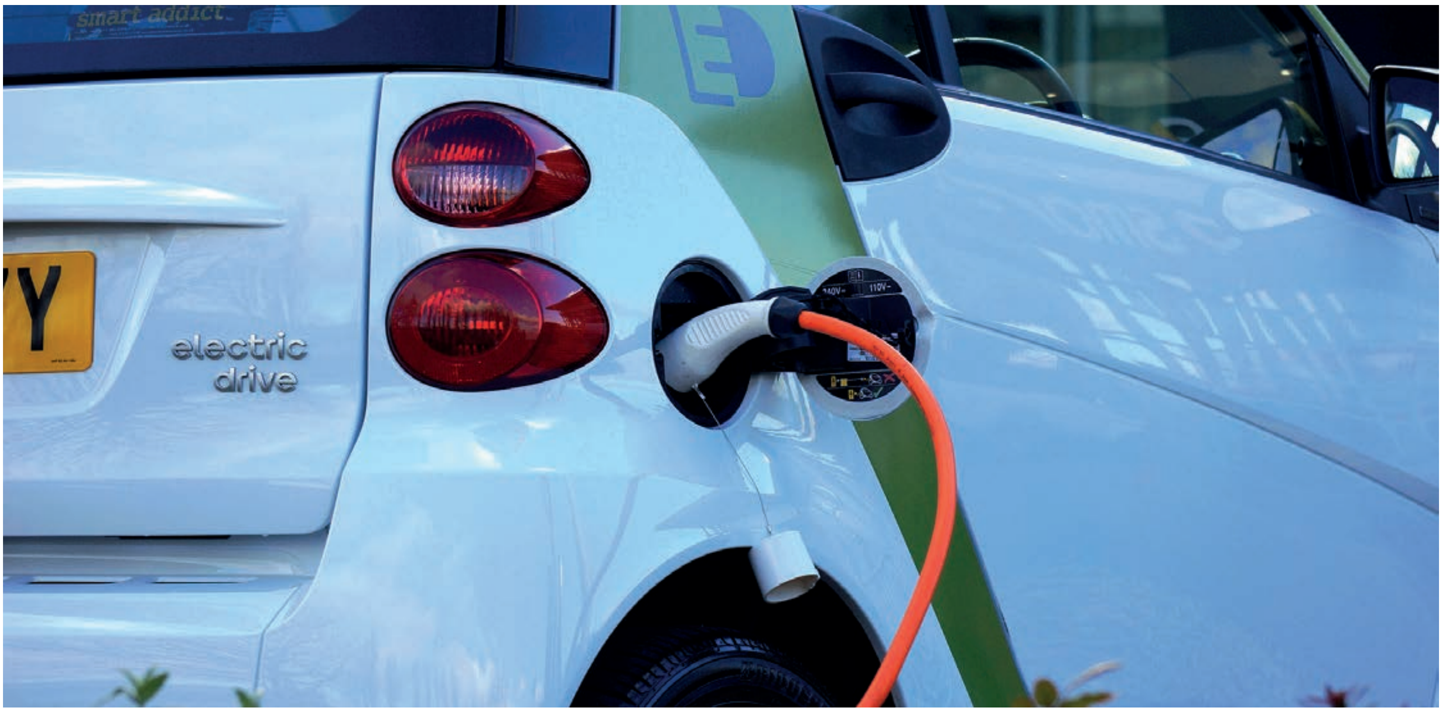
Although 90 per cent of EVs are currently charged at home, we will need more public charging stations to cater for those people without garages and external connection points or for those that drive longer distances. The US now has over 16,000 public charging stations, Germany has around 10,000 and the UK has over 14,000.

Although most EVs use an onboard charger, which consists of a rectifier circuit designed to convert AC to DC to charge the car's battery, it's only suited to slower charging modes. Fitting an onboard system capable of handling fast charging would not only be extremely costly, it would also pose thermal problems. If the car is to work with fast chargers that are rated beyond 240 V AC and 75 A, it is better if the charging station can directly deliver DC power.

As well as a more robust charging infrastructure, solving the problem of voltage drops at high load requires us to think more carefully about which parts of the grid will be most affected. For example, the demand on the low-voltage domestic grid can be alleviated by providing targeted access to charging systems on medium and high voltage grids, at places like commercial business parks, and incentivising the use of small-scale renewable solar and off-peak battery energy storage systems for residential use.

The third major barrier to the adoption of electric vehicles, and arguably the most important one, is the design of components. The modern motor vehicle is a far cry from the crude, greasy and heavy electromechanical systems of old.

Electric systems are now so capable of running efficiently that, if the car



One of today's hurdles for EV adoption is the lack of charging stations

was invented today, it would seem ludicrous to use inefficient petrol and diesel engines. However, for all their inefficiency, the components used in internal combustion vehicles are certainly robust, capable of handling a myriad of forces and ingress exerted over the course of hundreds of thousands of miles.

The average vehicle is made up of 30,000 parts right down to each individual screw. All of these parts must be able to withstand repeated bouts of acceleration and braking, as well as low and high-speed driving over smooth and rough terrain. The same parts must also perform in a variety of weather conditions, from hot and humid environments to cold and wet ones.

This is what makes it challenging for engineers to design the next generation of electric vehicles. Whereas internal combustion technology has undergone over a century and a half of design refinement, electric vehicles - despite being invented around the same time as the first production automobile – have only become commercially viable in the last decade.

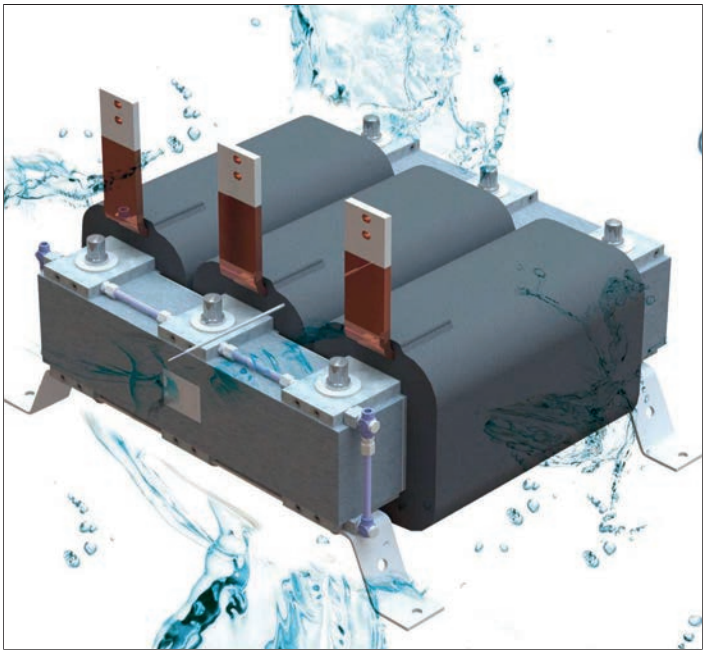
New EV components

As a manufacturer of wound components, German power quality specialist REO knows the challenges of EV component design better than most. Established in 1925, the company has extensive experience in designing and manufacturing components as diverse as electronic filters, resistors, transformers and other types of power electronics for sectors including renewable energy, rail and automotive.

The demand for electric vehicles has spurred the company to adapt its offering to include specialist components for EVs. Managing director of REO UK, Steve Hughes, believes that the challenge of EV component design stems from three issues: space, cooling and power quality.

"Over the last few years, we've delivered design and development projects for a few of the well known German vehicle manufacturers. One of the key constraints has been the small space-envelope available to design engineers to fit electrical components into a vehicle that already has a high component density. What's more, this means that we can no longer use air-cooling to dissipate the heat generated from the components during normal operation, so we have developed specialized liquid-cooling systems to manage the thermal properties of the electrical components while allowing them to meet the space constraints of the vehicle."

However, with so many electrical and electronic components working in such close proximity to each other, EVs pose a bigger problem in the form of power quality issues. Although EV components provide a much more efficient transfer of energy, the process of power conversion - especially for high frequency inverters - used by these electronics results in electromagnetic interference (EMI).



By using better core materials the size of charging transformer can kept small

Liquid cooled power braking resistors for cabin heating and safely discharge

This is compounded by the fact that the same lines used to deliver power to the electric vehicle are also used for data signalling to provide the battery management control system with information on variables like charge status, temperature and voltage. A failure to address EMI can result in overheating, efficiency losses and potential radio frequency issues that interfere with the vehicle's data communication systems.

To meet this challenge, REO has built on its extensive experience in railway electrification and developed a variety of inductive and resistive components for electric vehicles and their charging systems. EVs have some equivalent subsystems to those found in their internal combustion counterparts. The powertrain consists of batteries combined with an electric motor to generate propulsion and the drivetrain uses electric motors to drive the wheels.

For the EV charging systems, this takes the form of a single-phase transformer and electromagnetic compatibility (EMC) filter. As transformers get bigger for higher frequency applications, the proportion of losses and eddy currents rises. To keep these at bay, it's preferable to keep the size of the transformer small. REO achieves this by using better core materials such as amorphous cores, nanocrystalline cores and ferrite cores.

The cooling capacity of the high frequency transformers can also be increased by using aluminium housing, which can be attached to a cold plate for optimum heat dissipation. If ingress protection is a priority, the transformer can also be completely encapsulated within plastic housing, which also improves the insulation class.

In addition to the batteries and electric motors, the electric vehicle also consists of an inverter and a DC/DC converter to efficiently manage the power conversion using high frequency switching. Here, high frequency components such as transformers, chokes, braking resistors, filters, choppers and storage reactors help to protect the sensitive semiconductor power-electronics.

Chokes work alongside transformers to fulfil two functions; either attenuate undesired frequencies or for energy saving and energy storage. REO's common mode chokes suppress this electrical noise in the inverter, and the company's storage chokes are designed to effectively store and discharge magnetic energy from the core, regardless of whether it's made from a ferrite, amorphous or nanocrystalline material.

The next two components are designed to cope with day-to-day driving. Where a normal petrol or diesel vehicle uses friction to convert mechanical braking energy into heat and wear on the brake pads, the electric motor used to drive the wheels in an electric vehicle requires a braking chopper. The chopper is directly responsible for converting the energy that is created as a result of high speed changes.

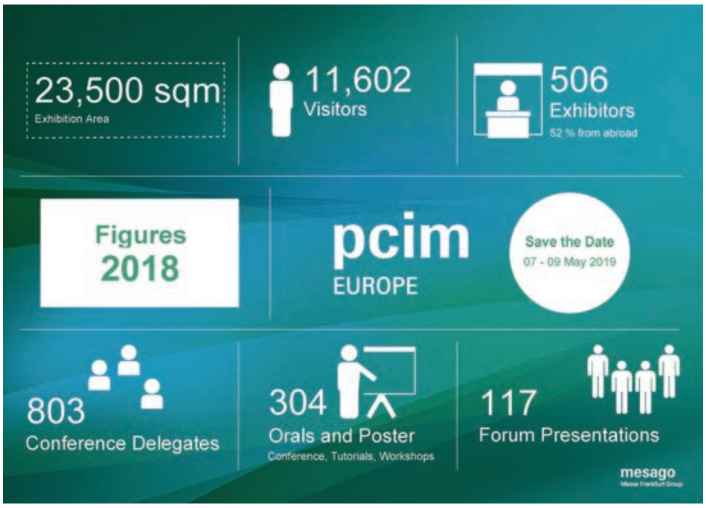
This heat energy is then made useful by the water-cooled braking resistor, which acts as a high-voltage recuperation heater, using the waste energy to heat the cabin and provide effective pre-heating to the car's batteries in cold weather. The same braking resistor also works with the DC-link to dissipate unwanted power from the system safely. This is especially vital in the event the drive system fails, the energy can be safely discharged.

www.reo.de, www.reo.co.uk

Automotive Goes SiC

PCIM Europe 2018 closed on June 7 again with tecord numbers in conference delegates, exhibition visitors, exhibitors and space due to the increasing interest in power electronics virtually in all industry segments, and here particularly in regenerative energies and automotive design/production.

Prospects for continuing strong growth in the SiC industry are high, fuelled predominantly by increasing sales of hybrid and electric vehicles. Market penetration is also growing, particularly in China, with Schottky barrier diodes, MOSFETs, junction gate field-effect transistors (JFETs) and other SiC discretes already appearing in mass-produced automotive DC7DC converters and on-board battery chargers. "It looks increasingly likely that powertrain main inverters using SiC MOSFETs instead of Si IGBTs, will start to appear on the market in three to five years. As there are many more devices used in main inverters, than in DC/DC converters and on-board chargers, the required quantity will also rapidly rise. There might come a time when inverter manufacturers eventually choose custom full SiC power modules over SiC discretes. Integration, control and package optimization are the major strengths of module assemblers", expects IHS Markit (**www.ihsmarkit.com**) analyst Richard Eden. "Not only will the number of per-vehicle SiC devices increase, but new, global registration demand for both battery electric vehicles and plug-in hybrid electric vehicles (PHEVs) will also increase 10-fold between 2017 and 2027, as many global governments aim to reduce air pollution and lower dependence on vehicles burning fossil fuels. China, India, France, Great Britain and Norway have already announced plans to ban cars with internal combustion engines in the coming decades, replacing them with cleaner vehicles. The prospects for electrified vehicles generally, and for wide band-gap semiconductors specifically, are therefore very good. The biggest inhibitor to massive growth for SiC components could be GaN components. The first automotive AEC-Q101 qualified GaN transistor was launched in 2017 by Transphorm, and GaN devices manufactured on GaN-on-Si epiwafers boast considerably lower costs. They are also easier to manufacture than anything produced on SiC wafers. For these reasons, GaN transistors could become the preferred choice in inverters in the late 2020s, ahead of more expensive SiC MOSFETs."



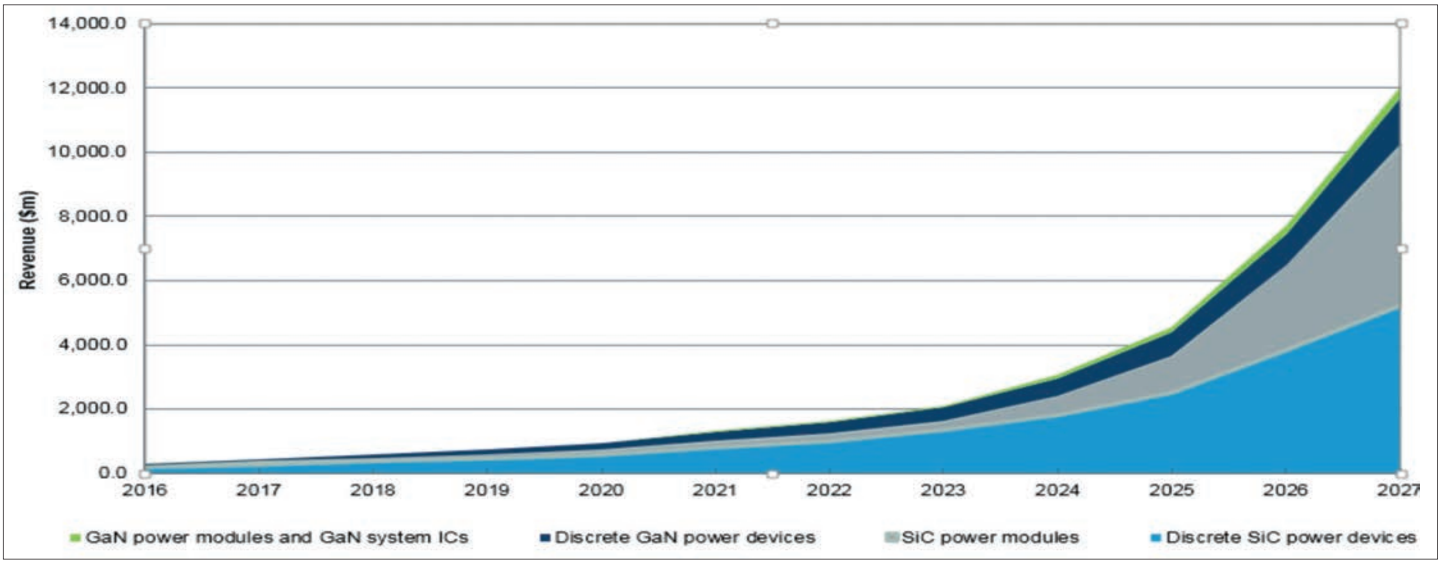
Statistics confirm PCIM Europe's leading position in power electronics Source: Mesago

The most interesting story for GaN power devices in recent years has been the arrival of GaN system ICs, GaN transistors co-packaged with Si gate driver ICs, or monolithic, all GaN ICs. Once their performance is optimized for mobile phone and laptop chargers and other high-volume applications, usage may become prevalent in wider applications. In contrast, commercial GaN power diode development never really started, because they would not offer significant benefits over Si devices, and developing them proved too costly to be viable. SiC Schottky diodes already work well for that purpose and a have a good pricing roadmap.

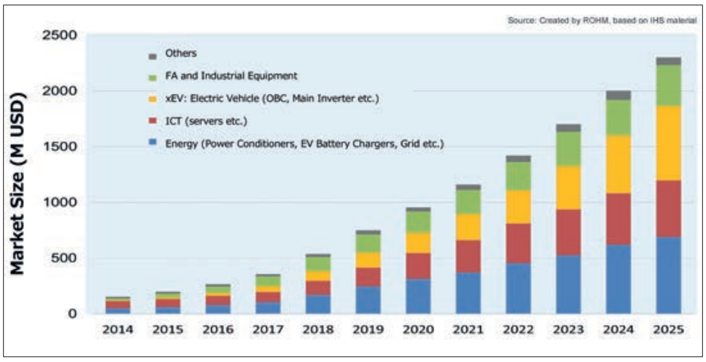
SiC capacity increase to meet market demand

Various other sources including semiconductor vendors such as ROHM (**www.rohm.com/eu**) confirm this trend towards xEV in the years to come and thus will react in order to catch up with the increasing demand for SiC MOSFETs. The company expects the global SiC market to exceed the $1 billion mark by 2021. The largest share is accounted for by power supply applications, such as power conditioners, battery chargers for electric vehicles and the power grid. However, main inverter of electric vehicles also represent a significant part of the market potential for SiC components.

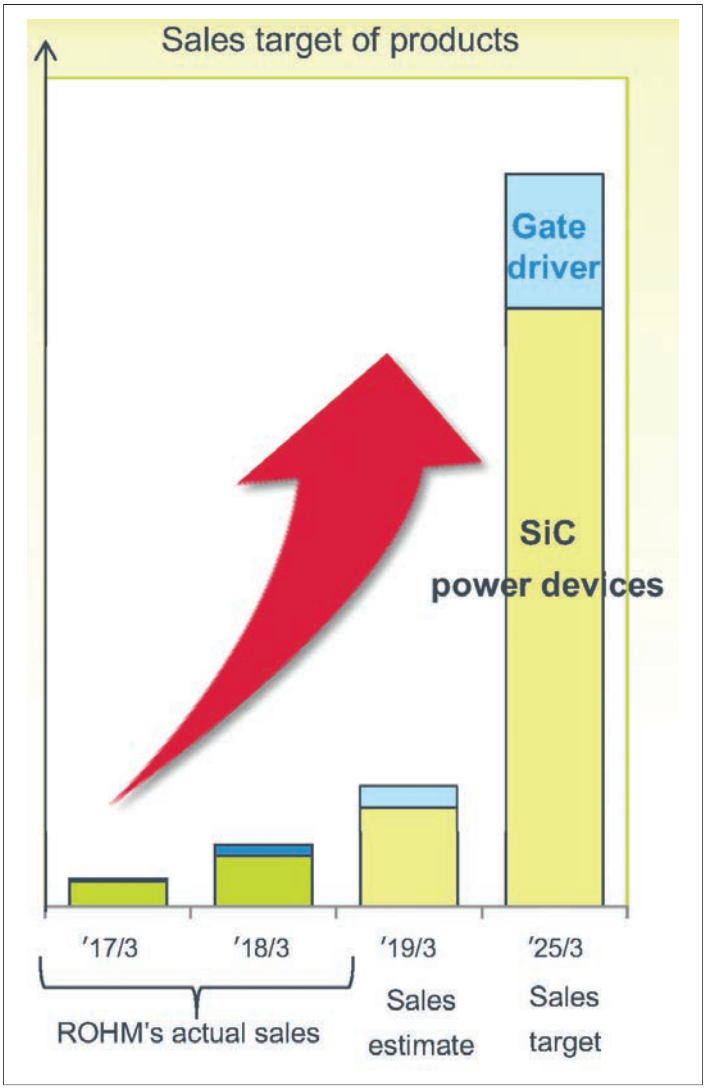
ROHM is aiming for a top market share from 20 % in 2018 to 30 % in 2025 on SiC wafers and components. To achieve this goal, production capacity must be greatly increased by further increasing the wafer size from



Overall SiC and GaN power semiconductor market development 2015 – 2027 (Souce: IHS Markit 3/18)



SiC market forecast various application areas until 2025 **Source: IHS Markit/ROHM)**



SiC MOSFET-based inverter's economic benefit vs. battery size in 2025 **Source: ROHM**

today's 150 mm diameter and using the latest equipment. Thus ROHM has announced plans for a new SiC production building at the Apollo plant in Chikugo, Japan. "The new building will increase the production area by approximately 11,000 m^2. Detailed planning has just begun, construction is scheduled to begin in February 2019 to be completed by the end of 2020. So far 150-mm-wafers will be processed. Compared to the year 2017 capacity will be increased by a factor of 16 by 2025. Accordingly we will increase our SiC turnover through aggressive investment, in-house SiC production from ingot to packaging, minimized crystal defects, and servicing growing markets such as electric vehicles and information technologies", underlined ROHM's Europe President Christian André.

Also Wolfspeed (**www.wolfspeed.com**) moves towards automotive applications. "There is a growing global demand for more electric vehicles on the road, with nearly all vehicle manufacturers announcing new electric platforms across their fleets," confirmed also Gregg Lowe, CEO of Cree. "We are at the forefront of enabling this change in the automotive industry with

"The story of Bipolar vs. CMOS could be continued in Silicon vs. SiC," Cree's CEO Gregg Lowe stated **Photo: AS**

new technologies, such as Wolfspeed's new SiC MOSFET portfolio, that help foster the adoption of electric vehicles." In his opinion the power industry is on a tipping point by moving towards SiC, fueled particularly by the automotive industry. If this change occurs the future market for WBG devices will be pretty big. One indicator – automotive companies recently have announced to invest over $100 billion in EVs and thus the SiC demand will grow and therefore the SiC market could be even greater than $10 billion in 2027. "If demand grows, cost will decline as a function of the learning curve. This expansion will driving scale in terms of yield improvement, will driving cost down and in return will accelerate demand as well. We have doubled capacity last year and again will double wafer capacity next year. And in driving scale we are in the process of qualifying 200-mm-4H-wafers to come to market in the next two years. We have to invest in our own machinery because you cannot buy this off the shelf," Lowe continued. And, by the way, around 60 % of Infineon's SiC material is supplied by Cree/Wolfspeed. In FY 2017 Wolfspeed's turnover was $220 million, for 2022 forecast is around $850 million!

Talking about new products, Wolfspeed's 3rd planar generation of SiC MOSFETs covers the range from 650 V to 10 kV, below 600 V GaN is coming, but Lowe sees the GaN USP around 200 V for POL and DC/DC conversion. Since the Wolfspeed acquistion by Infineon failed last year due to National Security concerns of the US President Lowe's aim now is to open new markets and driving SiC to the next level in industry. The story of Bipolar vs. CMOS could be continued in Si vs. SiC. "We are working on the integrated SiC chip", Lowe underlined at PCIM.

SiC for automotive applications

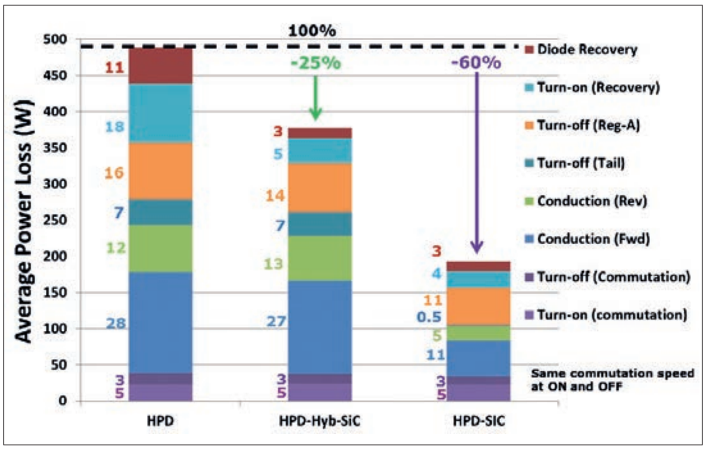
In motor traction inverter application requirements like space, weight and efficiency play an increasing role. Product development and manufacturing expenses should remain low while the design efforts should result in more compact systems and, at the same time, product quality and reliability should be guaranteed. This leads to more demanding design requirements on the system and component level and ultimately affects the overall system consisting of power devices, passive components, cooling technologies and PCBs. Use of SiC power devices in the power train inverter leads to an increase of the entire power train system efficiency and helps to miniaturize the system thanks to improved switching losses, conduction losses, and thermal conductivity. "Also the high efficiency of the SiC MOSFET based inverter allows the size of an EV system battery to be reduced while keeping the same driving range. The battery capacity reduction can lead to an economic benefit if the overall power train system is considered. An estimated battery capacity improvement ratio is 3 to 5 % based on the inverter efficiencies", explained ROHM's European Product Marketing Manager Masaharu Nakanishi at the conference.

The newly developed low stray inductance, high heat dissipation capable "Gtype"package is suitable for SiC MOSFETs. A traction inverter utilizing this new module reached 220 kW output power and a peak efficiency of 99.1%. Furthermore, the SiC MOSFET based inverter has less weight and volume than a Si IGBT based design. The power density is 22kW/l which is 57 % higher than that of the Si IGBT based solution. "A high efficiency inverter brings economic benefits for the user as it extends the driving distance for a given battery capacity or allows a battery size reduction while keeping driving distance, which can give an economic advantage", Nakanishi said.

For the SiC MOSFET a chip size of 25 mm^2 at 1200 V rated voltage is considered per 100 A of output current.

A 400 A inverter provides economic benefit at the system level if a battery of at least 32 kWh capacity is used. For a 600 A inverter the benefit exists above a battery size of approximately 48 kWh. With further increasing adoption of SiC devices in the near future and the resulting effects of economy of scale for SiC MOSFETs it is expected that the economic gap to Si IGBTs will get smaller and the benefits will thus get even larger.

"SiC technology is now mature to be deployed at broad scale in automotive systems", also stated Stephan Zizala, General Manager for Automotive High Power at Infineon (**www.infineon.com**). Thus the company presented the



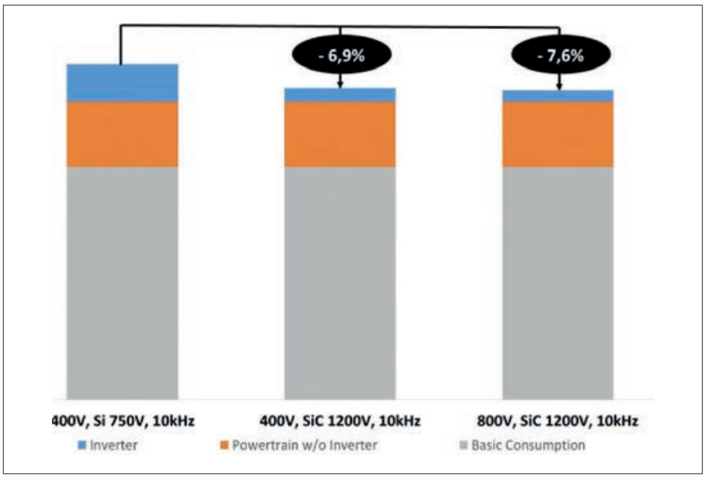
Split-up of the average power losses over the Artemis highway mission profile at equal commutation speed **Source: Infineon**

first products of its automotive SiC portfolio – the 650 V CoolSiC Schottky diode family for current and future on-board charger (OBC) applications in hybrid and electric vehicles. The diodes were designed specifically to meet the high requirements of the automotive industry regarding reliability, quality and performance. "Thanks to a new passivation layer concept, this is the most robust automotive device available in the market regarding humidity and corrosion. Moreover, because it is based on a 110 µm thin wafer technology, it shows one of the best figures of merit in its category", Zizala said. Compared to the traditional Silicon Rapid diode, this CoolSiC Diode can improve the efficiency of an OBC by one percentage point over all load conditions, Infineon claims.

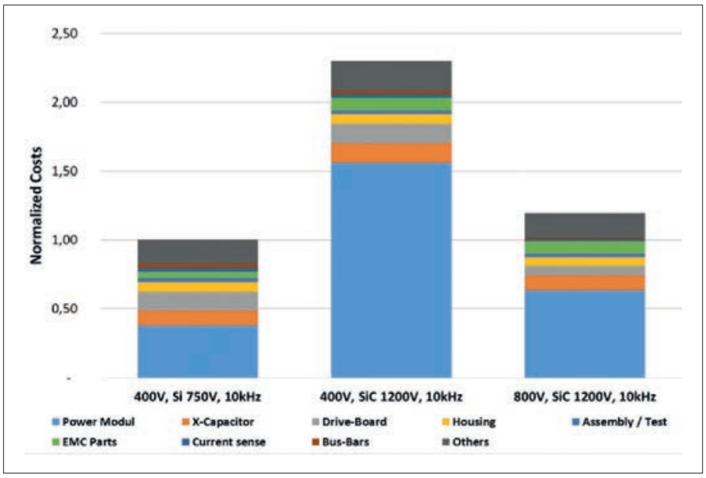
The mission profile efficiency performance of a 1200 V full-SiC Trench-MOSFET module based on Infineon's Automotive CoolSiC technology, suitable for traction inverter applications, has been compared by Ajay Poonjal Pai, Senior Application Engineer at Infineon Technologies, against a Si module with Si IGBTs/diodes, and a hybrid SiC module with Si IGBTs and SiC diodes (see also Power Electronics Europe issue 3/2018, pages 22 - 25).

The considered full-SiC 1200 V module is an automotive B6-bridge featuring 8 CoolSiC Trench-Mosfets, each with a die size of about 25 mm^2, in parallel per switch, resulting in a total semiconductor content of 200 mm^2 per switch. The full-Si IGBT module is based on the new EDT2 micro-pattern Trench-Field-Stop technology with a total semiconductor content of 450 mm? per switch. The hybrid-SiC module has been produced by replacing the Si diodes of HPD with Gen5 650 V SiC Schottky diodes. The module has 428 mm^2 of semiconductor content. Static and dynamic characterization of the three modules were performed, and these measurements were used to perform power loss calculations for different mission profiles, at different boundary conditions such as switching speed, chip area, working voltage and switching frequency. "It was found that the full-SiC module offered higher than 60 % reduction in the total losses compared to the full-Si module", Pai stated. Also the performance of the three modules for different public mission profiles have been investigated. "In each case, the average power losses over the mission profile are reduced by 60 – 80 % compared to the Silicon HPD. The highest reduction is for low-speed urban mission profiles. This is due to the absence of knee voltage in the SiC MOSFET, which makes it especially more efficient than the Si IGBT-based modules in the light-load region", Pai concluded. Mission profile analysis was performed with a mid-sized Sedan such as the e-Golf as reference.

Due to the constantly increasing demand for the electrical range and to the restricted installation space, the quest on energy efficiency of a traction inverter will increase. SiC MOSFETs are considered as the most promising semiconductor devices for future traction inverter applications. At the conference Daimler's R&D Engineer Alexander Nisch (**www.daimler.com**) discussed the potential and challenges of a three-phase voltage-source-inverter based on trench SiC MOSFETs in Infineon's new SiC HybridPack under automotive constraints, considering the complete drivetrain. To achieve the optimum efficiency the switching behaviors of different gate controls are



Reduction of energy consumption on vehicle side with SiC technology **Source: Daimler AG**



Normalized inverter cost for 400 V/800 V DC-link voltage in Si/SiC configuration **Source: Daimler AG**

investigated. Based on the results, a significant efficiency improvement for an electric vehicle application is possible, confirmed by measurements.

The majority of electric drivetrain applications in the automotive industry operates in the range up to 450 V DC-link voltage. For this voltage range a sufficient quantity of 750 V devices based on Si-IGBTs and modules is available. In the case of SiC MOSFETs it looks quite different. The availability of 750V rated SiC TMOSFETs and modules is small. Thus Daimler evaluated the potential of 1200V SiC MOSFETs in conjunction with an automotive qualified module, which is conform with both voltage requirements up to 450 V and 800 V. The special challenge was to design the DCB-layout in the existing module to meet the requirements of 160 kW of mechanical traction power, peak phase current of 550 A, switching frequency of 10 kHz, and maximum cooling temperature of 75°C.

The power module as a part of the traction inverter contributes significantly to the efficiency and functionality of the system. For enabling easy design in a well-established form factor, scalability, a lifetime as given today by IGBT modules, robust functionality, reliable switching behavior, and an adequate thermal setup are important. With the example of the CoolSiC Hybridpack Drive power module family a power capability of 220 % compared to the IGBT version is enabled.

Although SiC carbide offers the possibility to operate very high junction temperatures, the package technology must be adapted to the related high power density. The small local heat source must be able to dissipate the thermal energy to the environment. This is enabled by replacing standard DCB ceramics (typically Al_2O_3 with 24 W/mK to Si_3N_4 with 80 W/mK). In combination with the PinFin baseplate of the HybridPack module an adequate thermal performance can be reached. The relative duty cycle for a half bridge was calculated based on the phase voltage, from that it is possible to calculate the currents and losses in each device. These values were taken to calculate the energy consumption of the power electronics in the worldwide harmonized light vehicle drive cycle (WLTP class 3) for a heavy sports utility vehicle (SUV). "With a 1200V SiC MOSFET in combination with 250 – 450 V DC-link we calculated a potential of 3,9 % savings in power consumption. Even for the non-optimal case of a 450 V battery voltage, 1200V SiC MOSFETs allow an improvement of 3-6 %. Possible savings for an 800 V system are expected to be even higher", Nisch pointed out. But a SiC-based inverter for a 240 kW machine, both in 400 V and 800 V configuration, is more expensive.

More GaN sources

Kenichi Yoshimochi, Project Leader GaN at ROHM, announced a partnership with GaN Systems (**www.gansystems.com**) to to jointly develop form-, fit-, and function-compatible products using GaN semiconductor dies in both GaN Systems' GaNPX packaging and ROHM's traditional power semiconductor packaging. "GaN Systems and ROHM customers will now have the advantage of having two possible sources for package-compatible GaN power switches. Additionally GaN Systems and ROHM will work together on GaN research and development activities to propose solutions for the industrial, automotive, and consumer electronics fields."

Kenichi Yoshimochi, Project Leader GaN at ROHM, announced a partnership with GaN Systems to to jointly develop form-, fit-, and function-compatible products Photo: AS

Infineon is starting volume production for its so-called e-mode CoolGaN products, licensed in a joint effort with Panasonic's GIT (Gate Injection Technology), by the end of 2018. Engineering samples are available now. "We truly believe that the next big thing in power management is gallium nitride," said Steffen Metzger, Senior Director High Voltage Conversion at Infineon. "CoolGaN is the one of most reliable and globally qualified GaN solutions. During the quality management process not only the device is tested, but also its behavior in the application. At 100 parts per million, its predicted lifetime is about 55 years, exceeding the expected lifespan by 40 years." A GaN driver will be launched also in 2018.

PCIM Europe 2018 awards

Three young engineers have been awarded with a price money of € 1000, the best paper additionally with a trip to PCIM Asia 2019, co-sponsored by Power Electronics Europe.

Winner of Best Paper Award 2018 is Arne Hendrik Wienhausen, RWTH Aachen, Germany, for the work "Highly Integrated Two-Phase SiC Boost Converter with 3D Printed Fluid Coolers and 3D Printed Inductor Bobbins". With the use of Selective Laser Melting (SLM) new 3D printed cooling structures for power converters can be realized. In this paper, a highly

PCIM Europe 2018 award winners (from left): Arne Hendrik Wienhausen, Alexander Lange, Thomas Fuchslueger, Fabian Denk Photo: Mesago

integrated two-phase interleaved bidirectional boost converter using discrete SiC-MOSFETs and 3D printed fluid coolers as well as 3D printed inductor bobbins was designed. The converter operates at a high switching frequency of 400 kHz and features a high power density of 32.6 kW/l while delivering 15 kW of output power.

Alexander Lange, Friedrich-Alexander-Universität Erlangen, Germany, was awarded for the paper "High Efficiency Three-Level Simplified Neutral Point Clamped (3LSNPC) Inverter with GaN-Si Hybrid Structure". The second young engineer was Thomas Fuchslueger, Technische Universität Wien, Austria, for the paper "Reducing the dv/dt of Motor Inverters by a Two Leg Resonant Switching Cell". Finally Fabian Denk, Karlsruher Institut für Technologie, Germany, received the award for the paper "25 kW High Power Resonant Inverter Operating at 2.5 MHz based on SiC SMD Phase-Leg Modules".

These awards also confirm the increasing interest in wide band-gap technology. And what comes next? We have to wait for PCIM Europe in May 2019. **AS**

SiC Boost Converter with 3D-Printed Fluid Coolers and Inductor Bobbins

A highly integrated two-phase interleaved bidirectional boost converter using discrete SiC MOSFETs and 3D-printed fluid coolers as well as 3D-printed inductor bobbins was awarded as the Best Paper of PCIM 2018. The converter is operated at a high switching frequency of 400 kHz and features a very high power density of 42.1 kW/dm³ (or 26.9 kW/kg respectively) including control hardware while delivering 19.8 kW of output power. This subject was awarded as PCIM Europe 2018 Best Paper co-sponsored by Power Electronics Europe. **Arne Hendrik Wienhausen, Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University, Aachen, Germany**

Commercially available SiC power modules such as Wolfspeed CCS050M12CM2 feature a high parasitic inductance of approx. 30 nH in the power path with all three available phases in parallel, which limits the achievable switching frequency. Discrete SiC MOSFETs with kelvin source connection offer a better switching performance. Therefore, the switching frequency can be raised, smaller passive components can be used and system costs can be reduced. Thus Wolfspeed C3M0065100K SiC MOSFETs in TO-247-4 packages are used which are operated at switching frequency of 400 kHz. The converter is designed to boost an input voltage of 400 V to an output voltage of 800 V or vice versa. Converters in this voltage range are used e.g. in automotive applications to enable a variable DC link voltage.

In order to further reduce the converter size, 3D-printed fluid coolers are used. With these miniature fluid coolers a high power density can be realized. The 3D-printed water coolers were developed and manufactured by IQEvolution according to the specifications resulting from the dimensioning of the converter.

With high switching frequencies, carefully designed magnetic components are required. Therefore, water cooled inductors which are optimized for high-frequency operation were developed.

Converter electronics

The electronics located on three stacked PCBs occupy only 0.19 dm³ of space (box around the converter). This includes all power semiconductors, gate drivers and associated isolated supply, input and output capacitors, the 3D-printed fluid cooler and all electronics necessary for the control of the converter (Figure 1). Besides an FPGA and an MCU, galvanically isolated current measurement circuits for each phase and isolated voltage measurement circuits for the input and output voltages are integrated.

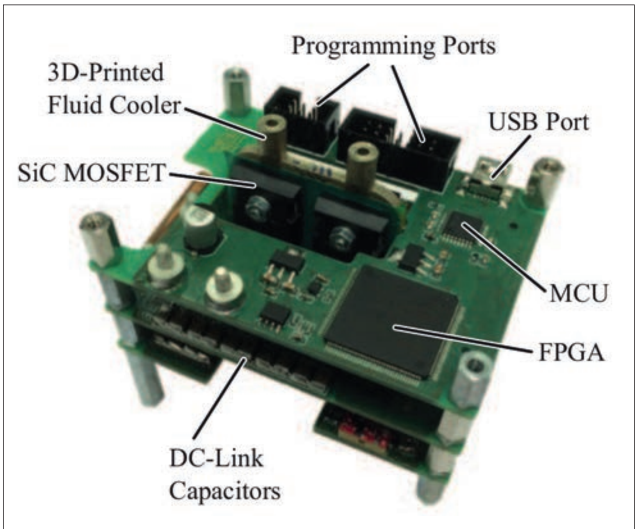


Figure 1: Converter electronics without inductors

As depicted in Figure 2, the water-cooled boost inductors are located below the electronics. The inductors are potted together with a 3D-printed fluid cooler to dissipate copper and core losses. The potted boost inductors feature a total volume of 0.28 dm³, which leads to overall converter volume of 0.47 dm³. In total, the converter features a weight of only 735 g while the potting compound highly contributes to the converter weight. This results in a weight-specific power density of 26.9 kW/kg. This value includes all control hardware and the dual inductor.

The converter electronics are optimized for high-frequency operation and a small total volume. The used SiC MOSFETs can be operated safely with a unipolar gate voltage of 15 V, which significantly reduces the complexity of the gate driver supply and the required board space. The low total gate charge Q_g of 35 nC, combined with the low driving voltage V_g, results in a very low gate power of only 210 mW per transistor at a switching frequency fs of 400 kHz.

As gate driver, 1EDI60N12AF from Infineon is used, which is specified for high switching frequencies of up to 4 MHz and high common-mode transients of 100 kV/µs. The integrated galvanic isolation of the gate driver keeps the required board area small. The drivers are supplied by one DC/DC converter each (Murata NXE2). These small surface mounted converters feature a coupling capacitance of only 2.1 pF, which is of utmost importance when high common-mode transients are applied. The common-mode current through the isolation barrier is directly proportional to the voltage slope and the parasitic coupling capacitance. Therefore, the coupling capacity has to be kept small in the presence of high common-mode transisients.

The gate drivers and the DC/DC

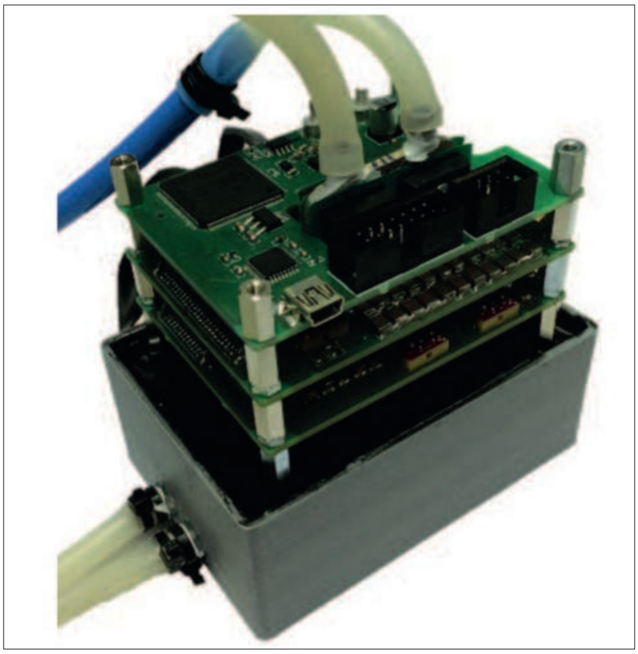


Figure 2: Converter including potted inductors

converters are mounted directly above one another on opposing board sides. This keeps the kelvin source referenced copper islands, which are directly connected to the switching node, very small (less than 1 cm^2) and, therefore, minimizes their parasitic capacitance. The contribution of the PCB cannot be neglegted as only 1 cm^2 of copper with a distance of 300 µm in FR4 results in a capacitance of 12.4 pF, which is nearly six times the coupling capacitance of the used DC/DC converters.

Galvanically isolated current sensors with a band-width of 1 MHz and a small footprint (SO-8) are used for each phase of the converter (AllegroACS730). The acquired signals are fed through fully-differential filter stages into a high-speed ADC, which features a differential input and LVDS outputs for a high signal integrity (Linear Technology LTC2311-12). High-precisionoptocouplers (Broadcom ACPL-C87A) are used to isolate the input and output voltage measurement circuit from the control logic.

As input and output capacitance, 184 ceramic SMD capacitors in 1812 package are used which are distributed over the PCB and interconnected by four to six interleaved power planes for a minumum DC link inductance. This leads to a total input capacitance of 16.2 µF and a total output capacitance of 7.6 µF.

A low-cost Spartan 6 FPGA is used for control purposes. It reads out the ADCs for current and voltage measurements and generates the gate signals for the power transistors. A low-cost Cortex-M0+ MCU is used as a USB-to-SPI bridge for communication with a PC. As the control logic is isolated from the power electronics, the communication can be realized without any isolation.

To obtain a high PWM resolution, four high-speed clocks are used within the FPGA each of which is phase-shifted by 90°. These clocks are fed into an asynchronous output logic which generates the required PWM pulses with a resolution four times higher than achievable by a single clock of the same frequency. In the presented converter design, a PWM resolution of 1.25 ns is realized.

3D printed fluid coolers

The 3D-printed fluid coolers are designed to achieve space efficient cooling of four power transistors in a TO-247 or TO-220 package. Due to 3D-printing, the shape of the fluid cooler can be adopted to fit nearly any other transistor package or other geometric constraints. A clear view on the 3D-printed fluid cooler with mounted SiC MOSFETs is shown in Figure 3.

The fluid coolers are produced from nickel which represents a good compromise between mechanical robustness and thermal conductivity. In order to compare different materials for the miniature fluid cooler, also a stain-less steel and a copper version of the cooler were produced and characterized. While the first nickel prototype still has a weight of 20.2 g, which corresponds to 2.7 % of the total converter weight including inductors, the even smaller version weights only 16.6 g. Both cooler sizes are designed to dissipate 400 W of losses. The reduced weight and height of the smaller version results in a significantly shorter production time and, due to the SLM (Selective Laser Melting) process, production time contributes most to the cooler costs.

Fluid cooled inductors

A water cooled set of boost inductors was developed, featuring various advantages compared to classic (litz) wire wound approaches. The inductors share a common 3D-printed plastic bobbin which serves as place holder and isolation for the used copper foil.

The inductors are potted together with a 3D-printed fluid cooler for efficient cooling within minimum space. For an optimal result, potting is done in a vacuum chamber to extract all enclosed air from the potting compound. The internal structure of the dual inductor is depicted in Figure 4. The copper foil is placed inside the spiral slot of the 3D-printed plastic bobbin before the 3D-printed top plate is fitted to serve as an isolation to the top ferrite core half.

Both inductors share one common 3D-printed fluid cooler. In order to reduce eddy currents in the metallic cooler induced by the winding parts which are not surrounded by ferrite material, the cooler is dimensioned slightly smaller than the ferrite cores. cooled inductors. A plastic spacer is fitted between the metallic 3D-printed water cooler and the inductors in order to further minimize eddy currents. This spacer also serves as a separator between the two ferrite cores. Tolerances during production can be kept extremely small with the use of modern high precision 3D printers (Figure 5). As a consequence, the two integrated inductors feature nearly identical characteristics, which is beneficial in terms of current distribution

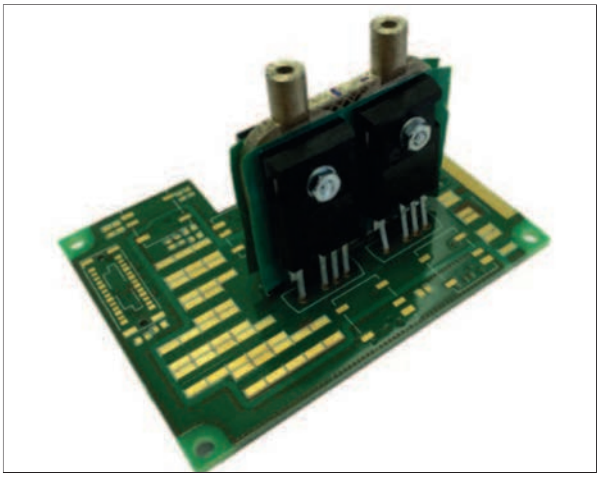
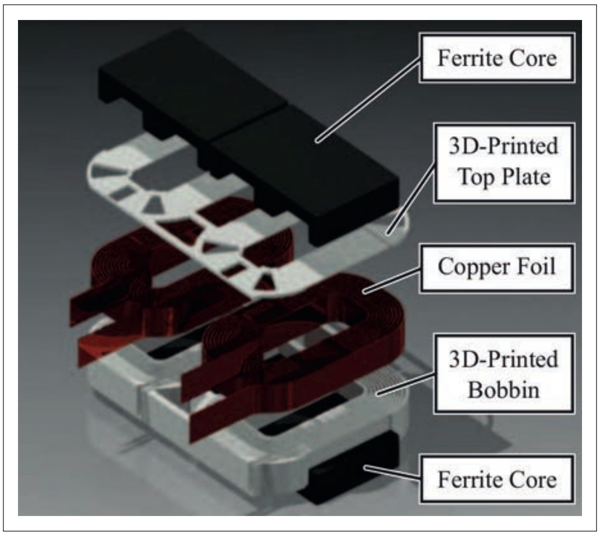
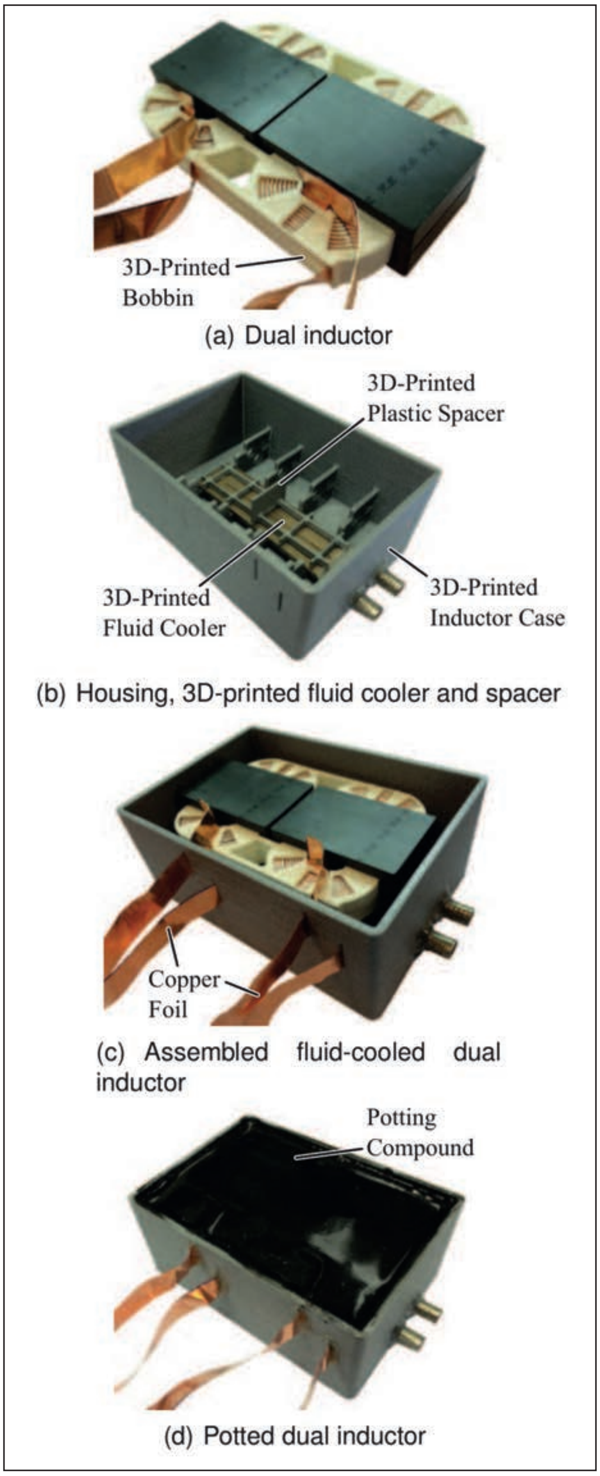


Figure 3: 3D-printed water cooler with mounted SiC power transistors



ABOVE: Figure 4: Internal structure of the liquid cooled dual inductor



RIGHT: Figure 5: Production steps for the fluid-cooled dual boost inductor

between the phases of a multi-phase converter.

Experimental results

In order to characterize the 3D-printed fluid coolers produced from different materials, four MOSFETs are mounted on each version. An electrically isolated thermal interface material (TIM) is used to prevent short circuits between the transistors. K-Type thermocouples are used to measure the fluid temperatures in the inlet and in the outlet of the cooler as well as the cooler temperature. The internal body diodes of the transistors are used to generate controllable losses.

Efficiency measurements have been conducted at a high switching frequency of 400 kHz and input voltages of 200 V and 400 V. The duty cycle was kept constant at 50 %. During the first measurements, the power was limited to 15 kW by the used power source. Efficiency measurements for higher output powers were conducted in a back-to-back configuration. The auxiliary converter is operated as a controllable current sink and feeds energy back to the 400 V input DC rail. In this configuration only system losses of the two converters have to be covered by the power source. At output power of 19.8 kW, a total loss of approx. 600 W can be dissipated effectively with the two 3D-printed fluid coolers.

Conclusion and outlook

A highly compact and light-weight 19.8 kW bidirectional boost converter operated at a very high switching frequency of 400 kHz using discrete SiC MOSFETs has been presented. With a total converter volume of 0.47 dm^3 and a total converter weight of 735 g, it features a very high power density of 42.1 kW/dm^3 and 26.9 kW/kg. This is enabled by the use of 3D-printed water coolers for the power transistors, as well as for the potted inductors. These inductors are developed and optimized for high-frequency operation and show excellent reproducibility due to the use of 3D-printed bobbins equipped with copper foil which is very beneficial in a multi-phase converter.

Measurement results show high efficiencies over a wide load range even though the converter is operated at a very high switching frequency. 3D-printed fluid coolers allow space efficient cooling of power electronic components and can be shaped to fulfill nearly any geometric constraint. Highly compact power converters with very high power densities can be realized by the use of miniature fluid coolers. The converter size can be reduced further more by the use of a shared 3D-printed fluid cooler for the power transistors and the power inductors as well. Also, the volume filled with potting compound can be decreased, which significantly reduces the weight. The thermal performance of the transistor cooler can be enhanced further more by a ceramic coating on the surface of the 3D-printed fluid cooler, which allows the use of a TIM.

Literature

"Highly Integrated Two-Phase SiC Boost Converter with 3D Printed Fluid Coolers and 3D Printed Inductor Bobbins", PCIM Europe 2018 Proceedings, pages 317 - 324

Solving Critical Ground-Shift Problems

Low-side gate-driver ICs are frequently used components in Switched Mode Power Supplies (SMPS). They serve to properly drive power MOSFETS into ON and OFF conditions. In Boost-PFCs they drive the low-side high-voltage power MOSFET. In high-voltage DC/DC-stages, such as LLC, ZVS, and TTF, they turn on and off the high-voltage power MOSFETs via a gate-driver transformer. In center-tapped synchronous rectification stages they are directly attached to the low-voltage MOSFETs. Gate drivers such as the 1EDN7550B and the 1EDN8550B provide sufficient robustness against GND shifts commonly present in large single-layer PCB designs as well as applications where the mechanical design requirements translate into large distances between the PWM controller IC and the gate-driver IC. **Hubert Baierl, Senior Marketing Manager, Infineon Technologies AG, Germany**

The input signal levels of conventional low-side gate-driver ICs in a typical SMPS (Figure 1) are referenced to the ground potential of the gate driver IC. False triggering of the gate-driver IC can occur if its ground potential shifts too far away from the ground potential of the controller IC. This can compromise the performance of the SMPS up to the level that half-bridge shoot-through occurs and the connected power MOSFETs are subject to functional disintegration due to electrical overstress.

Hard switching challenges

In hard-switching topologies such Boost-PFC and TTF stages, the parasitic inductances in the source contact of the power MOSFETs and in the ground-path of the PCB require special attention. Hard-switching goes hand in hand with high di/dt, which in turn leads to switching noise on the ground potential. This switching noise is a high voltage oscillation ranging between 50 MHz and 120 MHz, with amplitudes as high as up to ± 70 V. It is a prominent root-cause for transient shifts of the ground potential between the controller IC and the gate-driver IC. The higher the power rating of the SMPS the more pronounced tends this effect to be. Furthermore, if printed circuit board designs are not optimal due to cost constraints and industrial design requirements the situation can become

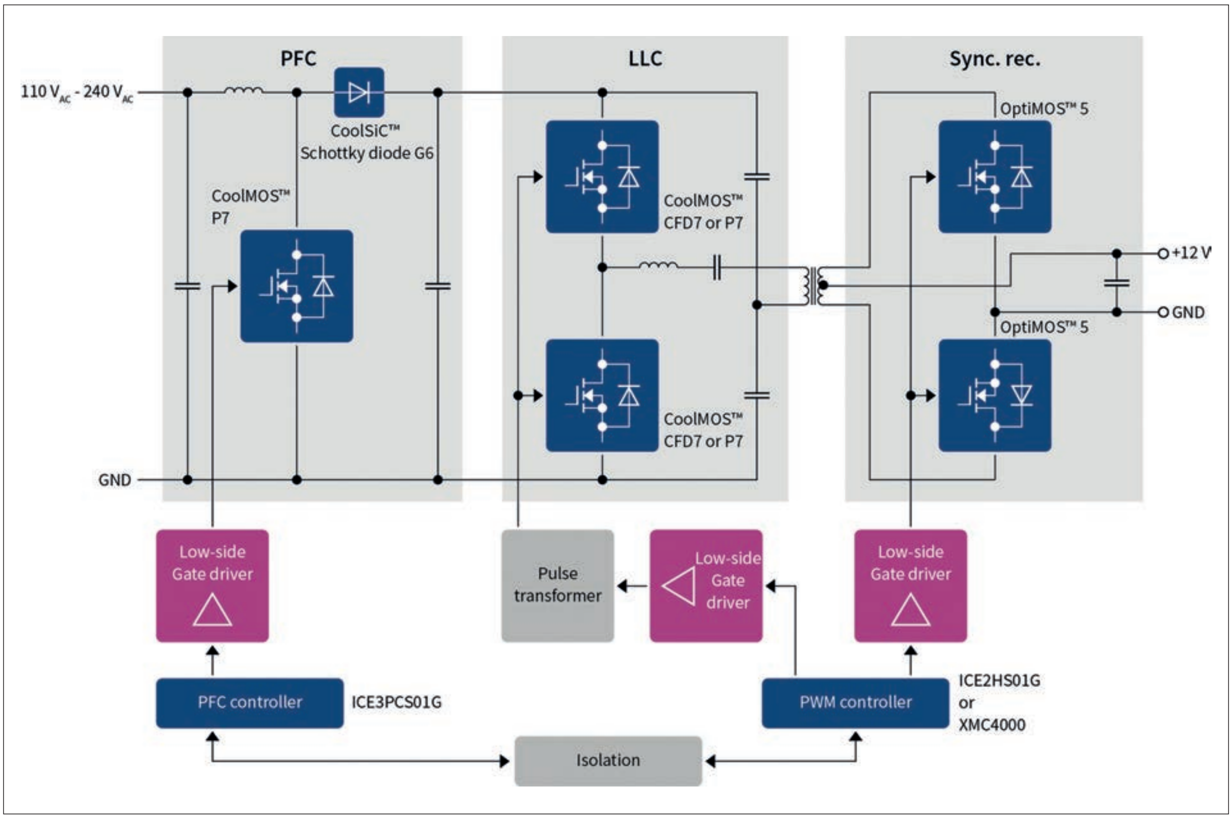


Figure 1: **Block diagram of a typical 800 W SMPS**

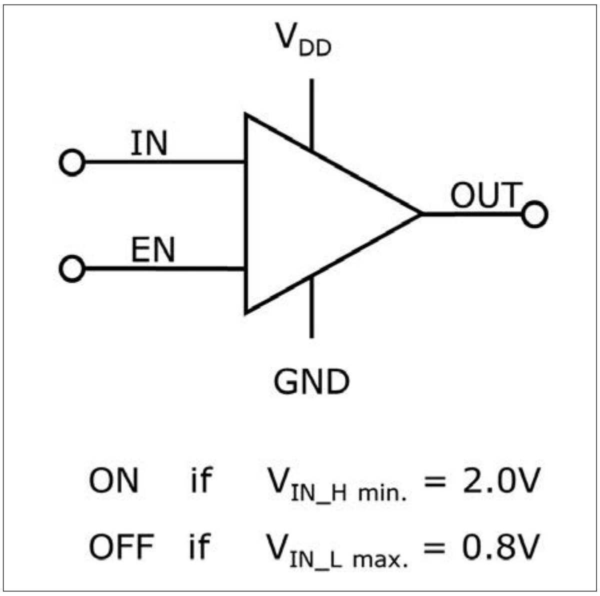


Figure 2: **Conventional low-side gate driver IC, inputs are referenced to the gate driver GND**

even more aggravated.

Solving this challenge is complex. Ultimately, the lower the parasitic ground inductances in the power loop the lower will be the induced ground oscillations and the lower the risk of false triggers. To keep the undesired ground shift as low as possible, designers have a few options. They can keep the dynamic gate-loop within a minimum physical PCB area and use in the PCB separate GND traces to provide a current path with the least possible inductance. Other solutions include designing gate driver output traces that are as wide as possible, using lead-less power MOSFETs or using power MOSFETs with a separate Kelvin Source connection to reduce the effects of the hard-switching impact on the gate-driving circuitry. All of these design solutions work, but may add complexity and significantly increase the design cost.

Conventional low-side gate-driver ICs are prone to false triggering

In a conventional low-side gate-driver IC, the interpretation of the control- and enable-input signals is always done through a comparison which is referenced to the ground potential of that gate-driver IC. In the example shown in Figure 2, the input is understood to be logically OFF as long as the input signal is not higher than 0.8 V relative to the ground. Conversely, if the input signal-level is at least 2.0 V higher than the ground potential then that input is logically ON.

To better understand the problem that arises if the gate-driver IC's GND-potential shifts, consider that the gate-driver inputs are typically connected to a controller IC. From an electrical design perspective, the controller IC is on a more stable ground potential then the gate-driver IC's ground. In some designs the situation is worsen if the ground contact of the gate-driver IC is far away from the ground contact of the controller IC. This can happen, for example, when the controller IC resides on a daughter board which is inserted onto the main power-PCB.

Figure 3a shows a Boost-PFC using a power-MOSFET with a Kelvin Source contact. A galvanically isolated gate-driver IC is used to decouple the two ground potentials, i. e. that of the controller IC and the gate-driver IC input side (GND1) from that at the gate-driver IC output side (GND2). This is called "cutting the ground loop".

In circuitries as shown in Figure 3a, the

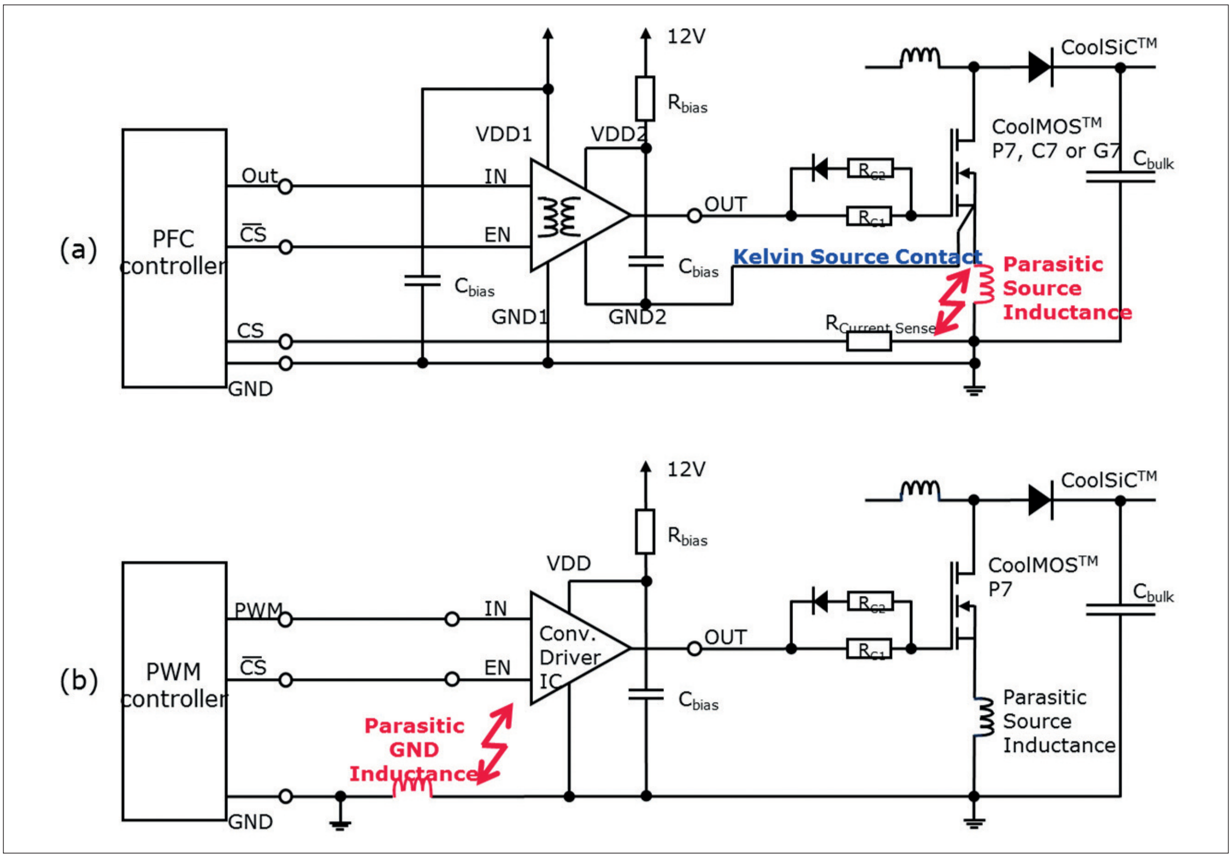


Figure 3: **Kelvin Source power MOSFET driven by galvanically isolated gate-driver IC to cut the ground loop (a) and parasitic ground inductance example (b)**

Kelvin Source contact is used to reduce the impact of the parasitic source inductance of the power MOSFET onto the gate-driver IC ground potential. Measurements of such topologies show that the oscillations between the PWM controller IC ground and the gate-driver IC GND2 can still amount to as much as ± 60 V.

In low-power SMPS, highest performance is not always the prime objective. In many cases, mechanical design requirements as well as component and PCB cost tend to be the overriding considerations. Such constraints can lead to SMPS designs with longer than desired distances between the gate-driver IC and the controller IC. This may force the designer to use single layer PCBs and preclude the use of isolated gate-driver ICs. Under such circumstances, high parasitic ground inductances are a frequent result (Figure 3b). In such applications, switching the power MOSFET can easily lead to a dynamic ground shift between the PWM controller IC and the gate-driver IC of up to ± 20 V.

Low-side gate-driver IC with truly differential inputs resolves GND shift problems

If a gate-driver IC has truly differential inputs, its control signals are largely independent from the ground potential of that IC. Only the voltage difference between its input contacts is of relevance to turn its output ON or OFF. For example, if the potential of V_{in+} is higher than the potential of V_{in-} by 1.8 V this is interpreted as a logical ON. If the difference is less than 1.5 V this is interpreted as a logical OFF.

The 1EDN7550B and 1EDN8550B EiceDRIVER™ from Infineon are single-channel low-side gate driver ICs that can resolve static GND shift problems of up to ± 70 V. If the ground shift is transient, which is typical for MOSFET switching induced ground noise, these gate-driver ICs are robust against shifts of as much as ± 150 V_{peak}. This can be referred to as static and dynamic common mode immunity of the gate-driver IC's control inputs.

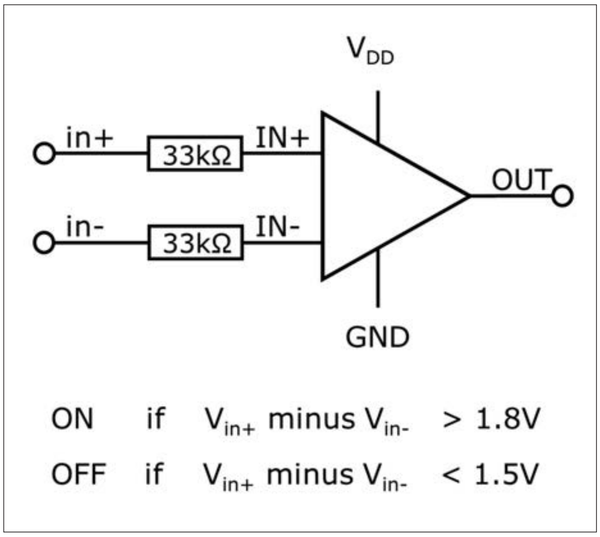


Figure 4: Low-side gate driver IC with truly differential inputs; inputs are independent from the gate driver GND

As these gate-driver ICs operation is based on the voltage difference between its two inputs, the most important design rule is to place two common mode resistors physically close to the two input contacts of the gate driver ICs. That layout has to be done geometrically and parasitically symmetrical. The output pinout arrangement and the VDD pin are in line with commonly used single-channel low-side gate driver ICs. Therefore, when up-grading existing designs with the 1EDN7550 or the 1EDN8550 only the input side of the PCB design must be modified.

The 1EDN7550B and 1EDN8550B EiceDRIVER have a small 6-pin SOT-23 package. This helps improving power density, relative to using galvanically isolated gate-driver ICs. A second advantage that comes along with this package type is that designers can place these gate-driver ICs in the most optimal location relative to the power MOSFET gate connection.

Conclusion

Low-side gate-driver ICs with truly differential control inputs, such as the 1EDN7550B or 1EDN8550B from Infineon, can withstand common mode ground shifts of up to ± 70 V statically and ± 150 V_{peak} dynamically (both are operational range values, applicable if PCB layout recommendations are followed). With the 1EDN7550B and the 1EDN8550B, it is possible to use a single-channel low-side gate-driver IC to drive Kelvin Source power MOSFETs such as CoolMOS P7, C7, or G7 in applications like 2.5 kW Boost-PFCs. There is no need to cut the ground loop with a galvanically isolated gate-driver IC. As has been shown, the 1EDN7550B and the 1EDN8550B provide sufficient robustness against GND shifts commonly present in large single-layer PCB designs as well as applications where the mechanical design requirements translate into large distances between the PWM controller IC and the gate-driver IC.

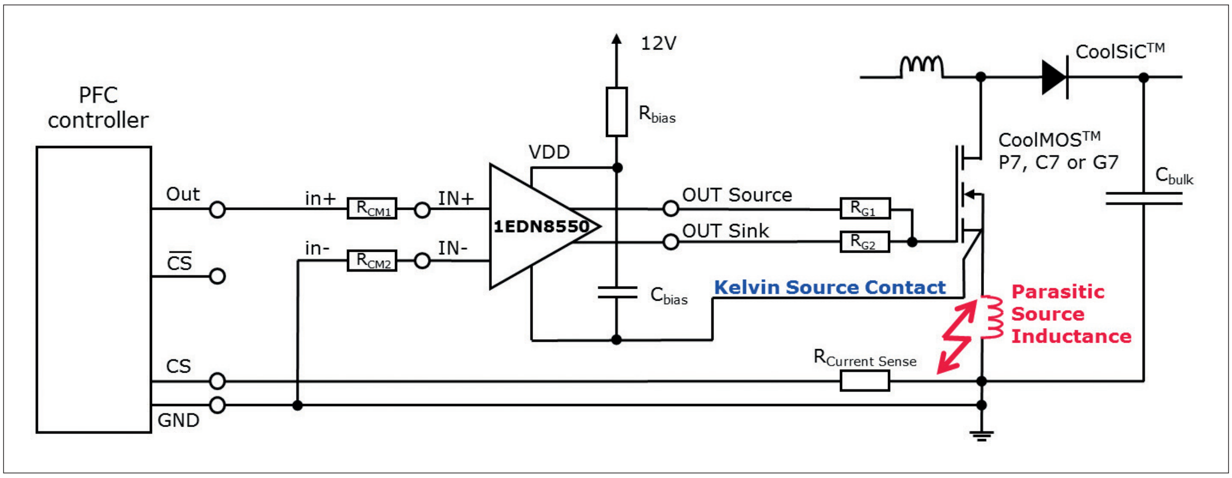


Figure 5: Kelvin Source power MOSFET driven by a gate-driver IC with truly differential control inputs

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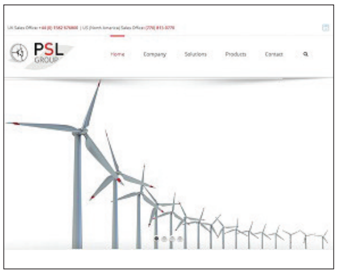

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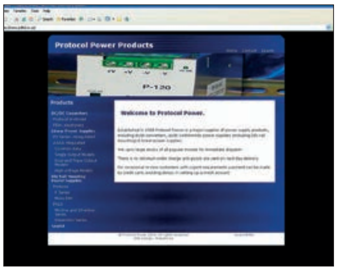

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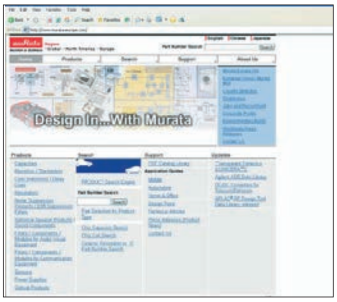

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