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AUTOMOTIVE POWER

Powering the Future of Autonomous Driving

THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

Also inside this issue

Editor Achim Scharf
Tel: +49 (0)892865 9794
Fax: +49 (0)892800 132
Email: PowerElectronicsEurope@t-online.de

Production Editor Chris Davis
Tel: +44 (0)1732 370340

Financial Manager Clare Jackson
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034

Reader/Circulation Enquiries
Perception
Tel: +44 (0) 1825 701520
Email: dfamedia@dmags.co.uk

INTERNATIONAL SALES OFFICES
Mainland Europe:
Victoria Hufmann, Norbert Hufmann
Tel: +49 911 9397 643 Fax: +49 911 9397 6459
Email: pee@hufmann.info

Armin Wezel
phone: +49 (0)30 52689192
mobile: +49 (0)172 767 8499
Email: armin@eurokom-media.d

Eastern US
Karen C Smith-Kernc
email: KarenKCS@aol.com
Western US and Canada
Alan A Kernc
Tel: +1 717 397 7100
Fax: +1 717 397 7800
email: AlanKCS@aol.com

Italy
Ferruccio Silvera
Tel: +39 022 846 716 Email: ferruccio@silvera.it

Japan:
Yoshinori Ikeda,
Pacific Business Inc
Tel: 81-(0)3-3661-6138
Fax: 81-(0)3-3661-6139
Email: pbi2010@gol.com

Taiwan
Prisco Ind. Service Corp.
Tel: 886 2 2322 5266 Fax: 886 2 2322 2205

Publisher & UK Sales Ian Atkinson
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034
Email: ian@dfamedia.co.uk
www.power-mag.com

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Editorial information should be sent to The Editor, **Power Electronics Europe**, PO Box 340131, 80098 Munich, Germany.

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COVER STORY

Powering the Future of Autonomous Driving

Analog Devices announced mid July a collaboration with First Sensor AG to develop products aimed at speeding the launch of autonomous sensing technology serving unmanned automotive, aerial and underwater vehicles in transportation, smart agriculture, industrial manufacturing and other industries. According to the auto industry, there are two standard terms for this transition: an evolutionary one where existing cars get there little by little (analogous to Tesla's autopilot feature) and a revolutionary one where we have totally self-driving cars (like the ones Google are working on). It is unclear at either path will succeed by itself, but it will more likely end up being a symbiotic amalgamation of the two. The car makers and high tech auto systems providers will need to closely collaborate with each other so as to ensure that light detection, LIDAR, radar sensors, GPS, and cameras all work cohesively together. LIDAR is a key pillar of Analog Devices' holistic Drive360™ Autonomous Driving Solutions strategy. LIDAR utilizes pulses of light to translate the physical world into 3D digital images in real time with a high level of confidence. How power electronics can pave the route to self-driving cars explains Tony Armstrong, product marketing director for Analog Devices' Power by Linear product group. More details on page 21.

Tap into the world of automation

Every day, *Drives & Controls*' Web site attracts hundreds of visitors from around the globe, eager to find out what's happening in the world of automation and motion engineering. The site's viewing figures often exceed 1,000 pages per day.

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Towards a Greener World

Electricity demand is set to increase 62 %, resulting in global generating capacity almost tripling between 2018 and 2050. This will attract $13.3 trillion in new investment, of which wind will take $5.3 trillion and solar $4.2 trillion. In addition to the spending on new generating plants, $840 billion will go to batteries and $11.4 trillion to grid expansion. Europe will decarbonize its grid the fastest with 92 % of its electricity supplied by renewables in 2050. Major Western European economies in particular are already on a trajectory to significantly decarbonize thanks to carbon pricing and strong policy support. The US, with its abundance of low-priced natural gas, and China, with its modern fleet of coal-fired plants, follow at a slower pace. The outlook for global emissions and keeping temperature increases to 2°C or less is mixed. On the one hand, the build-out of solar, wind and batteries will put the world on a path that is compatible with these objectives at least until 2030. One reason is that wind and solar will be capable of reaching 80 % of the electricity generation mix in a number of countries by mid-century, with the help of batteries, but going beyond that will be difficult and will require other technologies to play a part – with nuclear, biogas-to-power, green hydrogen-to-power and carbon capture and storage among the contenders.

WBG semiconductors hold great promise to significantly outperform and eventually replace traditional Si-based Power Electronics. While there are research and development efforts in various WBG semiconductors. Including GaAs, diamond, aluminum nitride, and gallium oxide. that could be used in advanced PE, SiC and GaN have currently reached a level of maturity that allows use in PE applications. Prices for SiC and GaN devices have been falling rapidly in the last few years, helping fuel recent market growth. SiC MOSFET prices dropped 50 % between 2012 and 2015. Though prices rose in 2017 due to wafer supply shortages, a growing number of wafer suppliers and improved wafer performance should allow prices to stabilize by 2019 and then continue falling for the foreseeable future. This increasing cost competitiveness has already helped SiC begin to dislodge Si in some applications (e.g., hybrid vehicles) and has enabled mass production of GaN-based end products (mainly in server and telecom rectifier power supplies). In addition, leading manufacturers now have trillions of hours of field device experience to assuage any reliability concerns that might dampen growth.

In the EV/HEV market's case, tough CO2 targets are pushing automotive OEMs towards high electrification levels in their new vehicle fleets. This market is expected to be the main driver for new technology developments, and many supply chain movements are expected over the next few years. Indeed, the inverter market for EV/HEV is expected grow at an impressive CAGR 2018-2024 of 20 %, despite constantly changing subventions. On the other hand, the rail market is slowly increasing despite it is a very volatile market, depending directly on government subsidies that might change over a short period.

The EV/HEV charging infrastructure is growing briskly to anticipate rapid EV market growth, and Yole expects that the inverter market for charging infrastructure will grow at a CAGR 2018-2014 of 20 %. The implementation of charging points must be gradually linked to EV growth, enough to sustain electric car deployment but not too big where it might negatively impact the charging segment. Another growing segment with EV/HEV is renewables, originating from the green energy demand for eco-friendly driving. Also, the grid infrastructure must be properly allocated to allow enough energy to reach all charging stations, including those located far from cities, including highways and rural towns.

Today's rechargeable Li-ion battery technology still has room for improvement, but not enough to significantly improve e.g. the range and autonomy of electrical vehicles. Therefore, researchers are working to replace the wet electrolyte with a solid material, which provides a platform to further increase the energy density of the cell beyond that of cells based on liquid electrolyte. The solid nanocomposite electrolyte that Imec has developed has an exceptionally high conductivity of up to 10 mS/cm with a potential for even higher conductivities. A distinguishing feature is that it is applied as a liquid – via wet chemical coating – and only afterwards converted into a solid when it is already in place in the electrodes. That way it is suited to be casted into dense powder electrodes where it fills all cavities and makes maximum contact, just as a liquid electrolyte does.

Regarding power semiconductors the European project Power2Power has recently started. Over the coming three years, 43 partners from eight countries will research and develop innovative power semiconductors with more power density and energy efficiency. The volume of the Power2Power project will be approximately €74 million. The European Union is funding the cooperation within the scope of the ECSEL (Electronic Components and Systems for European Leadership) program. The European semiconductor industry employs several hundred thousand people. But in its technology-related user industry, it has a much greater leverage effect,as outlined above.

More on that in this issue – enjoy reading!

Achim Scharf
PEE Editor

Low-Cost Renewables and Batteries to Attract $10 trillion to 2050

Deep declines in wind, solar and battery technology costs will result in a grid nearly half-powered by the two fast-growing renewable energy sources by 2050, according to BloombergNEF (BNEF). In its New Energy Outlook 2019 (NEO), BNEF sees these technologies ensuring that – at least until 2030 – the power sector contributes its share toward keeping global temperatures from rising more than 2°C.

Electricity demand is set to increase 62 %, resulting in global generating capacity almost tripling between 2018 and 2050. This will attract $13.3 trillion in new investment, of which wind will take $5.3 trillion and solar $4.2 trillion. In addition to the spending on new generating plants, $840 billion will go to batteries and $11.4 trillion to grid expansion.

NEO starts by analyzing technology trends and fuel prices to build a least cost view of the changing electricity sector. The results show coal's role in the global power mix falling from 37 % today to 12 % by 2050 while oil as a power-generating source is virtually eliminated. Wind and solar grow from 7 % of generation today to 48 % by 2050. The contributions of hydro, natural gas, and nuclear remain roughly level on a percentage basis. "Our power system analysis reinforces a key message from previous New Energy Outlooks – that solar photovoltaic modules, wind turbines and lithium-ion batteries are set to continue on aggressive cost reduction curves, of 28 %, 14 % and 18 % respectively for every doubling in global installed capacity. By 2030, the energy generated or stored and dispatched by these three technologies will undercut electricity generated by existing coal and gas plants almost everywhere," said Matthias Kimmel, NEO 2019 lead analyst.Europe will decarbonize its grid the fastest with 92 % of its electricity supplied by renewables in 2050. Major Western European economies in particular are already on a trajectory to significantly decarbonize thanks to carbon pricing and strong policy support. The US, with its abundance of low-priced natural gas, and China, with its modern fleet of coal-fired plants, follow at a slower pace.

China sees its power sector emissions peaking in 2026, and then falling by more than half in the next 20 years. Asia's electricity demand will more than double to 2050. At $5.8 trillion, the whole Asia Pacific region will account for almost half of all new capital spent globally to meet that rising demand. China and India together are a $4.3 trillion investment opportunity. The US will see $1.1 trillion invested in new power capacity, with renewables more than doubling its generation share, to 43 % in 2050.

The outlook for global emissions and keeping temperature increases to 2°C or less is mixed, according to this year's NEO. On the one hand, the build-out of solar, wind and batteries will put the world on a path that is compatible with these objectives at least until 2030. One reason is that wind and solar will be capable of reaching 80% of the electricity generation mix in a number of countries by mid-century, with the help of batteries, but going beyond that will be difficult and will require other technologies to play a part – with nuclear, biogas-to-power, green hydrogen-to-power and carbon capture and storage among the contenders.

In NEO 2019, BNEF for the first time considers 100 % electrification of road transport and the heating of residential buildings, leading to a significant expansion of power generation's role. Under such this projection, overall electricity demand would grow by a quarter compared to a future in which road transport and residential heat only electrify as far as assumed in the main NEO scenario. Total generation capacity in 2050 would have to be three times the size of what is installed today. Overall, electrifying heat and transport would lower economy-wide emissions, saving 126 Gt CO2 between 2018 and 2050

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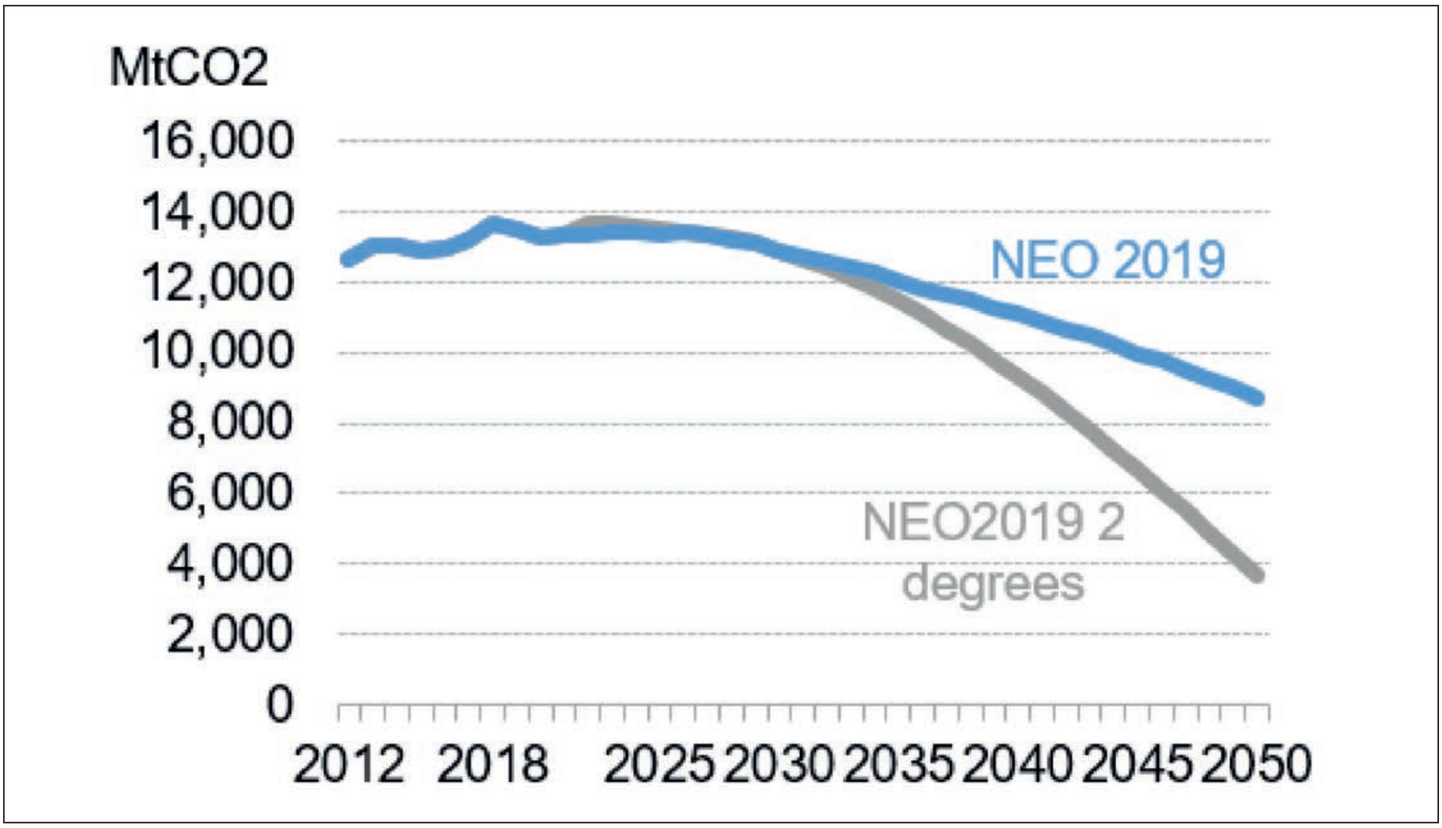
https://about.bnef.com/



Global power sector CO2 emissions

Power2Power for More Efficient Power Semiconductors

The European cooperation project Power2Power has recently started. Over the coming three years, 43 partners from eight countries will research and develop innovative power semiconductors with more power density and energy efficiency.

The volume of the Power2Power project will be approximately €74 million. Two thirds of this will be allotted to the German partners. The European Union is funding the cooperation within the scope of the ECSEL (Electronic Components and Systems for European Leadership) program. Funding from Germany will be provided by the Federal Ministry of Education and Research and from the two states of Saxony and Thuringia. The partners from the other seven countries are also being sponsored by their national authorities. "Collaboration across different levels of the supply chain is a basis for the success of the European microelectronics industry," said Infineon's CEO Reinhard Ploss. "We are also pursuing this approach in the Power2Power cooperation project. In collaboration with our partners, we will be working on new power semiconductors and system architectures with higher energy efficiency. Our goal is: more power from less energy."

The European semiconductor industry employs several hundred thousand people. But in its technology-related user industry, it has a much greater leverage effect. "An important focus is the booming market for power electronics," said Bert De Colvenaer, Executive Director ECSEL Joint Undertaking. "With regard to the global competition – especially from Asia – Power2Power will help increase the manufacturing share of European companies on the world market and further strengthen its leading positions." In Germany in particular, the Power2Power project will help extend the competitiveness of semiconductor production. The supply chain for power semiconductors is especially extensive, which is also evident in this this project: from special Silicon wafers (Siltronic), to IGBT production at Infineon in Dresden and subsequent module production in Warstein, to systems and the associated knowledge, for example from the SMEs EAAT and AVL and from Dresden University of Technology. On several supply chain levels, the Power2Power partners will develop pilot lines at German sites to produce innovative power electronics that are fit for the future.

www.infineon.com/power2power

Power America Focuses on WBG

WBG semiconductors hold great promise to significantly outperform and eventually replace traditional Si-based Power Electronics (PE). While there are research and development efforts in various WBG semiconductors. Including GaAs, diamond, aluminum nitride, and gallium oxide. that could be used in advanced PE, SiC and GaN have currently reached a level of maturity that allows use in PE applications.

Prices for SiC and GaN devices have been falling rapidly in the last few years, helping fuel recent market growth. SiC MOSFET prices dropped 50 % between 2012 and 2015 (according to IHS Markit. Though prices rose in 2017 due to wafer supply shortages, a growing number of wafer suppliers and improved wafer performance should allow prices to stabilize by 2019 and then continue falling for the foreseeable future. This increasing cost competitiveness has already helped SiC begin to dislodge Si in some applications (e.g., hybrid vehicles) and has enabled mass production of GaN-based end products (mainly in server and telecom rectifier power supplies). In addition, leading manufacturers now have trillions of hours of field device experience to assuage any reliability concerns that might dampen growth.

A recent study by IHS Markit projects annual SiC revenues will reach $10 billion by 2027, with hybrid and electric vehicles making up the vast majority of sales. Annual GaN revenues are projected to top $1.7 billion over the same timeframe, with power supplies, hybrid and electric vehicles, and military and aerospace applications holding the largest shares. In comparison, revenues for SiC and GaN combined were only $210 million in 2015. Across these applications, discrete power devices would account for most of the growth as they are expected to take off faster than power modules and integrated circuits.

A separate forecast from Cree Inc. also predicts EVs will present a tremendous growth opportunity for WBG materials, particularly SiC. To date, automakers have announced plans to spend $150 billion in the EV market. Cree estimates that even modest EV adoption - approximately 10 % of total vehicles sales by 2027 - could result in SiC revenues of $6 billion. The same forecast places the total SiC PE market at over $5 billion by 2022, largely driven by EV adoption but also industrial and telecom applications. For GaN, telecommunications stand out as an opportunity for strong growth. GaN devices support 10 times faster download speeds and better cellular coverage, which can enable the transition to 5G internet service.

The future is bright for WBG PE technologies. SiC and GaN have already proven their technical advantages over Si, and now decreasing prices are also driving adoption. SiC turned a corner in 2016 and GaN growth should shortly follow. For devices within certain voltage ranges, SiC and GaN will be viable options within the next 10 years and should continue to displace Si in the market.

Both SiC- and GaN-based power devices have distinct benefits for specific applications: SiC is generally a stronger candidate for PE above 1.2 kV, while GaN is highly competitive for PE below 1.2 kV. The device voltage range between 650 V and 1.2 kV is a competitive space that can be supported by either SiC or GaN technologies. Compared to Si, SiC-based power devices can operate at higher temperatures with higher thermal conductivity, higher breakdown voltage at lower on-stage resistance, faster switching speed, lower conduction and switching on-state loss, and exceptional radiation hardness. Advantages of GaN-based power devices include higher electron mobility and lower losses at higher frequencies, which can enable smaller devices with increased power density. While WBG technologies offer significant capabilities that can advance PE, industry must overcome numerous challenges including high material and manufacturing costs, reliability perceptions, packaging and performance requirements, and difficulty coordinating efforts across the entire WBG PE ecosystem.

Recent progress against these challenges in automotive applications, PV inverters, and power supplies is encouraging; however, SiC and GaN have not taken off as rapidly in traction applications, industrial motor drives, and wind turbines. Further strides are needed to begin manufacturing these devices at high volumes and competitive costs across the full range of useful applications.

https://poweramericainstitute.org/

Vicor Strenghtens Automotive Business

In 2018, Vicor established a dedicated sales effort to penetrate the automotive market with rapidly expanding 48V "mild hybrid" products. The automotive market is dominated by relatively few global OEMs and "tiers" of well-established suppliers. Penetrating this market will be challenging.

Thus the company has hired Patrick Wadden as VP Global Automotive Business Development, He will be responsible for developing and coordinating Vicor's business in the global automotive market. Prior to this job was leading North American sales in the automotive segment for Integrated Device Technology. "As 48 V based power systems gain traction in hybrid, pure electric, and autonomous driving vehicles, Patrick will lead our initiative to expand the use of our IP in automotive 48 V power systems with a mix of product sales and technology licensing agreements," stated Vicor's CEO Patrizio Vinciarelli. "The number and variety of automobile electronics and accessories is growing, fueling the need for more advanced power components to support these electronics. These systems rely on

Vicor's new VP Global Automotive Business Development Patrick Wadden outlined the company's automotive strategy in Munich multiple battery chemistries and can operate at different voltages, creating the need for a new generation of DC/DC regulators which can support both 12 and 48 V systems."

In the meantime the company goes beyond 48 V to support 800 V+ technology in electric vehicles.

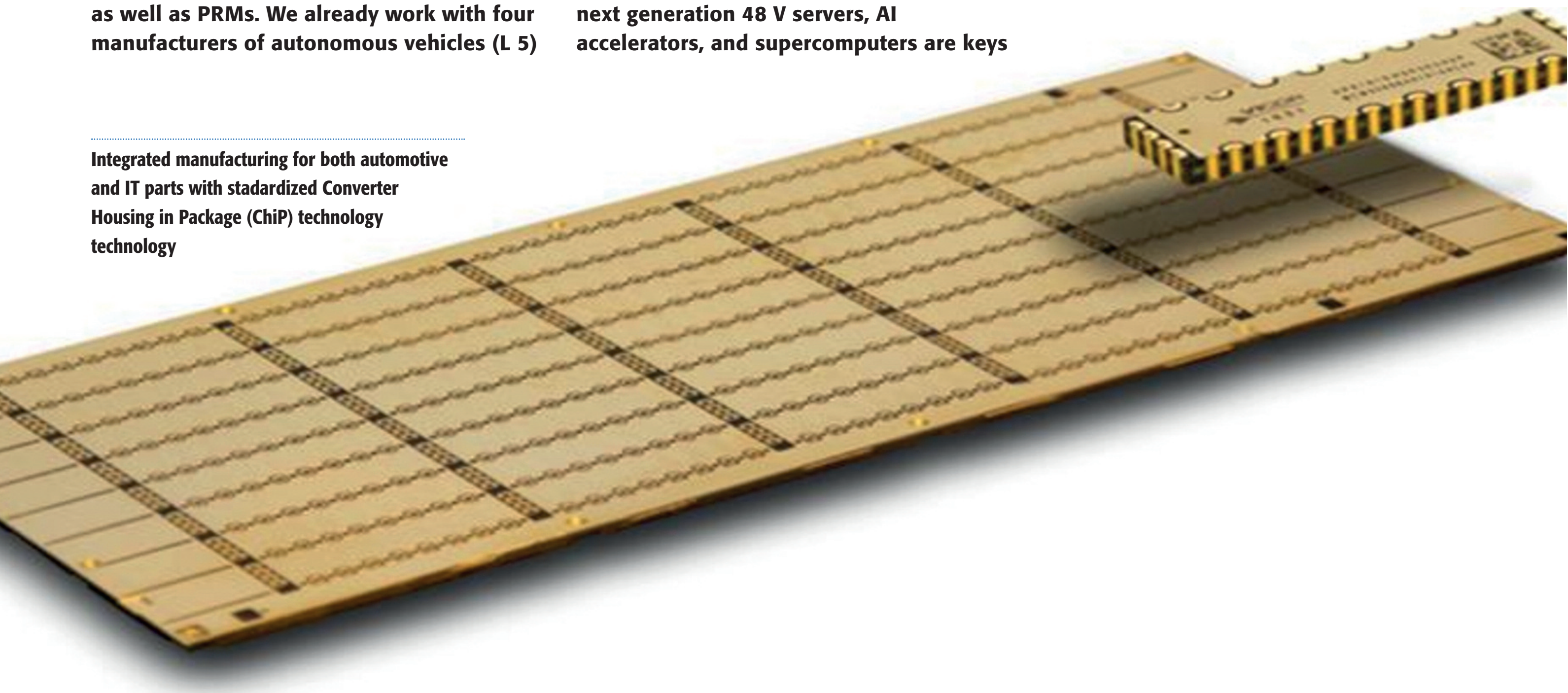
"800 V and 400 V to 48 V conversion provides 48 V native supply for engine coolant pumps, active suspension, chassis systems, or catalytic converter warm up. 48 to 12 V conversion is intended for Start-Stop applications, power for Chassis Systems, power windows, heated seats, or actuators. Routing 48 V to point of load reduce power losses, cable and harness weight, and size. For example, one NBM2317 provides fixed ratio conversion of 48 V and 12 V bidirectional at 800 W. The NMB2317 is one third the size of a conventional non-integrated solution and achieves over 97.5 % efficiency. To achieve this specs we make use of high-frequency switching of around 2 MHz, semiconductor integration, and planar magnetics integrated in 18-layer PCBs. Our upcoming Power Strip contains two BCMs and NBMs as well as PRMs. We already work with four manufacturers of autonomous vehicles (L 5) on 3.6 kW Power Strips, more are pending," Wadden underlined. All of the 800 V as well as the 48 V products for data centers and automotive are manufactued on the same line and differentiated by characterization.

Challenging market conditions

The company needs to address new market segments due to declining revenues. Revenues for the second quarter ended June 30 totaled $63.4 million, a 14.6 % decrease from $74.2 million for the corresponding period a year ago, and a 3.6 % sequential decrease from $65.7 million the first quarter of 2019. Revenues for the six months ended June decreased 7.4 % to $129.1 million from $139.5 million for the corresponding period a year ago. Net income for the six month period was $6.8 million, compared to $11.8 million for the corresponding period a year ago.

"Second quarter financial performance reflected challenges similar to those experienced in the first quarter, as shipment delays requested by contract manufacturers limited revenue from the datacenter market. Growing hyperscale infrastructure spending and design wins for next generation 48 V servers, AI accelerators, and supercomputers are keys to near term revenue growth from Advanced Products. Resolution of the Chinese trade dispute would reopen Chinese order flow which has slowed significantly and undo the impact of inbound tariffs on gross margins. Despite challenging conditions, our outlook is bright. The 12 V to 48 V transition in datacenter and automotive applications is underway and we are winning every demanding AI ASIC application with lateral or vertical Power-on-Package solutions. Our domestic business is healthy, customer design activity with Advanced Products is robust, and our opportunity pipeline across major segments continues to expand. In coming weeks, we expect to close the purchase of land abutting our Andover manufacturing facility to facilitate capacity expansion. Our outlook for the second half reflects steady demand for Brick Products and a resumption of strong demand for Advanced Products from an expanding list of AI applications for which there is no viable competitive alternative," CEO Patrizio Vinciarelli commented.

www.vicorpower.com



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Motor Drives Still Powers Inverter Market

The industrial market depends on the inverter business's leader: motor drives. Millions of inverters for compressors, pumps, and other motors were installed during the last few years, and this trend will continue in the future, reaching a motor drive inverter market of $29 billion by 2024, a new report from market researcher Yole points out. Another growing industrial inverter market is the UPS business, resulting in a growth of 5.6 % from 2018-2024.

Electrical power-conversion optimization is driven by different factors: for example, electrification trends in transportation, CO_2 emission reduction goals, the development of clean electricity sources, and industrialization. The power inverter market follows the big megatrends, and so one could directly link these different markets' growth with the inverter market's dynamics.

Yole differentiates between two business types: transport (EV/HEV and rail) and energy (wind, photovoltaics (PV), electricity grid, and charging infrastructure) segments, which are often linked to big projects dependent on subsidies and political/governmental decisions; and industrial segments (UPS and motor drives), which are less volatile and more linked to electrification.

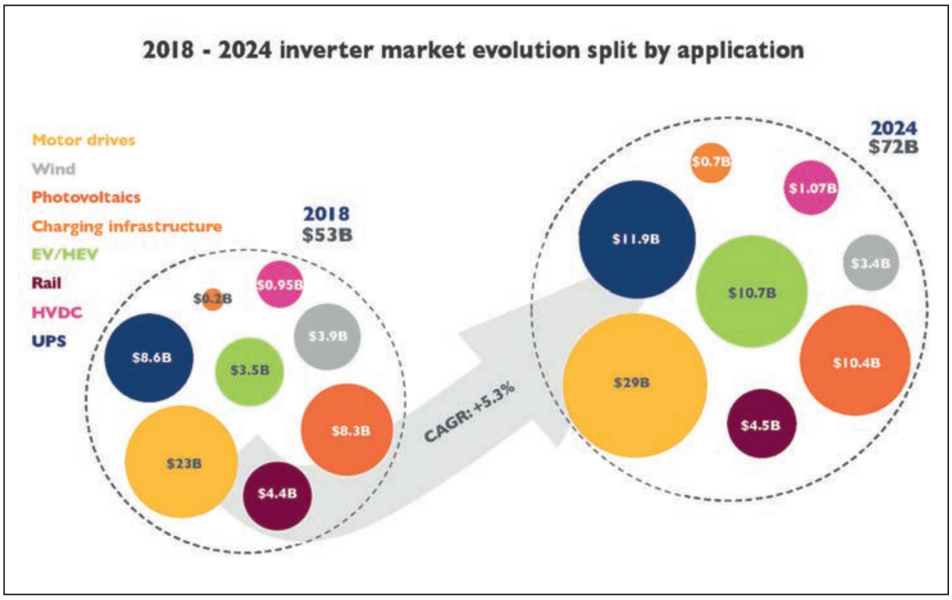
In the EV/HEV market's case, tough CO2 targets are pushing automotive OEMs towards high electrification levels in their new vehicle fleets. This market is expected to be the main driver for new technology developments, and many supply chain movements are expected over the next few years. Indeed, the inverter market for EV/HEV is expected grow at an impressive CAGR 2018-2024 of 20 %, despite constantly changing subventions. On the other hand, the rail market is slowly increasing despite it is a very volatile market, depending directly on government subsidies that might change over a short period.

In the energy segment, clean energy sources continue to be championed worldwide. PV installations keep increasing every year (CAGR for the inverter PV market is 3.8 %), even if subsidies in China, the world's largest PV installer, decreased in 2018. The wind market is expected to remain almost steady over the next several years, in number of GWs installed. Meanwhile, the grid segment must continue being deployed, since the world requires more and more energy to be transported efficiently.

The EV/HEV charging infrastructure is growing briskly to anticipate rapid EV market growth, and Yole expects that the inverter market for charging infrastructure will grow at a CAGR 2018-2014 of 20 %. The implementation of charging points must be gradually linked to EV growth, enough to sustain electric car deployment but not too big where it might negatively impact the charging segment. Another growing segment with EV/HEV is renewables, originating from the green energy demand for eco-friendly driving. Also, the grid infrastructure must be properly allocated to allow enough energy to reach all charging stations, including those located far from cities, including highways and rural towns.

Motor drive continues to be the inverter market's largest segment, with about the 50 % of the market. In terms of excellence, EV/HEV will be the driving market for power electronics for the next several years. Many investments and efforts to develop high-quality, high performance inverters are underway.

www.yole.fr



Coping with the EV Surge

125 years after the first practical electric car was developed, the EV market is booming. January 2019 saw the number of EVs sold in the UK increase 110 % from the previous year, and Ireland saw a 500 % growth. Franky So, CTO of solar cell development company Nextgen Nano, expects nanotechnology could facilitate the surging demand for power for EVs.

In January 2019, the Society of Motor Manufacturers and Traders (SMMT) revealed that 1,334 electric cars were sold, a significant increase from 635 in January 2018. Alongside this, registrations of traditional diesel and petrol cars have started to decrease year on year – a promising sign for the UK market. There is a caveat to this, however. One of the concerns around the growth in the EV market has been the pressure new vehicles will add to existing electrical infrastructure. More cars necessitate more charging points, which requires more power from the national electrical grid. By nature, many drivers will choose to recharge their EVs during or following the early evening drivetime period. This is where we encounter problems. The electrical infrastructure is not robust enough to handle a sudden spike in demand, which would lead to power outages and electrical issues like harmonic currents that damage electrical and electronic components. This would have the most significant impact on local infrastructure in areas with a high concentration of EVs.

To mitigate this risk, the UK's energy regulation body, Ofgem, has called for incentives to encourage drivers to charge EVs outside of peak hours. The trouble is, this isn't convenient for drivers. As such, another solution is needed. Nextgen Nano believes the solution is to rethink how EVs can

charge. Instead of just plugging into charging points connected to the grid, charging through solar panels contained on the car itself can be facilitated, which enhances convenience for drivers and complements charging points. This can be achieved using Nextgen Nano's PolyPower organic solar cell technology. PolyPower combines the latest advancements in nanotechnology, biopolymer materials and organic polymer solar cells (PSCs) to offer a robust, flexible, sheet-like photovoltaic product that can be easily incorporated into the design of EVs. Effectively, this technology means that EVs can be decentralized and, as long as there is sufficient sunlight for the cells to harvest, the vehicle's battery can be recharged on-the-go. This complements the existing charging infrastructure, alleviates the strain on the grid and allows EV manufacturers to extend the range of their vehicles.

It's not just the electrical infrastructure that would benefit from this design choice. Consumers get the benefit of recharging becoming a convenient process that fits their lifestyle, while the technology itself has the potential to be low-cost and will therefore keep the price of the vehicle low. Likewise, the technology means that EV manufacturers can produce solar-powered cars that boast much higher ranges than their competitors, at a competitive price. And because solar is a renewable energy source, EV brands can also ensure vehicles can run on entirely sustainable power.

http://nextgen-nano.co.uk/

LEFT: "Our sheet-like photovoltaic product that can be easily incorporated into the design of EVs for charging at sunlight", underlines Franky So, CTO of solar cell development company Nextgen Nano

Imec Doubles Energy Density of Solid-State Batteries

Belgium-based Imec paves the way to long-range electrical vehicles with its announcement of a solid-state Li-metal battery cell with an unsurpassed energy density of 400 Wh/liter at a charging speed of 0.5 C (2 hours). Imec also announced that they have started to upscale the materials and processes in a pilot line for fabrication of solid-state pouch cells at the EnergyVille Campus in Genk (Belgium) and is set-up in collaboration with the University of Hasselt. Its engineering roadmap for solid-state batteries aims to surpass wet Li-ion battery performance and reach 1000Wh/L at 2-3 C by 2024.

Today's rechargeable Li-ion battery technology still has room for improvement, but not enough to significantly improve e.g. the range and autonomy of electrical vehicles. Therefore, researchers are working to replace the wet electrolyte with a solid material, which provides a platform to further increase the energy density of the cell beyond that of cells based on liquid electrolyte. The solid nanocomposite electrolyte that the R&D center has developed has an exceptionally high conductivity of up to 10 mS/cm with a potential for even higher conductivities. A distinguishing feature is that it is applied as a liquid – via wet chemical coating – and only afterwards converted into a solid when it is already in place in the electrodes. That way it is suited to be casted into dense powder electrodes where it fills all cavities and makes maximum contact, just as a liquid electrolyte does.

Also Imec has commenced the upscaling of the cells in a state-of-the-art lab, including a 300 m? battery assembly pilot line which includes a dry room of 100 m?. It is set-up together with the university of Hasselt and allows manufacturing of prototype pouch cells of up to 5Ah capacity. "The new battery demonstrates that our breakthrough electrolyte can be integrated in performant batteries. The pilot-line allows us to take the next step and upscale the battery breakthrough to industrially relevant processes and formats, using manufacturing processes similar to those for wet batteries," said Philippe Vereecken, Scientific Director at Imec/EnergyVille.

www.imec-int.com

A look into Imec's Solid-State Battery lab

New Growth Opportunity for Conductive Pastes

Power electronics is a growing market thanks to electrification of many industries including the automotive industry. The power electronic modulus are also growing in performance. In particular, they are becoming smaller, lighter weight, more tightly integrated, and better able to handle higher power levels. In some cases the semiconductor technology is also shifting from Si IGBT to SiC MOSFET. The dies are shrinking in area and the number of push-pull pairs in the circuit are being reduced. All these translate into higher power densities and higher operating temperatures.

In many cases, the bottleneck today is the material used in the power module package. The aluminium wire bond and the die and substrate attach are common modes of failure. The high operating temperatures push performance requirements beyond the capabilities of solders. This opens the door to alternatives. In particular, metal sintering has emerged as a promising high-performance and high-cost alternative. The most common version is based on micron-sized Ag particles and requires pressured sintering. The trend now is to improve pressure-less sintering which is traditionally constrained to small die areas and suffers from long sintering times. To this end, nano Ag or hybrid (nano and micro) sinter particles are developed. Furthermore, there is today innovation in form factor, going beyond pastes to offer dry films and dips to make it easier for the user to adopt. The metal sintering technology is now qualified in the automotive sector after 5-7 years of development. Cu versions are also in competition. As usual, the promise is the same: offer same or higher performance than Ag whilst cutting costs. The early results are promising but as usual Cu solutions are not a drop-in replacement since their sintering conditions are different. This year and next year will probably be make-or-break years for Cu alternatives as serious testing is well underway.

In general, metal sintering is high performance. The thermal conductivity is high and the melting temperature of a sintered die attach line is comparable to a solid metal, thus offering very high homologous temperatures. The cost however is still a significant barrier. This is both direct material costs and also the associated costs in terms of new equipment, new required surface finishes/metallizations, and so on.

This technology is however now on the move. The number of suppliers has multiplied. Almost all module makers have worked with and prototyped using metal sintering solutions. As such, IDTechEx Research has assessed that the future of this market as highly promising. It analyzed the market needs/requirements, discussed the business dynamics, market leadership and technology change trends, competing solutions, latest product/prototype launches, key players and market forecasts in tonnes and value.

www.IDTechEx.com

Thermal Management Materials Market Doubles

The electronic thermal management materials market share is set to rise from $1.6 billion in 2018 to $3.1 billion by 2025, according to a 2019 Global Market Insights report. The reducing size of consumer electronics is projected to drive the demand for the electronic thermal management materials market during the forecast period. Electronic thermal management materials are extensively used in the electrical assemblies for heat dissipation purposes.

However, the volatility in raw material prices is anticipated to be a major downside to the growth of the market. Additionally, polymer-based thermal management materials pose a major threat to the environment as these products are not readily biodegradable, hence the presence of stringent regulation is anticipated to act as a major restraint throughout the forecast period. In terms of end-user industries, the global electronic thermal management materials market has been segmented into consumer goods, healthcare, automotive, aerospace, telecom and others. Among the aforementioned segments, the consumer goods segment is projected to generate the maximum gains during the review period. The growing product innovation in the global electronics market coupled with augmenting demand from emerging economies is set to positively contribute to the growth of the segment. Automotive, healthcare and telecom are major end-user industries contributing to the growth of the market. The telecom end-user industries are projected to grow at a CAGR of over 8 % during the review period. This growth can be attributed to growing application of thermal management materials in routers, switches, and high-performance servers among others.

Asia Pacific was the major revenue pocket in the global electronic thermal management materials market in 2018 and is estimated to grow at CAGR of over 8 % throughout the forecast timeframe. The presence of major electronic manufacturing countries such as China, Taiwan, Japan and India among others is projected to positively influence market growth. Moreover, the shifting of major manufacturing bases into the region shall also add to the demand for electronic thermal management materials during the given period 2019-2025. Europe and North America are other major regional electronic thermal management materials markets. The presence of large scale automotive and aerospace bases in these regions along with developed consumer electronics industry shall further fuel the electronic thermal management materials market size in these regions.

www.gminsights.com

Diamond for Power Semiconductors

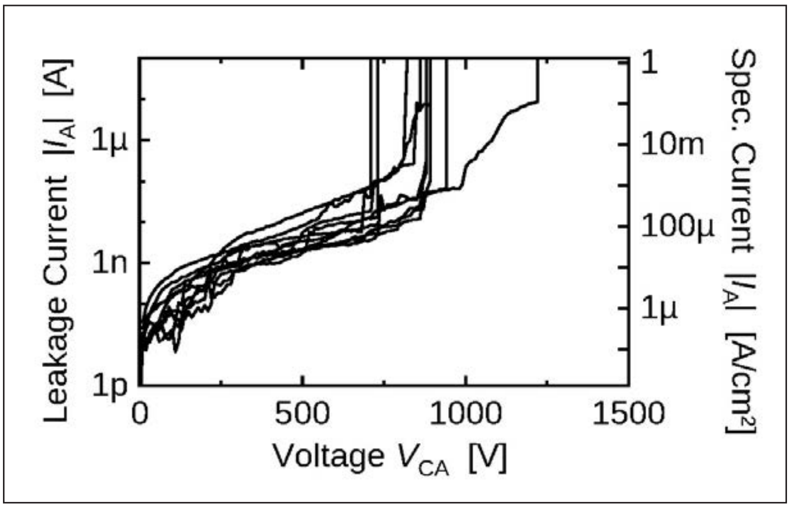
As a representative of the group of semiconductor materials with large bandgaps, the material diamond with its interesting properties is ideal for high-voltage power devices that can be used at elevated temperatures. The high breakdown voltage and outstanding thermal conductivity of diamond enable the development of devices that far exceed the performance of comparable Silicon solutions. Fraunhofer IAF utilizes these properties and uses single crystalline diamond for the development of novel electronic high-performance devices.

The performance demand for power semiconductors is growing significantly, while testing the limits of existing Silicon-based power devices. Power-hungry applications, such as high-performance artificial intelligence (AI) chips, graphical processor unit (GPU) chips, and harsh environment applications, have pushed the semiconductor industry to look beyond SiC and GaN devices because the transistor size decreases to improve computing speed, and the power consumption increases dramatically as well when processing huge amounts of data. In the case of harsh environment applications, such as spacecraft, devices must function effectively at high temperatures, which will be effective when diamond semiconductors are used. Moreover, reports have emerged that indicate diamond-based sensors are being developed to aid the life sciences industry.

Market momentum

According to market researcher Frost & Sullivan (**www.frost.com**), the demand for diamond devices has increased, especially for high-power devices because of their electrical resistivity and heat dissipation capabilities. In addition, several compound semiconductor materials, such as SiC and GaN, have been explored in the past; however, the breakdown voltage of these materials still poses a limitation for high-power applications. Therefore, diamond has been explored because of its superior intrinsic characteristics, such as higher breakdown voltage, electron mobility, and superior thermal conductivity. Furthermore, diamond's breakdown strength is estimated to be at least five times higher than SiC and 15 times higher than Silicon wafers.

Applications that need to operate in extreme conditions include automotive engines, spacecraft, data centers, and defense technologies. High-power radio frequency (RF) electronics are needed in evolving communication technologies as well. Moreover, because diamond-based power devices perform more efficiently and reliably, building greener electronic systems are possible.



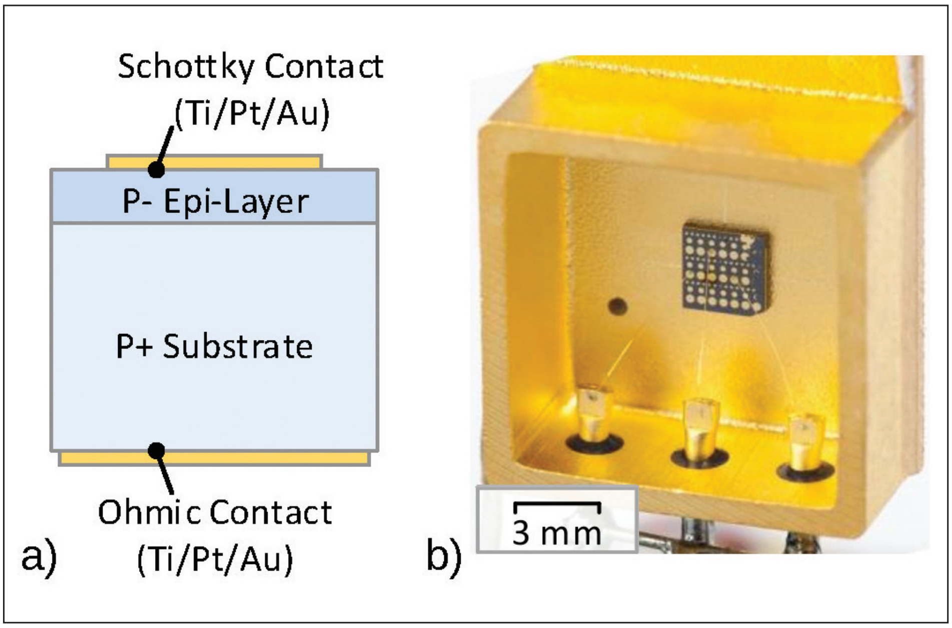
Off-state characteristic measurements at room temperature

Diamond semiconductors' potential is available for power devices partly because of the development of design and processing technologies. For instance, the fin field-effect transistor (FinFET) processing technology can improve the diamond semiconductor's conductivity without the need to add dopants in the channel. On the other hand, researchers are working on the MOSFET by using the deep-depletion of a bulk boron-doped diamond. The research on MOSFET-based devices will enable the production of the simple device structure and improve the magnitude of mobility of charge carriers.

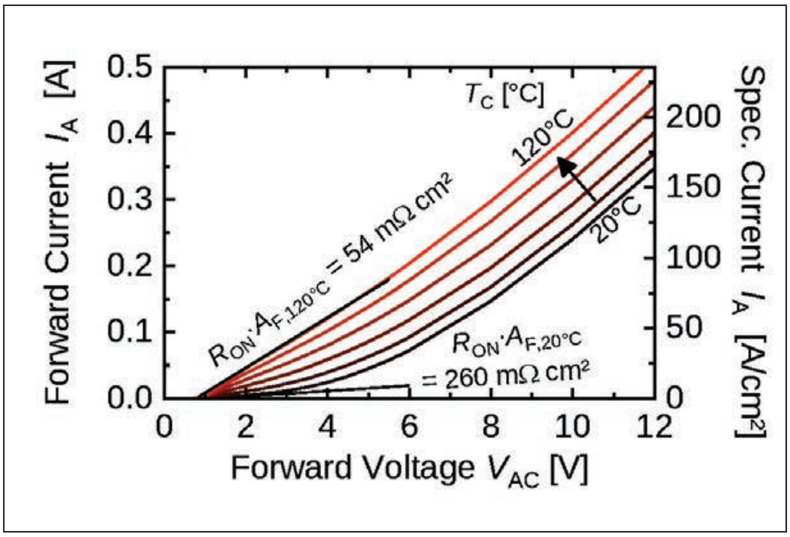
Eventually, the resultant diamond-based device will demonstrate higher-power performance and durability, even under extreme temperatures and other external factors. With advancements in processing technologies, such as epitaxy, selective doping, and lithography, the formation of a diamond-oxide interface for devices such as transistors and diodes will be easier. Because of such developments, diamond semiconductors can achieve high-speed switching as well.

Given all the positive factors, the term diamond semiconductor might sound costly to integrate with electronics; however, the industry is not mining diamonds but artificially growing electronics-grade diamonds. Synthetic diamonds are manufactured by processing methane gas in a microwave plasma chemical vapor deposition (MPCVD) reactor. This process produces a perfect diamond substrate on which active and passive semiconductor devices can be fabricated.

The diamond semiconductor market is in the



Diamond Schottky diode a) schematic cross-section, b) assembled device in a TO247 package



Output characteristics of the packaged Schottky diode at different case temperatures

emerging stage; therefore, the market is witnessing a growth challenge in terms of high investment costs. This cost pressure is in terms of synthetic diamond production as well as the process equipment that supports production. Specifically, the doping of devices to fabricate n-type semiconductors has technical challenges; therefore, several research activities are focused on improving the doping techniques. Researchers believe that breakng the barrier in doping will help realize the full potential of diamond semiconductors. Because using diamond semiconductors is still in the R&D phase, demand is expected to be low in the short term; therefore, an investment surge on fabrication facilities is not expected. As a result, prices will remain high and create an entry barrier for emerging market participants.

According to Frost & Sullivan, diamond-based power semiconductors will enable several mission-critical applications; however, in the current scenario, the market is in the R&D phase, and market participants are working on cost-effective processing technologies to improve performance as well. Eventually, the potential of diamond-based power semiconductors to replace all other existing technologies will be highly dependent on the cost-to-performance ratio rather than on existing technologies. Therefore, the ability of diamond semiconductors to grow into mainstream power semiconductors may not be possible, at least in the near future.

Diamond for a Schottky-diode

At PCIM Europe 2019 the in-circuit operation of a diamond Schottky-diode in a non-isolated buck converter for LED applications at mains voltage was presented by Fraunhofer IAF. Already today, diamond Schottky- and PIN-diodes achieve remarkable performance in static and dynamic measurement setups. However, investigations in power electronic applications are still pending.

For the fabrication of the Schottky-diodes 3×3×0.3 mm³ Iib HPHT diamond substrates of (001)-orientation with boron concentrations of 2×10^{20} cm^{-3} were used as base material. On top of those p+ substrates, p- layers were grown by microwave-enhanced chemical vapor deposition with doping concentrations of around 10^{16} cm^{-3} as characterized by cathode-luminescence and capacitance-voltage measurements of the Schottky contact. The boron doped p- layer has a thickness of about 5.5 µm. Schottky electrodes of Ti/Pt/Au with diameters of 100 µm, 200 µm and 300 µm were realized on top of the p- layer and an ohmic contact using Ti/Pt/Au was formed on the backside of the p+ substrate. The fabricated device is attached with conducting adhesive in a TO247 engineering package. Three of the 300 µm diameter Schottky contacts are connected to the package-pins by Au wire bonds having a diameter of 25 µm. Furthermore, the pins are interconnected in parallel to achieve a total active device area of 0.0021 cm².

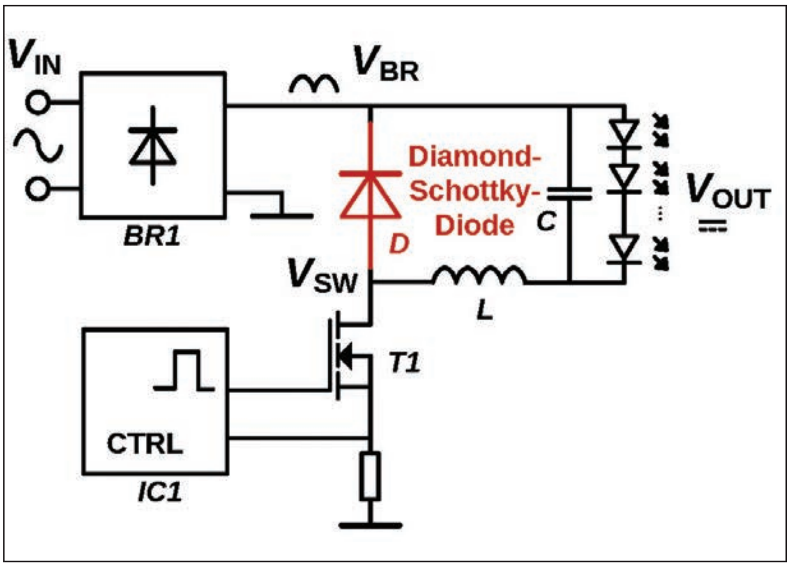
The off-state characteristic was measured on a number of Schottky contacts using a high voltage prober and the leakage currents were detected with a power device analyzer. Arcing between chip surface and chuck is prevented by using a highly insulating inert fluid. Breakdown occurs in the range of 750 V up to a maximum value of 1250 V, and the leakage currents are in the range of nA.

The on-state behavior was characterized on the packaged device under pulsed conditions with a pulse time of 100 µs and different device temperatures. Therefore, the device was mounted on the heat-plate and measured with a source measurement unit. The diodes feature forward voltages in the range of 1 V. The forward resistance is thermally dependent due to thermal generation of holes from deep acceptors with an activation energy of 0.37 eV. The on-state resistance decreases with increasing temperatures from 260 mΩ•cm² at a case temperature of 20°C to a specific on-state value of 54 mΩ•cm² at 120°C.

A demonstrator was developed to investigate the diamond device in continuous converter operation. The device was tested in a non-isolated buck converter for LED-lighting applications. The topology is similar to a double pulse measurement setup. The converter achieves a maximum total efficiency of more than 87 % at an output power of 14 W. In continuous operation, the diode reaches a stable case temperature of 125°C. The negative temperature coefficient reduces the effort for cooling and is beneficial for high temperature applications.

The physical properties of diamond are ideally suited for power electronic devices. Current research aims for the improvement of process and material quality as well as device technology. The fabricated diamond diodes in this work show a promising performance with breakdown voltages up to 1250 V at small diameters, forward currents up to 1 A at an area of 0.0021 cm² and a very low corresponding reverse recovery charge below 1 nC.

"Despite the early development status of this technology, the promising results of this work substantiate the suitability of diamond devices for power electronic applications, though the cost of diamond of 1000 $/cm² on a 2-inch wafer is very high compared to GaN of 100 $/cm²," IAF presenter Stefan Moench concluded. **AS**



Simplified schematic circuit diagram of the non-isolated buck converter

Literature

"Diamond Schottky-Diode in a Non-Isolated Buck Converter", PCIM Europe 2019 Proceedings, pages 212 – 216.

Power Integrations Enters GaN-on-Sapphire Power Applications

Power Integrations recently announced new members of its InnoSwitch™3 families of offline CV/CC flyback switcher ICs. The new ICs feature up to 95 % efficiency across the full load range and up to 100 W in enclosed adapter implementations without requiring a heatsink. This increase in performance is achieved using an internally developed high-voltage GaN switch technology.

Quasi-resonant InnoSwitch3-CP, InnoSwitch3-EP and InnoSwitch3-Pro ICs combine primary, secondary and feedback circuits in a single package. Though size 7 is the lowest on-resistance Silicon MOSFET that will fit in the InSOP-24 package, GaN switches provide even lower on-resistance per unit area and switching losses. Thus GaN transistors are leading the way to "no-heatsink" designs at high power levels. PI's GaN transistor fabrication done at existing Silicon fab partners, and InnoSwitch3 Size 9 and 10 devices use the same assembly and test facilities as Silicon InnoSwitch3 parts.

In the newly GaN switches the Silicon high-voltage transistors are replaced on the primary side of the IC, reducing conduction losses when current is flowing, and considerably reducing switching losses during operation. This results in substantially less wasted energy and therefore increased efficiency and power delivery from the space-saving InSOP-24D package. InnoSwitch 3 ICs are available now, priced at $4/unit in 10,000-piece quantities.

Targeting high-efficiency flyback designs, such as USB-PD and high-current chargers/adapters for mobile devices, set-top boxes, displays, appliances, networking and gaming products, the new ICs provide accurate CV/CC/CP independent of external components, and easily interface to fast-charging protocol ICs. The InnoSwitch3-CP and EP variants are hardware-configurable, while the InnoSwitch3-Pro incorporates a digital interface for software control of CV and CC setpoints, exception handing and safety-mode options.

"GaN is a pivotal technology offering significant efficiency and size benefits over Silicon, thus we anticipate a rapid conversion from Silicon transistors to GaN in many power applications." said PI's CEO Balu Balakrishnan

"GaN transistor technology is the future for power conversion. Our strategy is to enclose and protect the GaN device within our ICs. Engineers see significant performance benefits, but won't otherwise notice a change. We anticipate a rapid conversion in many power applications. InnoSwitch3 has been the clear technology leader in the offline switcher IC market since we launched the Silicon variants 18 months ago, and the new GaN-based ICs extend both the efficiency and power capability of our flyback products," said PI's CEO Balu Balakrishnan, CEO of Power Integrations.

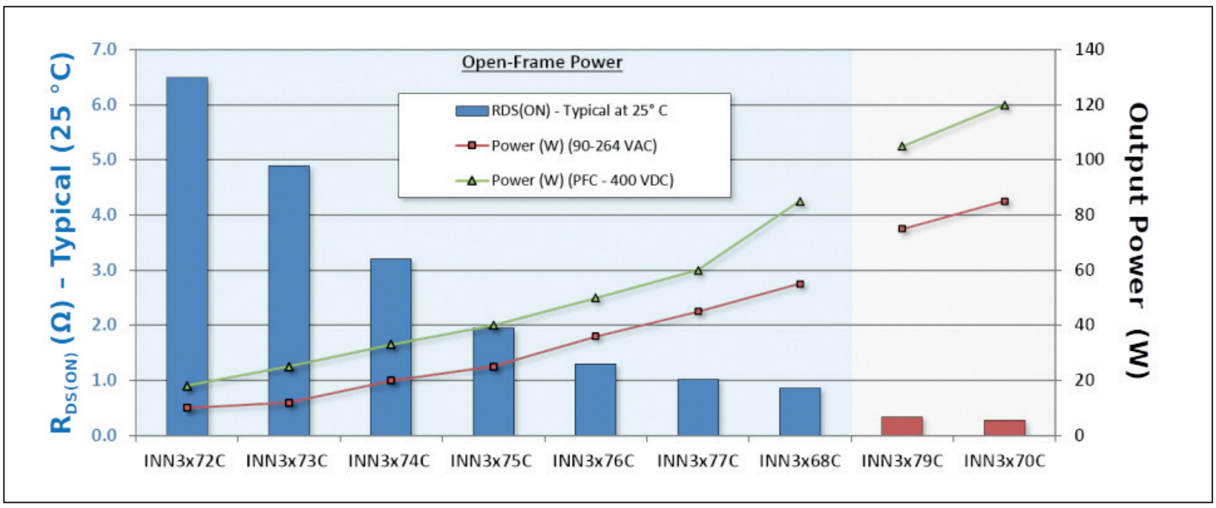
Innoswitch3-GaN in a USB-PD application

An innovative approach

In fact, it is the first GaN-on-Sapphire die that has been integrated in a commercially available device. The die is co-packaged with three ICs constituting primary-side and secondary-side controllers, in the Wall-Charger PowerPort Atom PD1 - A2017 from Anker. "To our great surprise, the power GaN HEMT was processed on a Sapphire substrate which is a major breakthrough that we did not observe before in other power GaN HEMTs, which are generally being processed on Silicon substrates", said Amine Allouche from French System Plus Consulting while performing a teardown analysis at microscopic level of the ICs and HEMT's designs. "Different manufacturers' solutions for GaN die design and packaging integration bring strong competition, which will accelerate technical innovation and lower prices. In turn, lower prices can make GaN devices good competitors to the currently-used Si-based fast-switching power transistors. Wall chargers are the first consumer application that uses GaN devices. The main advantage of moving from Si to GaN is to increase the device's operating frequency and thus decrease the charging time, size and weight of the components."

But it will be interesting to see how PI solves the problem of significant bowing at wafer level, arising from the difference in the temperature expansion coefficients of GaN and Sapphire. For these subjects PI did not disclose any details. AS

www.power.com, www.systemplus.fr



GaN increases InnoSwitch3 efficiency and power

Power Analyzer Accelerate Motor System Testing

The Yokogawa WT1800E Power Analyzer is being used by Atmos UAV to optimize the range, efficiency and safety of Marlyn, the world's first drone, to combine Vertical Take Off and Landing (VTOL) and forward flight in a fully autonomous flight.

Atmos UAV is a Delft (NL) based company specialized in the design and production of high-end aerial surveying and data collection drones that allow professionals to gather geospatial data from the sky. The flagship drone model, Marlyn, has a worldwide unique design that combines the high performance of a conventional fixed-wing aircraft with the flexibility of helicopters. With its patented technology the company targets mapping, construction, mining, agriculture, environmental and related applications. To facilitate the fast growth of the company, Atmos (**www.atmosuav.com**) is currently attracting new talent to expand the team and scale-up the production.

Drone Marlyn is capable of high-speed flight, which typically enables it to survey an area of 12 km^2 in a single flight

Unique drone technology

Like a fixed wing drone, Marlyn is capable of high-speed flight, which typically enables it to survey an area of 12 km^2 in a single flight, while the VTOL capability allows it to be launched from almost anywhere. This superior flying performance means that surveyors can dramatically reduce the required flying time, and thus achieve higher productivity and lower operating costs. Benefiting from the ability to operate safely and reliably in wind speeds up to 45 km/h, Marlyn is being used to survey, map, and gather geospatial data in the mining, agriculture, forestry and construction industries, and by government agencies.

The challenge for Atmos was to select a combination of motor system and propeller which could provide the required thrust in-flight and during take-off and landing, while maintaining a flat and safe power dissipation profile across all the varying load conditions.

By using the Yokogawa WT1800E, Atmos was able to significantly reduce the time required to test combinations of off-the-shelf motors and propellers, and enabled them to find the optimal configurations quickly.

Previous attempts to measure motor/propeller combinations used readings from a temperature sensor as the basis to calculate power dissipation. This was a slow procedure and it was difficult to compare results. By utilizing the WT1800E, which provides up to six measurement channels to enable electrical power measurements of up to six voltages and six currents at a sampling of rate of 2 MS/s, Atmos was able to take measurements at the motor's power supply, the motor drive circuit and at the motor simultaneously. These measurements were used to rapidly calculate power dissipation in the motor drive and the motor. "We performed our first tests without using a power analyzer - it took over four hours to do a test for each single motor drive combination", says Dirk Dokter, Technical Director & Founding Partner of Atmos. "With the power analyzer, the test time fell dramatically. After fine-tuning the power analyzer test set-up, the time to test a single motor fell to just 30 minutes."

"The Marlyn design has exceeded our expectations in terms of reliability. That's not just in normal operation – because of the results from our power dissipation testing, we know that we can produce more thrust without risk of the drive overheating. We have a safety margin over and above what's required in normal operation. That's very important for us, because our name is on the aircraft, and the Atmos brand stands for reliability and performance", Dokter adds.

Advanced power measurements

The WT1800E is a high-performance power analyzser which guarantees a power accuracy of 0.05 % of reading, plus 0.05 % of range. Unlike measuring instruments which are not designed to measure power as their primary function, the power measuring accuracy is specified for all factors such as power factor, crest factor, phase angle error, temperature range, warm-up time, stability period and common mode rejection. The high levels of stability also mean that measurements are consistent when repeated over the lifetime of the instrument.

The WT1800E was developed to be flexible enough to provide engineers with accurate and reliable power measurements for applications as demanding as the manufacture of energy efficient devices and appliances, plug-in hybrid/electric vehicles, lighting, aircraft and for renewable energy technologies. With one to six channels and the capability to measure harmonics up to the 500th order, it is suited for comparisons of the input and output of three-phase systems, such as motors, inverters, actuators, energy recovery systems and generators and other applications requiring multiple input channels.

Providing GP-IB, USB and Ethernet Modbus/TCP connections and a web server, the WT1800E also gives engineers a comprehensive tool for power analysis which may easily be integrated with design or production software tool suites.

Literature

"Next Generation of Precision Power Analyzer for Drive and EV Technology", Power Electronics Europe 2-2019. pages 37 – 40

BELOW: WT1800E power analyzser which guarantees a power accuracy of 0.05 % of reading plus 0.05 % of range

Powering the Future of Autonomous Driving

Analog Devices announced mid July a collaboration with First Sensor AG to develop products aimed at speeding the launch of autonomous sensing technology serving unmanned automotive, aerial and underwater vehicles in transportation, smart agriculture, industrial manufacturing and other industries. How power electronics can pave the route to self-driving cars explains **Tony Armstrong, product marketing director for Analog Devices' Power by Linear product group, USA**

As part of the collaboration, Analog Devices and First Sensor are developing offerings that shrink the LIDAR (light detection and ranging) signal chain to enable higher system performance as well as reduce size, weight, power and cost for manufacturers designing sensing and perception technology into their autonomous safety systems. The companies also plan to develop other LIDAR products that will serve automotive and industrial manufacturing applications.

LIDAR (see Figure 1) is growing in importance in automotive. It is one of the primary perception sensors in today's robo-taxi test vehicles. Additionally, LIDAR systems have appeared in high end luxury retail cars such as the Audi A8, where a short range system is used in a semi-autonomous driving function limited to speeds up to 60 km/h. Cars with autonomous or semi-autonomous driving functions will require a multiplicity of perception sensors to have adequate redundancy in the sensor types for safe operation. The main perception sensors today are cameras, with radar now becoming more ubiquitous and lidar coming in the near future. Cameras have the lowest cost and are already widely deployed in cars. The range of camera systems is limited, particularly in bad weather. Radars are ramping up in volume in mass market automotive and they are robust against weather out to ranges greater than 200 meters. Assuming that a minimum of two sensor modalities are required to enable autonomous modes of driving, then it is likely that LIDAR will be an important and necessary sensor to accompany radar for long-range sensing. In addition to its higher base cost, there are significant technical challenges with lidar systems beyond ranges of 150 meters. Data converter, power management, and signal condition technologies are also making their way into first and second generation LIDAR systems.

The timeline to self-driving cars

There can be no doubt that self-driving cars are coming, even if there are a few setbacks along the way. So, a couple good questions might be: when will we get there and how long will it take to get there?

According to the auto industry, there are two standard terms for this transition: an evolutionary one where existing cars get there little by little (analogous to Tesla's autopilot feature) and a revolutionary one where we have totally self-driving cars (like the ones Google are working on). It is

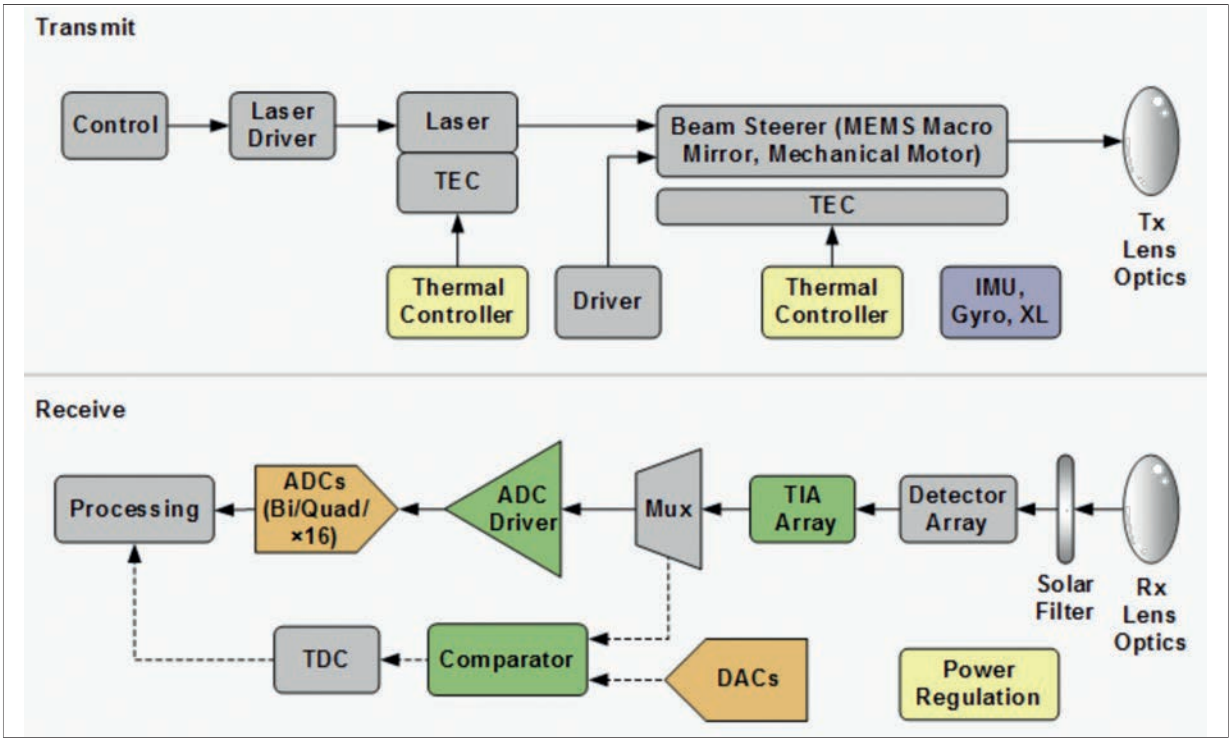


Figure 1: LIDAR utilizes pulses of light to translate the physical world into 3D digital images in real time with a high level of confidence

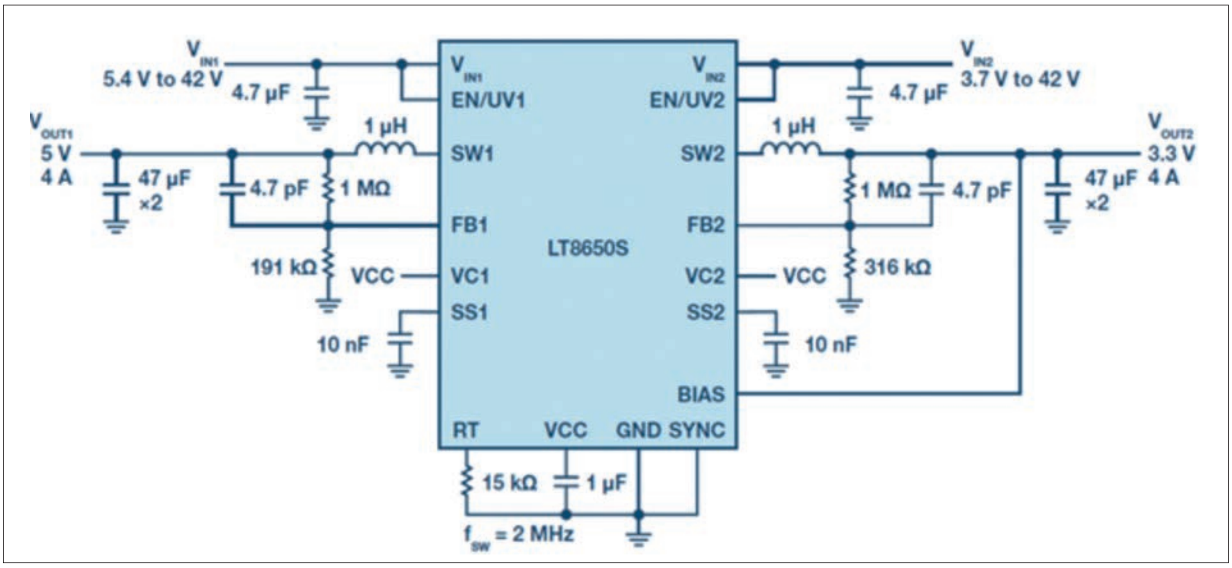


Figure 2: **Simplified LT8650S schematic delivering 5 V at 4 A and 3.3 V at 4 A outputs, at 2 MHz**

unclear to me that either path will succeed by itself, but it will more likely end up being a symbiotic amalgamation of the two. The car makers and high tech auto systems providers will need to closely collaborate with each other so as to ensure that light detection, LIDAR, radar sensors, GPS, and cameras all work cohesively together.

Looking ahead, vehicles equipped with semi-autonomous features should be able to navigate through intersections, traffic lights, and stop-and-go traffic conditions. Nevertheless, even these highly autonomous cars will still require an actual human being to be up front in case of emergency situations. Looking further ahead, these semi-autonomous vehicles will also function normally in more stringent conditions, such as severe weather and night time. By this timeframe, lift-service providers may start using these types of cars without any driver. Of course, automakers will have to make sure their vehicles understand human signals from pedestrians, like waving them on at a crossing or intersection. All of these advancements will necessitate the automakers having many autonomous features in their vehicles, which could potentially allow for autonomous self-driving cars to be on the roads by the mid-2030s.

Of course, all the advancements needed to make this timeline a reality will be a boon to the IC semiconductor industry, since it will supply the majority of the Silicon content for the many systems needed to make it all happen.

Analog ICs

Fully autonomous cars will clearly have many different electronic systems with a mix of both digital and analog ICs. These will include advanced driver assistance systems (ADAS), automated driving computers, autonomous parking assist, blind spot monitoring, intelligent cruise control, night vision, LIDAR, and more. All of these systems require a variety of different voltage rails and current levels for their correct operation; however, they can be required to be powered directly from the automobiles battery and/or alternator and, in some instances, from a postregulated rail from one of these rails. This is usually the case for the core voltages of VLSI digital ICs such as FPGAs and GPUs that can need operating voltages sub-1 V at currents from a couple of amps to 10th of amps.

System designers must also ensure that the ADAS comply with the various noise immunity tandards within the vehicle. In an automotive environment, switching regulators are replacing linear regulators in areas where low heat dissipation and efficiency are valued. Moreover, the switching regulator is typically the first active component on the input power bus line and therefore has a significant impact on the EMI performance of the complete converter circuit.

There are two types of EMI emissions: conducted and radiated. Conducted emissions ride on the wires and traces that

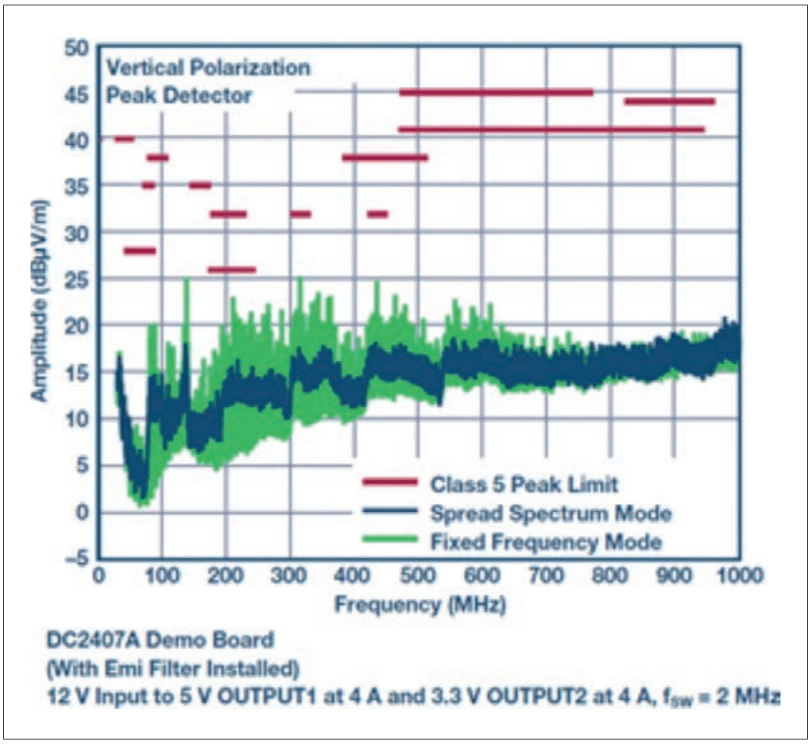


Figure 3: **LT8650S radiated EMI performance graph**

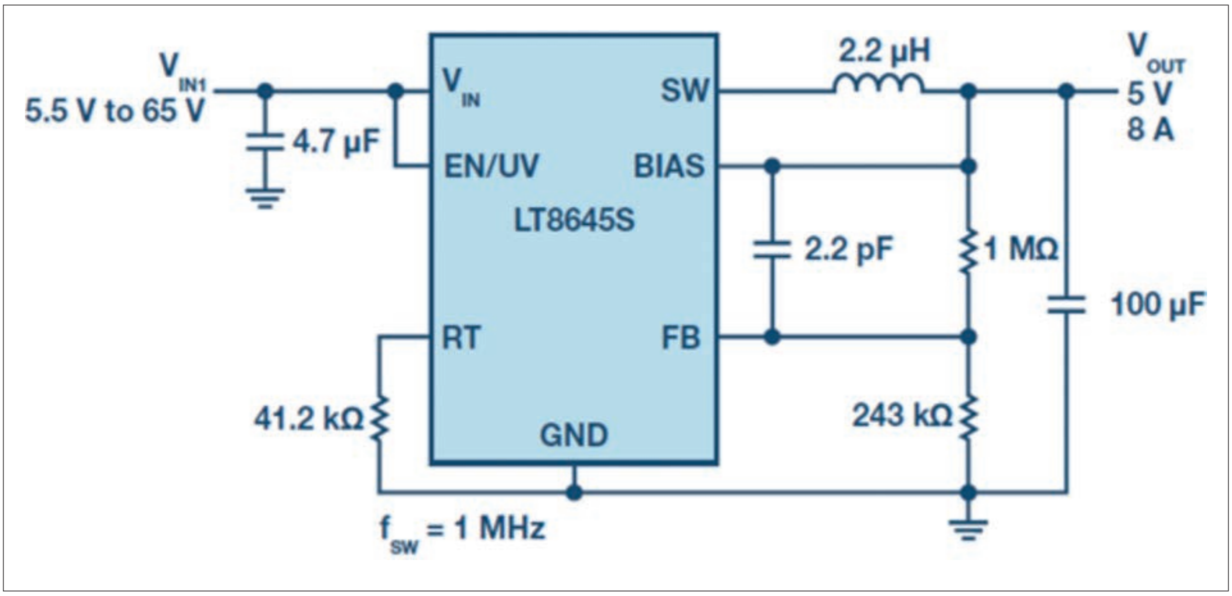


Figure 4: **Simplified LT8645S schematic delivering 5 V at 8 A output at 2 MHz**

connect up to a product. Since the noise is localized to a specific terminal or connector in the design, compliance with conducted emissions requirements can often be assured relatively early in the development process with a good layout or filter design as already stated.

However, radiated emissions are another story altogether. Everything on the board that carries current radiates an electromagnetic field. Every trace on the board is an antenna and every copper plane is a resonator. Anything other than a pure sine wave or DC voltage generates noise all over the signal spectrum. Even with careful design, a power supply designer never really knows how bad the radiated emissions are going to be until the system gets tested, and radiated emissions testing cannot be formally performed until the design is essentially complete.

Filters are often used to reduce EMI by attenuating the strength at a certain frequency or over a range of frequencies. A portion of this energy that travels through space (radiated) is attenuated by adding metallic and magnetic shields. The part that rides on PCB traces (conducted) is tamed by adding ferrite beads and other filters. EMI cannot be eliminated, but can be attenuated to a level that is acceptable by other communication and digital components. Moreover, several regulatory bodies enforce standards to ensure compliance.

High-voltage converter with Low EMI/EMC emissions

It was because of the application constraints outlined herein that Analog Devices' Power by Linear™ Group developed the LT8650S - a high input voltage capable, dual output monolithic synchronous buck converter that also has low EMI/EMC emissions packaged in a small thermally enhanced 4 mm × 6 mm IC pin LGA package. Its 3 V to 42 V input voltage range makes it suited for automotive applications, including ADAS, which must regulate through cold crank and stop-start scenarios with minimum input voltages as low as 3 V and load dump transients in excess of 40 V. As illustrated in Figure 2, it is a dual-channel design consisting of two high voltage 4 A channels, delivering voltages as low as 0.8 V, enabling it to drive the lowest voltage microprocessor cores currently available. Its synchronous rectification topology delivers up to 94.4 % efficiency at a switching frequency of 2 MHz, while Burst Mode® operation keeps quiescent current under 6.2 µA (both channels on) in no-load standby conditions making it suited for always-on systems.

The LT8650S's switching frequency can be programmed from 300 kHz to 3 MHz and synchronized throughout this range. Its 40 ns minimum on-time enables 16 VIN to 2.0 VOUT step-down conversions on the high voltage channels with a 2 MHz switching frequency. Its Silent Switcher® 2 architecture uses two internal input capacitors as well as internal BST and INTVCC capacitors to minimize the area of the hot loops. Combined with very well

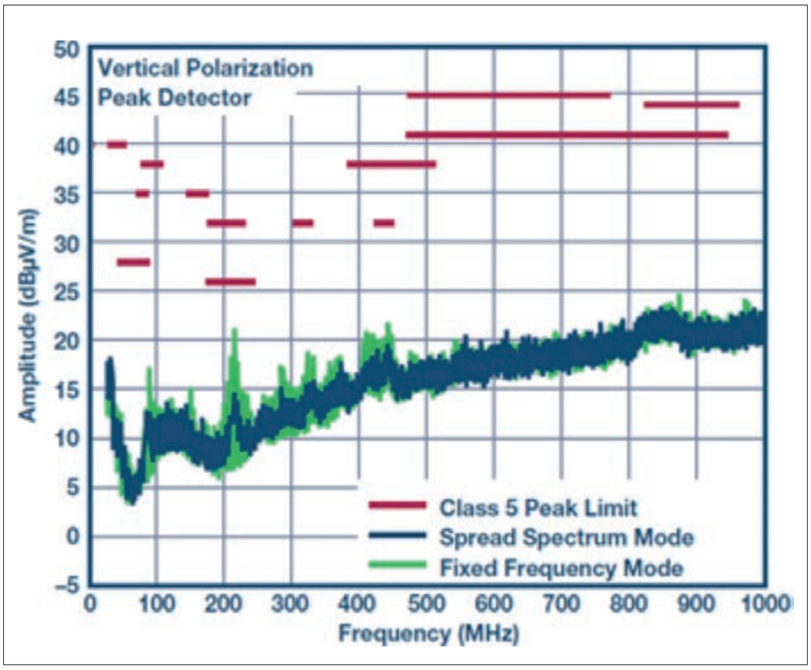


Figure 5: **LT8645S radiated EMI performance graph**

controlled switching edges and an internal construction with an integral ground plane and the use of copper pillars in lieu of bond wires, the LT8650's design dramatically reduces EMI/EMC emissions (see Figure 3). This improved EMI/EMC performance is not sensitive to board layout, simplifying design and reducing risk even when using 2-layer PC boards. The LT8650S can easily pass the automotive CISPR 25, Class 5 peak EMI limits with a 2 MHz switching frequency over its entire load range. Spread spectrum frequency modulation is also available to lower EMI levels further.

Similarly, for applications needing a wider input range than that afforded by the LT8650S, the LT8645S is a high input voltage capable monolithic synchronous buck converter that also has low EMI emissions. Its 3.4 V to 65 V input voltage range makes it ideal for both automotive and truck applications that must regulate through cold crank and stop-start scenarios with minimum input voltages as low as 3.4 V and load dump transients more than 60 V. As can be seen in Figure 4, it is a single channel design delivering an 8 A output at 5 V. Its synchronous rectification topology delivers up to 94 % efficiency at a switching frequency of 2 MHz, while Burst Mode operation keeps quiescent current under 2.5 µA in no-load standby conditions, making it suited for always-on systems.

Combined with very well controlled switching edges and an internal construction with an integral ground plane and the use of copper pillars in lieu of bond wires, the LT8645's design reduces EMI/EMC emissions (see Figure 5). This improved EMI/EMC performance is not sensitive to board layout, simplifying design and reducing risk even when using 2-layer PC boards. The LT8645S can easily pass the automotive CISPR 25, Class 5 peak EMI limits over its entire load range. Spread spectrum frequency modulation is also available to lower EMI levels further.

The LT8645S utilizes internal top and bottom high efficiency power switches with the necessary boost diode, oscillator, control, and logic circuitry integrated into a single die. Low ripple Burst Mode operation maintains high efficiency at low output currents while keeping output ripple below 10 mV p-p. Finally, the LT8645S is packaged in a small thermally enhanced 4 mm × 6 mm IC 32-lead LQFN package.

Conclusion

The proliferation of automotive systems that will be necessary for the autonomous self-driving cars (and trucks) of the future continue to gain momentum even here in the present. Of course, voltage and current levels will change; nevertheless, the requirements for low EMI/EMC emissions will not go away - and neither will the hostile environment in which they need to operate. Fortunately, there are a growing number of solutions to assist the system designer in the present and the future, even if the mid-2030s seems a long way off.

Literature

https://www.analog.com/en/technical-articles/self-driving-cars-are-powersystems-up-to-the-task.html

Elegant Hot-Swap Solution for Server Design

The need to implement protections and control circuits is a crucial design requirement in datacenter severs, telecoms systems, and networking equipment applications. Solutions with a minimal number of components are implemented to address space-constraint issues. A hot-swap solution with PMBus integration provides an innovative way for engineers to solve these design challenges. **Yat Tam, Product Marketing Manager, Monolithic Power Systems, San José, USA**

As with many communications infrastructures, high availability and reliability are critical elements of system design in a datacenter. Pluggable modules and PCBs, such as servers and storage, require a protection and control circuit at the power entry point. This is commonly referred to as a hot-swap control circuit.

To appreciate what a hot-swap control circuit does to the system, it is important to understand the status of the system before and after the hot-swap event. Figure 1 shows that the host system's backplane is fully powered at the outset. In a live system, all bulk and bypass capacitors are fully charged. Inserting an uncharged card into the live system quickly charges the card and discharges the live system. Uncontrolled card charging demands a large inrush current, and uncontrolled system discharging significantly reduces the backplane voltage.

Hot-swap solutions control the power-up of uncharged cards and manage system response. Cards mating into a live system connector will connect and disconnect power (bounce power on and off) as the card is rocked into the connector. It can take several milliseconds for the card to mate properly. As the card is inserted, the capacitors on the card start to charge and draw current from the live system. As the capacitors initially charge, the card appears as a short and instantaneously draws a large amount of current. This inrush current produces a large demand on the system, and can cause the system capacitors to discharge and the system voltage to droop. Hot-swap solutions therefore allow cards/boards to be inserted and removed from a live backplane without disturbing the power distributed to other boards.

Design challenges

The hallmarks of hot-swap solution in applications such as servers and storage generally include safe control of live board inrush current control during insertions and removals, fault monitoring diagnostic and protection, and high accuracy electrical (voltage, current, power) and environmental (temperature) parameters to provide real-time system telemetry in analog or digital domains. In particular, if a fault occurs in one line card/board in a server rack, that fault should remain isolated to that particular line card/board, and impact neither the system backplane nor the other line cards/boards powered from that live backplane.

The best way to prevent system downtime is to detect, respond, and correct potentially damaging conditions as quickly as possible. Conventional wisdom in designing the hot-swap protection control circuits is to use discrete components. A typical discrete hot-swap solution combines a controller IC, a pass device like a MOSFET, and a sense resistor to manage the flow of power between the backplane and the main board for preventing glitches and faults from disrupting power to the rest of the system. This method fulfills the fundamental protection requirements. However, discrete solutions have well-known shortcomings, including:

- they need more components and occupy more board space. More components also raise concerns regarding solution robustness and reliability,
- they do not incorporate thermal protection for the MOSFET. The thermal design often exceeds the safe operating

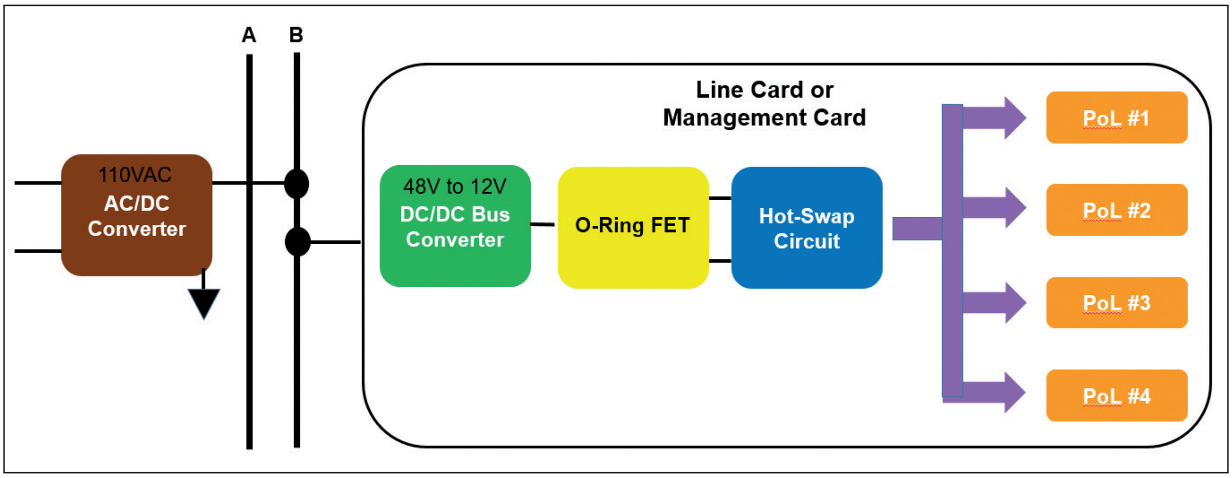


Figure 1: **Example of Distributed Power Architecture in a Telecommunications System**

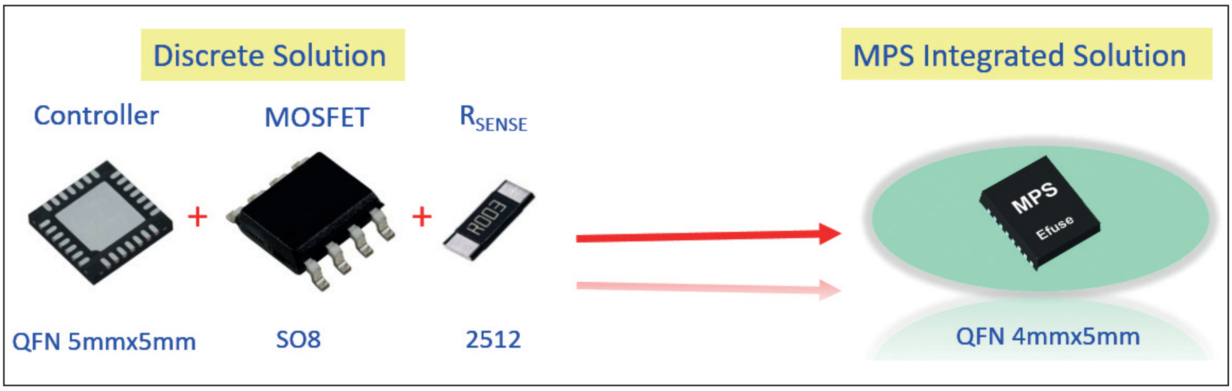


Figure 2: The MP5023 vs. discrete hot-swap solution

area (SOA) limits for device protection under extreme cases,

- They require careful PCB layout. Engineers must understand Kelvin current-sensing technique in order for current monitoring and current limiting to be correctly and accurately implemented.

Design resources have been stretched thin by increasing system complexity and shortening design cycles, with resources primarily being allocated to developing the key intellectual property of the system. This often means that the power scheme related circuits are ignored until later in the development cycle.

With little time, and perhaps limited power design expertise to address the drawbacks described above, there is a growing need to develop reliable hot-swap solution. The ideal hot-swap solution would have a small form factor, be cost-effective and reliable, and require minimal design effort.

An innovative approach

Unlike conventional discrete solutions, MPS implements a monolithic solution. The MP5023 is a 16 V hot-swap solution with an integrated MOSFET and sense resistor, as well as a PMBus interface that can handle 50 A of current – all on a single Silicon die (see Figure 2). It is available in a small QFN (4 mm x 5 mm) package.

The MP5023 requires a minimal number of external components, which helps simplify system design (see Figure 3). Engineers only need to select the correct values of resistors for setting the current monitoring, current limit and PMBus address, and correct values of capacitors for soft-start and other timer features. The MP5023 also simplifies PCB layout issues by optimizing MOSFET and sense resistor connections inside the IC package. It can compensate internally for an incomplete or improper implementation of Kelvin-sensing, requiring less time and effort from engineers.

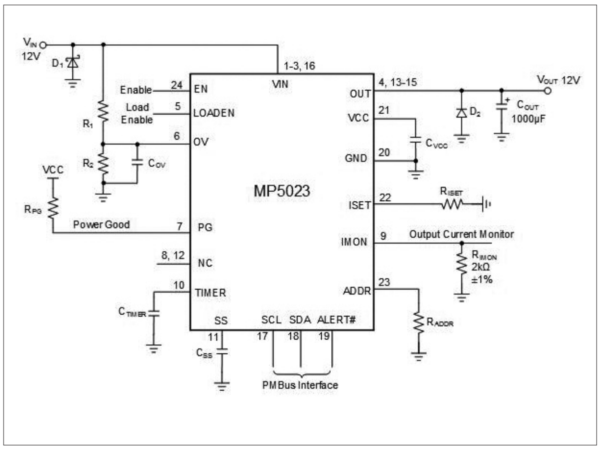


Figure 3: Typical application circuit of the MP5023

One significant advantage of the MP5023 over discrete solutions is that the current monitor and current limit accuracy are well under control due to the advanced monolithic process. It can achieve ±1.5 % current monitoring between 10 A and 50 A in various temperature ranges (see Figure 4).

An integrated MOSFET provides the ability to monitor the on-die temperature to shut down the MP5023. Once the device enters thermal shutdown, it either remains off (latch-off) or attempts to restart (auto-retry) after the junction temperature falls below the over-temperature protection threshold. The on-die temperature can be monitored and read via the PMBus. Therefore, engineers do not need to over-design the MOSFET or thermal design to keep the device in SOA limits under extreme fault conditions.

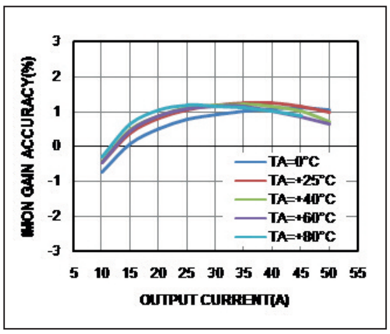


Figure 4: IMON Gain Accuracy vs. Output Current and Temperature

PMBus interface

The MP5023's PMBus interface is PMBus 1.3 compliant, which offers ease and flexibility of configuration, broad and accurate system control, as well as detailed precise monitoring and telemetry. Parameters such as the voltage, current, temperature, and faults are programmable via the PMBus, which can read and report real-time information. The adjustment of these parameters can be changed dynamically. Real-time monitoring enables comprehensive visibility into solution performance, which gives engineers the ability to optimize the system run-time through predictive analysis and minimize downtime by having more data available when repairs become necessary.

Conclusion

Incorporating these elements into a hot-swap solution such as the MP5023 makes it possible to adapt the operation of the system to the needs at hand, eliminates repetitive and labor-intensive activities, and allows engineers to address shrinking space constraints and tight project turnaround times.

Field Control Leads to Better AC Motor Efficiency

Many of AC motor designs are relatively low cost and easy to drive. They are also quite inefficient in terms of energy use, particularly at low speeds. However, such AC motors are not inherently wasteful. With the correct form of electronic control, their efficiency can improve dramatically. Using control techniques available today it is possible to reduce energy consumption for a given level of work by as much as 60 percent. **Rich Miron, Applications Engineer, Digi-Key Electronics, USA**

By 2035, the world will consume more than 35 trillion kilowatt-hours of electricity per year, rising from just under 21 trillion kWh in 2015. Close to a third of the electrical energy needed today feeds the motors employed in industrial production. Many of these motors are based on simple AC designs, i. e. volts per hertz. It is both conceptually simple and easy to implement on a basic microcontroller. The core algorithm takes advantage of a core property of the design of the AC motor. Each motor has a characteristic magnetizing current and a resulting maximum flux and torque. These properties are related through the volts per hertz ratio. The motor turns through the switching of stator coils arranged around the moving rotor that turns the mechanical load. Switching between the coils forces the magnetized elements of the rotor to turn in sympathy to move to a stable state where the magnetic fields are held in equilibrium.

An increase in the frequency at which the coils are switched will in turn increase the speed. But without a commensurate increase in electrical energy supplied, the torque applied falls. Volts per hertz control provides a simple way around the problem by increasing the line voltage with rising frequency so that torque can be maintained at a constant level. Unfortunately, the relationship is not particularly consistent at low speed. Higher voltages are required to maintain high torque at low speed, but the efficiency drops and increases the likelihood of coil saturation and overheating.

More precise at low speed

Field-oriented control provides a means of optimizing motor control, particularly at low speeds, and additionally provides the ability to make positioning control of the motor much more precise. This increases the range of applications for AC motors overall, which helps to reduce the cost of industrial machinery as well as the cost of operation.

In field-oriented or flux-vector control, the link between speed and torque implied by volts per hertz control is broken. The idea of field-oriented control can be expressed using the model of a wound DC motor where the currents supplied to the stator and rotor are independent. In this model, the torque and the flux produced can be controlled independently. The strength of the field inside the motor set developed by the current determines the flux. The current supplied to the electromagnetic windings in the rotor controls the torque – as the magnetic fields try to align themselves into a stable state.

A DC motor uses a commutator on the rotor that performs the job of controlling which coils on the stator are energized at any one time. The commutator is designed such that the current switches to the windings that are mechanically aligned to produce maximum torque at that point. As a result, the windings are managed in such a way that the flux changes to keep the rotor windings orthogonal to the field developed in the stator.

In an AC motor, only the stator currents are under direct control. The rotor often uses permanent magnets to provide its field. This means flux and torque rely on the same current. But field-oriented control provides the ability to manipulate them almost independently. In practice, the stator flux is controlled dynamically to provide the ability to independently manipulate torque. In general, stator coils can be driven so that they either generate torque or apply force along the axis of the stator, a mode that does not affect rotation. These directions are the quadrature and direct axes, respectively. To deliver motion, each coil is driven in turn to produce high quadrature force.

Several mathematical transforms are used to provide the ability for changes in current and voltage to decouple the torque and flux. Under field-oriented control, the currents that flow through the different parts of the stator are represented by a vector. Matrix projections transform a three-phase time- and speed-dependent system into a two coordinate time-invariant system. The coordinates are conventionally described using the symbols d and q, which represent flux and torque components, respectively. In the (d,q) reference frame, the torque applied is related linearly to the torque component.

Under field-oriented control, the electrical signals are received from the motor and incorporated into the (d,q) coordinate model. This model is normally calculated relative to the rotor making the calculation of desired flux easier. A typical method used for the calculation is to pair the Clarke and Park transforms.

Transforming currents from different phases

The Clarke transform takes the currents from the different phases, usually three, and uses them to estimate currents in a Cartesian coordinate system. The axes of these systems use the symbols alpha and beta rather than the conventional x and y to reduce the potential for confusion with a spatial coordinate system. These are then applied to the Park transform to provide the current vectors that are seen in the rotating (d,q) coordinate system. Trigonometric functions provide the core of the transformations, requiring the use of a microcontroller or digital signal processor (DSP).

Through the Clarke and Park transforms, the flux and torque components of the current vector in the (d,q) space are derived from the currents fed to each electrical phase and the rotor flux position, which takes the symbol theta in most descriptions of the algorithm. This structure has applicability to a range of motors. An inverse Park transformation is used to yield

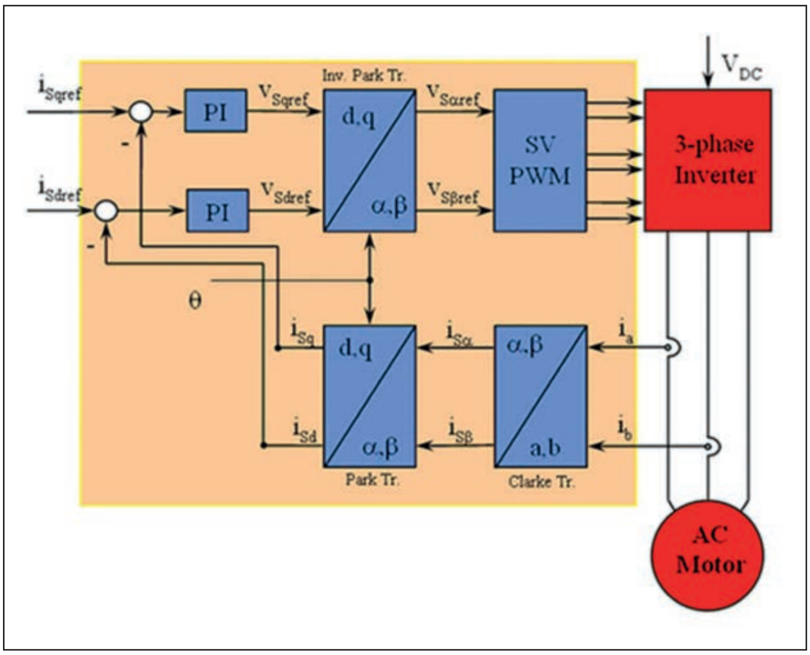


Figure 1: Basic configuration of transforms and control blocks for field-oriented control

voltage outputs that are then employed in an algorithm that controls power to each of the three phases. The overall structure is shown in Figure 1.

The same core structure can be used to control both synchronous and induction machines by simply changing the flux reference and obtaining the rotor flux position. In a synchronous permanent magnet motor, the rotor flux is fixed, as it is determined by the permanent magnets. Induction motors need rotor flux to be created in order to function, so this is incorporated into the flux reference as a non-zero value.

Key to the success of field-oriented control is real-time prediction of the rotor flux position. There is a complication to this control strategy. Inside an AC induction motor, the speed of the rotor does not match the speed at which the magnetic flux driving it rotates. The rotor tends to lag, leading to a difference known as the slip speed. In older schemes, motor manufacturers used sensors to analyze rotor position, but this lead to unwanted additional cost. In practice, it is possible to compensate for slip using feedback from the voltages and currents developed within the motor.

Using back-EMF to estimate rotor slip

Many systems use the measured back-EMF to estimate rotor slip. The magnitude of the back-EMF voltage is proportional to the speed of the rotor. However, using this input directly causes problems at low speeds or at a standstill, and it is not easy to estimate the initial position. Starting from an unknown rotor position may lead to the motor reversing a small distance unexpectedly or to a full starting failure. A further drawback with simply sampling the back-EMF is its sensitivity to stator resistance which is prone to change with temperature.

Indirect model-based schemes provide greater performance. There is a strong trade-off between computational overhead and performance, but in general, efficiency, especially at low speeds, is improved through the use of more sophisticated model-based algorithms. An indirect model-based scheme estimates the real-time values of these based on available sensor readings.

As with back-EMF estimation, the core problem is determining the starting point for the motor. One solution is to start with an estimate of the initial state from which a vector of predicted outputs can be derived, which is compared with the measured output vector. This difference is used to correct the internal state vector of the model. However, noise can upset the stability of the model.

The extended Kalman filter can compensate for the effects of noise and sudden disturbances. The architecture of the Kalman filter allows updates deemed to have lower uncertainty to be given a higher weighting than those estimated to have a larger uncertainty. The filter works recursively such that each estimation requires only a set of new readings and the filter's previous state to generate a new state.

The Kalman filter employs two main stages: prediction and update. In the prediction phase, the filter calculates the next state of the system based on the previous state, which, in the case of a motion algorithm, provides the last known speed and acceleration values. From this, the filter calculates a prediction of the current position.

In the update phase, the freshly sampled voltage and current values are compared to their predicted values. The closer the input data matches the prediction, the lower the error probability. This error probability feeds into the Kalman filter gain. At the algorithm level, the Kalman filter relies on a number of matrix multiplications and inversions. The key to implementing the extended Kalman filter in motor control is therefore high arithmetic performance, in common with other aspects of field-oriented control.

Handling the computational load

To implement the many arithmetic operations required every second in a real-time motor control situation, a high-performance MCU or DSP is required. The TMS320F2833x family of devices by Texas Instruments was developed to handle the typical computational load of AC motor applications, supported by a variety of on-chip peripherals to aid integration with the power conversion electronics.

The TMS320F2833x is built around a high-performance 32-bit CPU with floating-point support that is compliant with the IEEE754 standard for single-precision arithmetic. By implementing an IEEE compliant floating-point unit, the TMS320F2833x eases algorithm development as it handles a very wide numeric range with built-in support for errors such as not-a-number (NaN) and divide-by-zero conditions. A Harvard architecture coupled to a dual 16 x 16 multiply-accumulate (MAC) unit provides high throughput for matrix and projection-based operations. For additional precision, the units can be tied together to perform 32 x 32 MACs. On-chip peripherals include a 16-channel analog-to-digital converter (ADC) to perform sampling of voltage and current feedback signals from the motor.

As a member of the C2000 range of DSP enhanced MCUs, the TMS320F2833x is supported by the TI Digital Motor Control Library, which provides configurable software blocks that can be reused to implement a variety of control strategies. The library is composed of functions represented as blocks, which provide transforms such as the Clarke and Park, in addition to control blocks for closed-loop operations, and peripheral drivers for functions such as pulse-width modulation (PWM).

In a motor control situation, PWM outputs control six power transistors that together deliver voltage and current to the three electrical phases. Each phase uses a half-bridge transistor configuration. A common algorithm used for control in

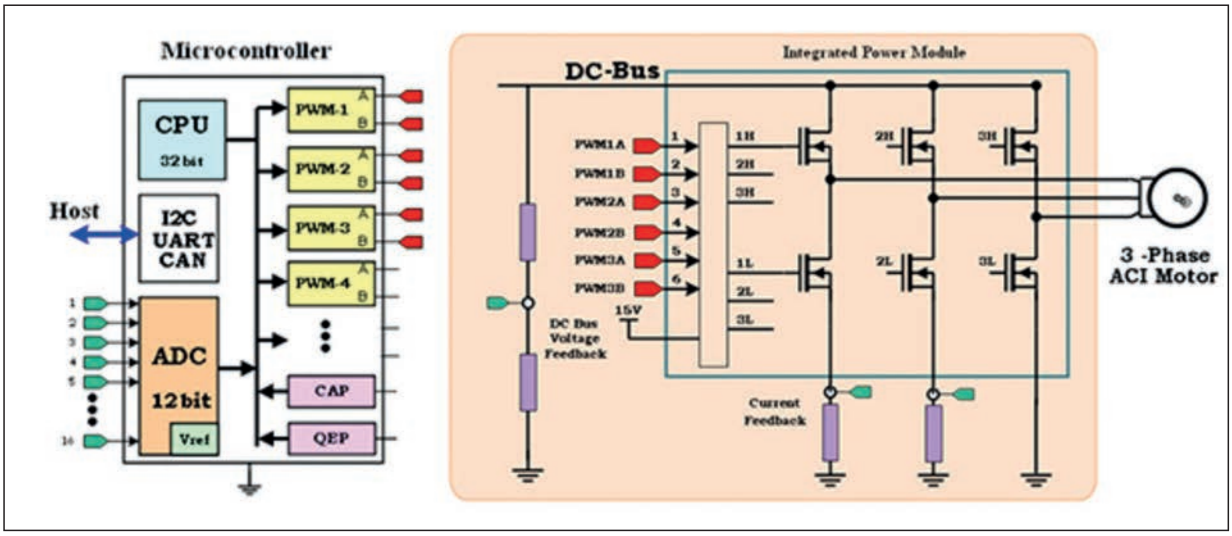


Figure 2: **Block diagram, showing control of power phases by PWM outputs of F2833x**

these situations is space-vector PWM. This reduces harmonics compared to simpler PWM techniques and employs eight switching states. There are six active states and two zero states, each of which is the target state of eight corresponding space vectors. The states are arranged in such a way that two sets of complementary states are active at any one time. One set is for the three high-side power transistors and the other for the low-side. The algorithm cycles through the states to switch power to the states as required by the field-oriented control model. The TMS320F2833x includes PWM hardware suitable for software control that employs space-vector switching. Six of the 18 total PWM outputs support high-precision control, with a resolution of 150 ps. The result is a digital controller that requires comparatively little external hardware to manage the power transistors, as shown in Figure 2.

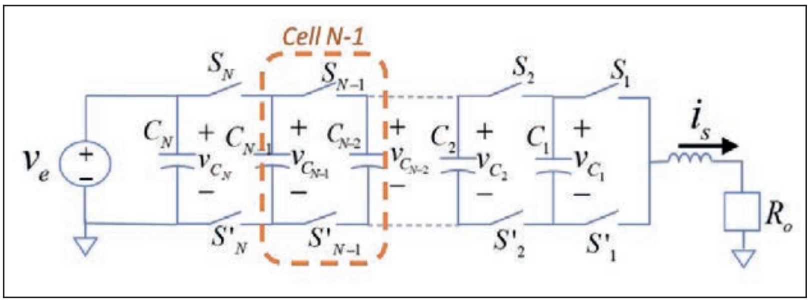
Conclusion

Utilizing a microcontroller that has the necessary core and high-performance building blocks, in conjunction with the TI Digital Motor Control Library, designers are poised to drive a new generation of efficient AC motors.

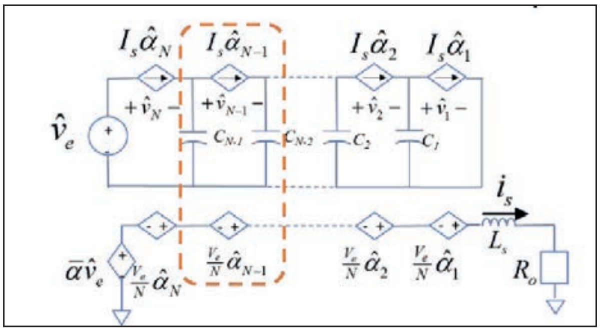
Decentralized Controller for a Multilevel Flying Cap Converter

This awarded paper for Young Engineers presents a decentralized method to balance the capacitor voltages of a Flying-Cap converter. In this study, a change of variable is proposed replacing the voltage of the capacitors by the cell-voltages to provide an appropriate model of the converter. The control strategy involves several cell-voltage-balancing local controllers associated to each cell and a global output current controller. The local controllers cancel the difference between their own local cell-voltage with the average value of the neighboring cell-voltages. Using this control method any number of cells constituting the converter can be handled. It provides also an auto-balancing property in case of an insertion or a removal of an active cell during operation, which can be useful to address fault-tolerant concerns. Furthermore, the study demonstrates that the dynamics of the two types of loops, the cell-voltage balancing and the output current regulation are uncorrelated. **Miguel Vivert, Marc Cousineau, Philippe Ladoux, Pontificia Universidad Javeriana, Bogotá, Colombia; Joseph Fabre, LAPLACE, Université de Toulouse, CNRS; Toulouse, France**

Multicellular converters are widely used in medium and high-power applications. Ones of the most popular multilevel topologies are the FC-converters and the multiphase converters. One of the main challenges for the control of multilevel converters is to regulate a large number of internal state variables. One solution is to decentralize the control. The technique consists to split the main controller into several local controllers, each managing only one part of the system. To balance the inductor currents, each leg current is compared with the neighbouring leg currents and the difference is cancelled by a corrector. Using a similar approach, the interleaving of the carrier signals of each leg is obtained. An adaptation of this method for the control of a FC-converter is proposed here.



ABOVE Figure 1: Schematic of the FC-converter where the cells are cascaded (connected in series)



RIGHT Figure 2: Small-signal model of the FC-converter

Description of the system

The system is a flying-cap converter made of N cells. Figure 1 shows the topology of theconverter.

Defining the CV variable as vj = vcj -vcj-1 , equation 1 shows the obtained model.

Equation 1

$$\begin{cases}\dot{V} = \frac{1}{C} i_s A_{sys}\alpha + E\dot{v}_e \\ \dot{i}_s = \frac{1}{L_s}\left(\alpha^T V - i_s R_o\right)\end{cases} \quad (1).$$

where A sys and E are the matrices related to the topology of the converter, V and α are the vectors respectively of the cell-voltages and the cell's duty-cycles.

In order to perform a small-signal analysis, the system has to be linearized. Equation 2 shows the system linearized.

Figure 2 shows the resulting small-signal model of the converter. This figure clearly shows that the current and the CVs are decoupled.

Design of the controllers

Figure 3 shows the block diagram of the proposed method of control with the bypass selector.

The LC receives the capacitor voltages of its own cell v_{cj}, computes its local CV v_j, and receives also the CVs of the neighbouring cells v_{j-1} and v_{j+1}. The error between v_j and the average value of v_{j+1} and v_{j-1} is computed and cancelled with $K_{v(s)}$. Then, this compensation is added to the output of the OCC to provide the local duty-cycle α_j. If a failure occurs on the cell, the cell is disabled ($en_j = 0$) and the local signals exchanged between the adjacent LCs are bypassed in order to maintain the communicating chain closed. Inserting a cell consists to enable the cell ($en_j = 1$) and reactivates the communications with the neighbouring LCs.

The second major interest of this

Equation 2

$$\begin{cases}\dot{\hat{V}} = \frac{1}{C} I_s A_{sys}\hat{\alpha} + E\dot{\hat{v}}_e \\ \dot{\hat{i}}_s = \frac{1}{L_s}\left(\bar{\alpha}\hat{v}_e + \frac{\bar{v}_e}{N} V_1^T\hat{\alpha} - R_o\hat{i}_s\right)\end{cases} \quad ; \quad \text{with} \quad \begin{matrix}\alpha = \bar{\alpha}V_1 + \hat{\alpha} & ; i_s = I_s + \hat{i}_s \\ V = \frac{\bar{v}_e}{N}V_1 + \hat{V} & ; v_e = \bar{v}_e + \hat{v}_e\end{matrix} \quad \text{where } V_1 = \begin{bmatrix}1 \\ \vdots \\ 1\end{bmatrix} \qquad (2)$$

Where $\hat{\alpha}, \hat{V}, \hat{i}_s, \hat{v}_e$ are the small-signal variables.

Equation 3

$$\begin{cases}\hat{V} = \frac{I_s}{Cs} K_v(s) A_{sys} D_{iff} \hat{V}' + E\hat{v}_e \\ \hat{i}_s = \frac{1}{L_s s + R_o}\left(\bar{\alpha}\hat{v}_e + \bar{v}_e K_s(s)\left(\hat{I}_{ref} - \hat{i}'_s\right)\right)\end{cases} \qquad (3)$$

control method is that both control loops are completely uncoupled, i.e. the cell-voltage is not affected by the current controller and vice versa, as shown by (3).

In equation 3) the variables are not linked together. The gains of the controllers are selected to have a bandwidth 60 times less than the switching frequency for the cell-voltage balancing controller and 50 times less for the current controller.

Simulation and experimental results

The simulation results are obtained for a 5-cells FC-converter with $v_e = 450$ V, $C_1 = C_2 = C_3 = 42$ µF, $C_4 = C_5 = 21$ µF, $L_s = 200$ µH, $R_o = 18.75$ Ω and a switching frequency $f_{sw} = 10$ kHz.

The first test concerns the current loop response to a load transient on Ro stepping from 18.75 Ω to 12.5 Ω. The second test is related to the insertion of the cell 3 (Figures 4 and 5).

The experimental results are the same tests of the simulation and are done with the same parameters, increasing 50% the load transient and for the dynamic insertion of cell 3 during operation.

Figure 6 shows the load transient response of the system with a settling time of 5 ms for the current. The CV are lightly disturbed by the step event. Figure 7 shows the voltages of the capacitors and the cell-voltage v_3 during the insertion of cell 3. The CVs are well balanced stepping from $v_e/4$ to $v_e/5$ with a settling time of 40 ms. The current is almost not affected by the insertion, validating the uncoupling of the system.

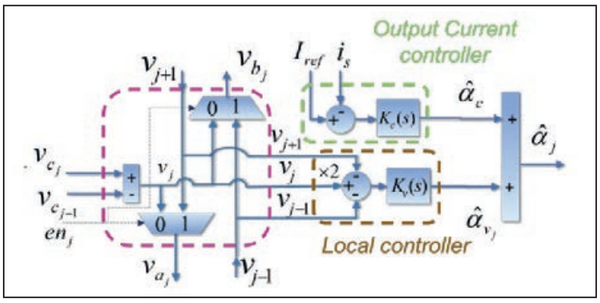


Figure 3: Block diagram of the control loops

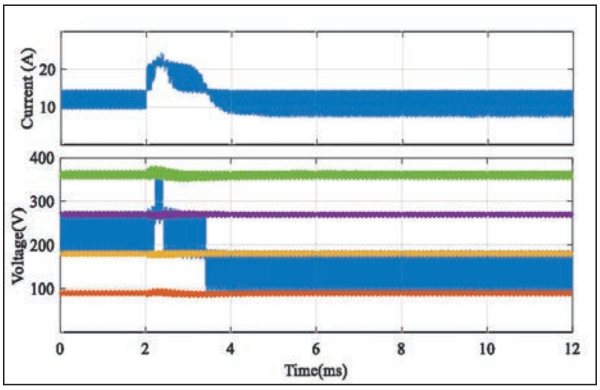


Figure 4: Response to a load transient

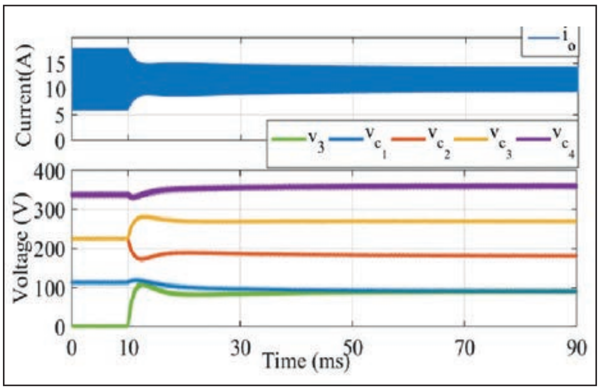


Figure 5: Inserting of cell 3 during operation

Summary

This paper presents a decentralized control strategy dedicated to the cell-voltages balancing in a flying-cap converter. Using local communications with their neighbors, the local controllers are able to balance their own cell-voltage with the others for any number of cells N involved in the converter, without having access to neither the value of N nor the value of the input voltage.

A theoretical study is developed providing both a model of the converter

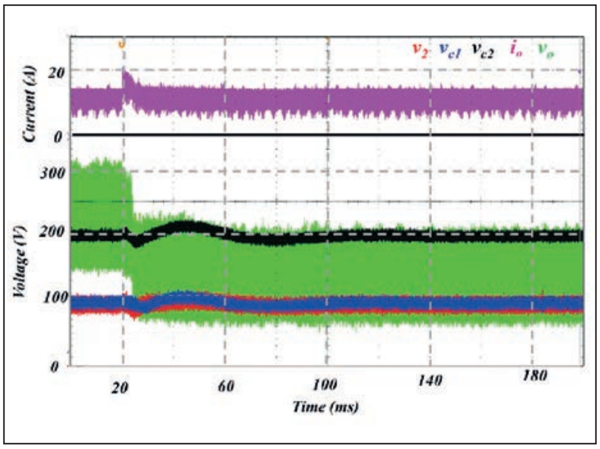


Figure 6: Load transient response of the FC-converter

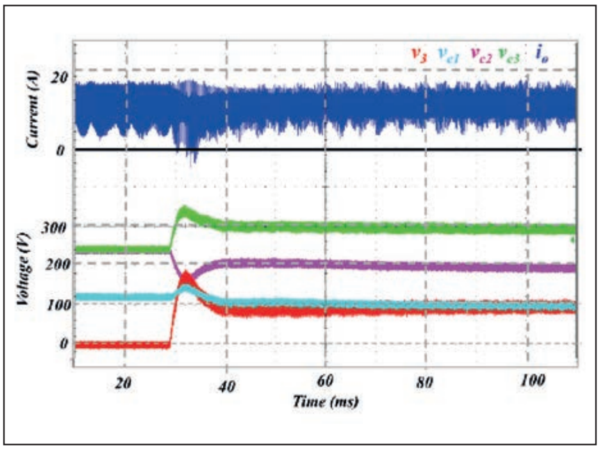


Figure 7: Output current - insertion of the cell 3 during operation (Math $v_3=v_{c3}-v_{c2}$)

using the cell-voltages as the new state variables and an analytical description of the overall system involving the two types of control loops, i.e. the CV balancing and the output current regulation. It is then shown that the two loops are uncorrelated. Moreover, this control strategy allows to easily insert or remove an active cell of the converter by using a simple bypass circuit included in each local controller, the balancing functionality remaining always operational.

The simulations of the converter responses to several types of transients and the experimental results obtained thanks to a prototype implemented in the laboratory validate the expected performances of the proposed control method and confirm it relevance.

Literature

"Decentralized controller for the cell-voltage balancing of a Multilevel Flying Cap Converter", Miguel Vivert, Young Engineer Awardee PCIM Europe 2019, Pontificia Universidad Javeriana, Bogotá, Colombia; PCIM Europe 2019 Proceedings, pages 571 - 578

PCIM Europe 2019 Proceedings, pages 344 - 351

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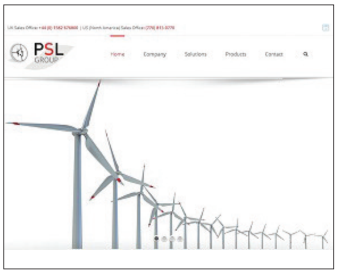

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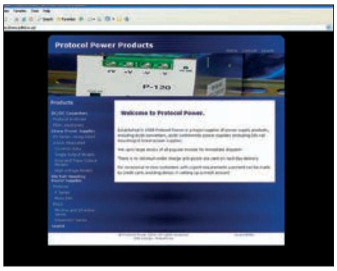

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