POWER ELECTRONICS EUROPE

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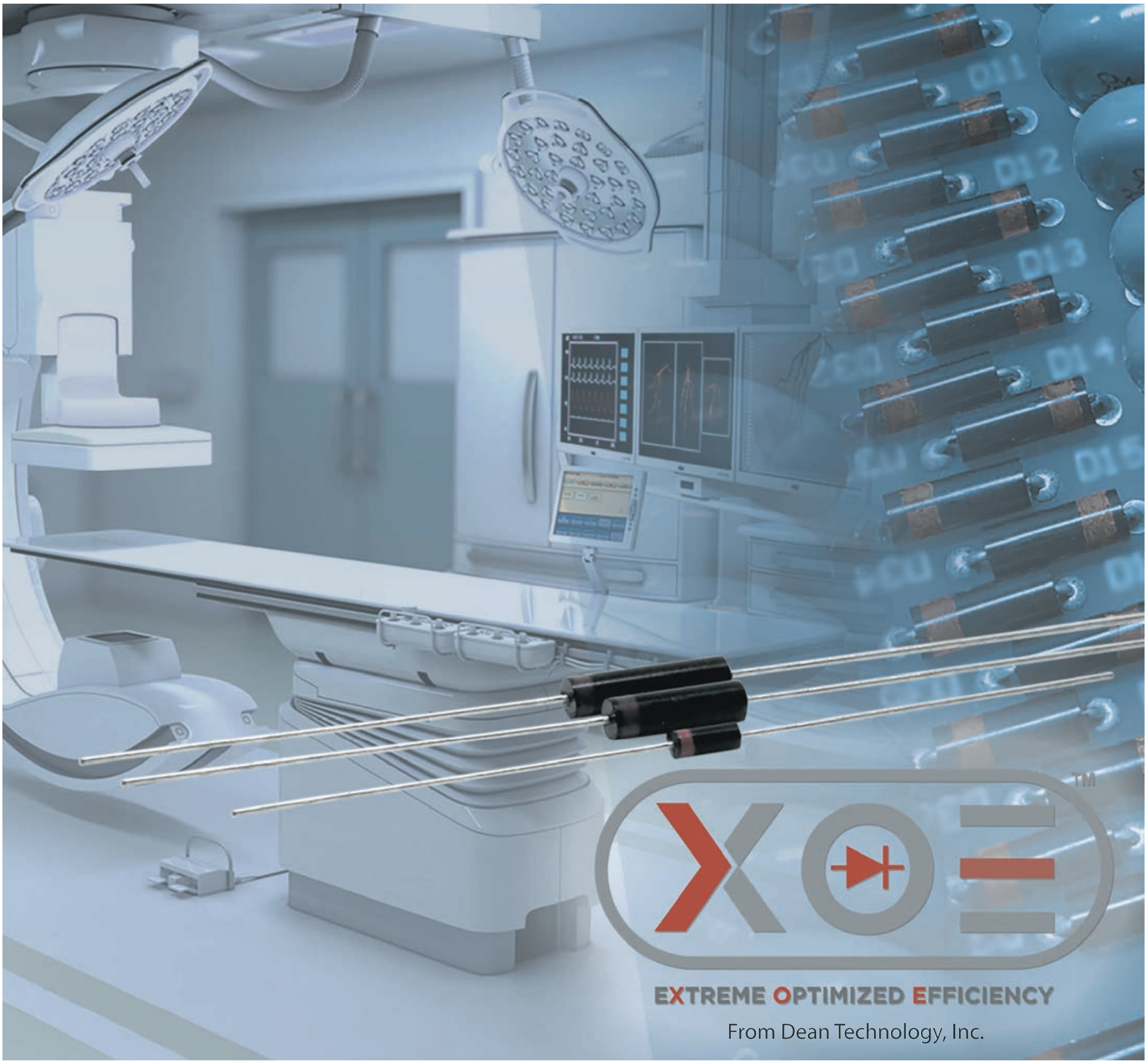
# HIGH-VOLTAGE DIODES

## Optimized High-Voltage Diodes




THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

**Also inside this issue**

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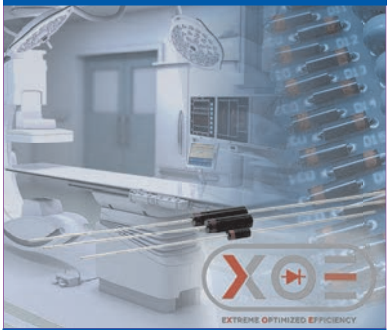
## COVER STORY




## New Powerful Power Diode Technology

Dean Technology is introducing a new high-voltage diode production technology called XOE™, eXtreme Optimized Efficiency. By tightly controlling all of the variables during the Silicon diffusion process with a particular focus on ensuring maximum efficiency, this technology is able to offer dramatically increased performance over similarly sized parts using the same raw materials. XOE diodes have a higher current flow (at least a 2 times factor),and a lower voltage drop (usually at least a 10 % decrease) while, in most cases, achieving better reverse recovery. This all is accomplished using the same materials already found in Dean Technology's standard products, thus providing users with a high-performance yet cost-effective diode solution. XOE products can be used in all applications where standard high-voltage diodes are already found and will help engineers to develop new solutions with higher performances in smaller sizes. The article focuses on the research that led to the development of this new technology, the benefits of the new process with graphical comparison data, the products available at this time, and Dean Technology's intended roadmap for products using XOE.

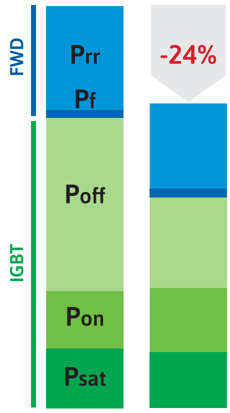
Full story on page 28.


# PrimePACK™ 7G IGBT Modules

## Upgrading to 1200 A in PP2 and 1800 A in PP3

series 7G

**Power dissipation at 6 kHz**
6 Gen vs 7 Gen
Modul rating: 1700 V/1400 A




## FEATURES

- IGBT & FWD
- High reliability solder material
- Higher lifetime at same ΔTj
- Increased output power at same lifetime
- Higher power cycling capability
- Lower losses at same conditions
- 2nd label with $V_{CE(sat)}$ and $V_F$ classification for easier paralleling

PrimePACK™ is registered trademark of Infineon Technologies AG, Germany.

# Electronics Drive the World

Electronics and software already account for over 90 % of all "automotive" innovations. And these developments are not only being driven by autonomous and connected driving alone, but also the electrification of roads for example. In addition, the growing demand for driving performance, safety, comfort and environmental compatibility can only be achieved using the latest electronically-managed vehicle functions. Thus the amount of power MOSFETs per car continuously increases, as more features are embedded in every new car sold worldwide. According to Infineon the amount of MOSFETs becomes even higher in electric high-end cars where up to 400 MOSFETs can be found in a single car. For this reason it gets more and more important to use high quality Automotive MOSFETs. The value of semiconductor devices in the car is also increasing, the worldwide sales of automotive semiconductors will go up from $45.5 billion in 2017 to $53.4 billion by 2022, with an average year-on-year growth of 5.5 %. Thus, the automotive sector plays an important role at electronica 2018. But there are other sectors to be considered also.

More and more customers are becoming "prosumers", i.e. consuming and producing electricity at the same time. Many small power plants are also obtaining energy from renewable resources. This increasingly fragmented, bidirectional, and volatile supply structure urgently requires an intelligent load and generation management system, in other words, a smart grid. Analysts expect there to be 285 million smart meters in households, offices, and factories around the world by 2025. This will generate turnover of $50 billion. But electricity meters are just one component of the smart energy concept. Smart-home and smart-city technologies also cover a whole range of sub-areas. These includes wireless and embedded as well as the Internet of Things and autonomous systems. Even electric vehicles have a role to play as flexible storage systems and grid stabilizers.

aKey technologies for climate-friendly, resource-saving, yet competitive energy supply are also power electronics technology minimizing losses through the conversion, distribution, and consumption of electrical energy. For many applications, Silicon is no longer the first choice here. Wide bandgap semiconductors such as SiC and GaN deliver higher efficiency in a high frequency and temperature range. Passive components such as heat sinks, capacitors, and coils can therefore be smaller in size, which has a positive impact on the form factor of the overall system. This makes them important components for the smart grids of the future. In these intelligent power grids, decentralized distributed intelligence controls the generation, storage, and consumption of energy. As such, the performance fluctuations caused by fluctuating renewable energies must be compensated for. However, smart grids not only transport energy but also data from smart meters, sensors, and other devices. This is another industry segment where the Internet of Things can be found—in fact, electrical grids are even set to become the largest IoT installations of all. This process involves the networking of various components using modern information and communication technology.

With the advent of the "Internet of Things, IoT", the Internet is continuing to force its way deeper into all areas of private and professional life. Sensors play a key role in this development, as they turn every "thing" into a source of data. In doing so, they build bridges between the analogue and digital worlds in vehicles, smart cities, smart factories, smart homes, and in medicine. The sheer variety of applications is naturally leading to explosive growth in the number of different types of sensors available, all of them based on around a dozen basic measurement principles. The development of smart sensors plays a particularly important role in this context. In addition to acquisition, sensors now also combine preparation and processing in a single component. With the help of microprocessors, sensors become interfaces with higher-level systems without the need for an external computer.

In automotive driver assistance systems and comfort functions have led to an enormous increase in the number and variety of sensors on the market. The electrification of drive systems, autonomous driving and connectivity will accelerate this trend even further over the coming decade. Sensors are subject not only to demanding technical requirements, but also to increasingly high expectations regarding cost, miniaturization, strength, and reliability. Even so, meeting the safety requirements for autonomous driving requires the use of multi-sensor systems and combining the data from the widest possible range of sensors (sensor fusion).

Electronica 2018 in Munich from November 13 to 16 will highlight all these trends, and we cover these in detail. Enjoy reading this issue!

**Achim Scharf**
**PEE Editor**

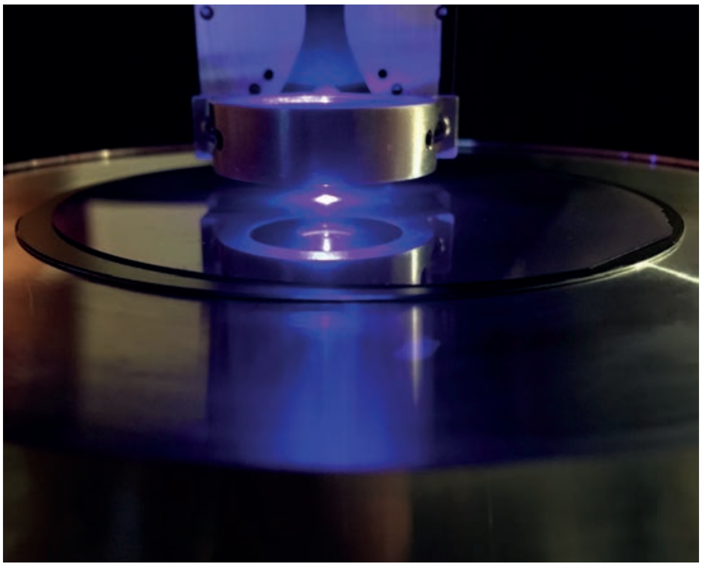
# Commercial Agreement for Compound Semiconductor Applications

The Compound Semiconductor Applications (CSA) Catapult has announce that it has secured its first commercial agreement with the University of Bristol.

The university has developed a technology called TherMap, which uses a non-destructive technique to measure the thermal properties of semiconductor wafers and other multilayer structures. This technique is suitable for most wide bandgap layer structures, such as GaN on SiC, and can be used for in-line process monitoring and yield optimization. The University of Bristol has commissioned the CSA Catapult to provide an analysis of the potential market for this technology in order to inform the commercialization roadmap. The Catapult will interview potential users of the technology to establish their current approach to wafer characterization and inform them about TherMap.

Located in South Wales, the CSA Catapult works collaboratively and has built strong relationships with key players across the UK wafer fabrication industry. This outreach to CSA Catapult's network will enable it to advise the university on how its TherMap technology could be used in innovative applications within the compound semiconductor industry. "This innovation could potentially make a huge difference to the compound semiconductor industry globally by enabling it to assess the quality of semiconductor wafers, improve yield and improve its processes", said Stephen Doran, CEO of CSA Catapult. "TherMap is a development of Bristol's CDTR labs for innovative thermal wafer mapping, the result of many years' of research which we aim to translate into an industry product. We very much appreciate the Catapult's support in exploring the market", added Professor Martin Kuball from the Center for Device Thermography and Reliability (CDTR) Labs at Bristol University.

CSA Catapult is currently in start-up mode to build its full technology capability. Power electronics activities are focused initially on the transportation sector covering, for example, automotive vehicle electrification and more electric aircraft. The power electronics facilities at the new CSA innovation center cover converter and power module modelling, PCB and package design, simulation, system evaluation and reliability testing. The equipment includes programmable AC and DC sources and loads to 500 kW, and an EMC anechoic chamber for pre-compliance radiated emissions and immunity assessment. The team has expertise in system design, simulation and modelling, as well as system level test and evaluation. The Catapult is actively looking to fill positions across all levels of the



TherMap uses a non-destructive technique to measure the thermal properties of semiconductor

organisation and in particular its technology sections, besides power RF & Microwave and Photonics.

The University of Bristol is also offering a free trial service to wafer fabs and device manufacturers around the world, and the Catapult is fielding enquiries from interested fabs.

www.csa.catapult.org.uk

# Overcoming Component Shortage

**Since the launch of the Model 3, Tesla has been under significant pressure to scale up its manufacturing capacity and overcome its current struggle with meeting demand. Currently, the component supply chain is trying to tackle a similar challenge.**

**The need for electronic components is growing exponentially. "In conjunction with our greater use of handheld devices and their relatively short product lifecycles, there is increased use of electronics in industries that did not traditionally use them. The rapid evolution of the automotive industry and internet of things (IoT) are two key factors that have resulted in a stronger-than-expected demand for components, which manufacturers are finding difficult to keep pace with", commented Steve Hughes, managing director of specialist components manufacturer REO UK.**

Like most modern technological devices, automotive systems use multi-layer ceramic capacitators (MLCCs) and traditional combustion engine cars can require approximately 3,000 capacitors, but as cars move from hardware driven machines to software driven machines, their infotainment, driver assistance and comfort systems require even more components. For example, the requirements for display systems, LED lighting, sensors and artificial intelligence (AI) features have all contributed to the inflation of components required by this market. As a result, forecasts suggest that the number of MLCCs

**could rise to 22,000, in just one car in the near future. To add to this, annual production of Electrical Vehicles (EVs) is expected to reach 2.4 million units in 2021, compared to 409,000 in 2014. This substantial rise has been driven by new emissions regulations and incentives from governments and it doesn't appear to be slowing down any time soon. Similarly, IoT devices were nothing but a figment of the imagination 30 years ago, but smart devices are now adding a further burden to an already constrained market. In fact, forecasts show that IoT devices are set to grow to almost 31 billion worldwide and this alone has raised concerns among many manufacturers.**

**"Nearly every industry uses electronic components and we are finding that many customers are double-ordering components and panic-buying to try and eliminate further production delays along the line. However, this does not provide a suitable long-term solution", Hughes commented. "Instead, at REO UK, we are urging businesses to implement a more effective planning strategy and flexible ordering system for their projects, which can strongly protect against any unexpected supply chain issues, such as the current shortage."**

**As it stands, analysts' predictions are varied, but it's expected that the shortage will continue into the early months of 2020 at the very least and so businesses need to set realistic expectations and regularly update their customers to retain good relations. This has been the approach taken by Tesla, which even now is still trying to boost its production output and still generating orders. "This is not the first time there has been long delays for key components in industry and we expect that this will not be the last, especially as buying behavior and purchase decisions can be so unpredictable. By implementing a procedure that allows for longer lead times, managers will be able to better manage operations to respond effectively to fluctuating lead times in the future", Hughes concludes.**

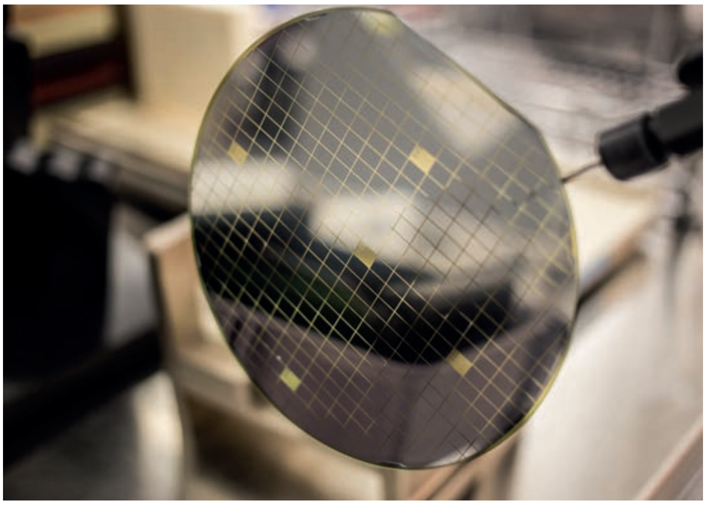
**www.reo.co.uk**

# Doubled 6-Inch SiC Foundry Capacity

X-FAB Silicon Foundries SE (Belgium) will double their 6-inch SiC process capacity at its fab in Lubbock, Texas in response to increased customer demand for high efficiency power semiconductor devices.

Thus X-FAB Texas has purchased a second heated ion implanter for use in manufacturing 6-inch SiC wafers. Delivery of this heated ion implanter is expected by the end of 2018, and production release is planned during the first quarter of 2019 in time to meet projected near-term demand. Advantages of X-FAB's SiC process capabilities for power semiconductors include superior high voltage operation, significantly lower transistor on-resistance, significantly lower transmission and switching losses, extended high temperature operation as high as 400°F/204°C, higher thermal conductivity, very high frequency operation, and lower parasitic capacitance. X-FAB's SiC process capabilities allow customers to realize high efficiency power semiconductor devices including high power MOSFETs, JFETs, and Schottky diodes. "With the rising popularity of SiC we understood, early on, that increasing our ion implant capability would be critical to our continued manufacturing success in the SiC marketplace. This is just the first step in our overall capital plan for SiC-specific manufacturing process improvements", stated Lloyd Whetzel, CEO of X-FAB Texas. X-FAB's Lubbock manufacturing site is certified for automotive manufacturing according to the new IATF-16949:2016 International Automotive Quality Management System (QMS). More than 50 % of X-FAB's revenue is in the automotive sector.

SiC transistors are clearly being adopted, penetrating smoothly into different applications. Yole's recent analyzes forecast a $1.4 billion SiC power semiconductor market by 2023 - showing a 29 % CAGR between 2017 and 2023.



**X-FAB will double their 6-inch SiC process capacity in response to increased customer demand**

**www.xfab.com**

# Study Addresses the Challenges of Embedded 3D Power Packaging

**The Power Sources Manufacturers Association (PSMA) Packaging Committee announces the publication of its latest report titled, "3D Power Packaging with Focus on Embedded Passive Component and Substrate Technologies." This is the third in a series of reports focused on using embedded substrate technology for building power sources. It is the first extensive study of embeddable passive components both available and in development for use in the power path of power sources. The report contains extensive research and product illustrations geared to an audience of technology executives and design engineers.**

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Next to Power Electronic Stacks and IPMs, SEMIKRON offers a broad portfolio of Power Modules for 1500VDC solar applications.

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- Up to 180kW without paralleling
- Baseplate-less design for direct PCB mounting
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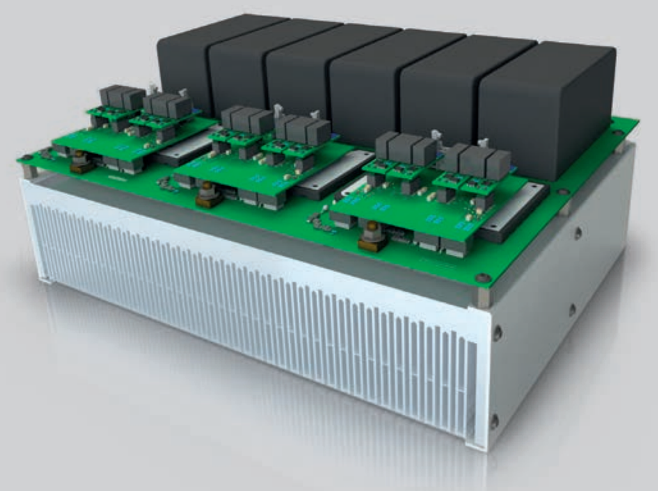
- Ready for 1500VDC solar applications
- Reliable MiniSKiiP SPRiNG technology

## MiniSKiiP Dual Split MLI in string inverters for 1500$V_{DC}$ / 180kW



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Miniaturization of passive components without compromising their power handling and efficiency and their integration with actives has always been a key focus for power packaging. There is also an increasing trend to vertical or 3D package integration to address the performance issues by eliminating parasitics from interconnections. Embedding gives lowest package inductance and enables co-integration of power systems and drivers in a single package with direct interconnection between gate driver circuits and switches with shortest interconnection length. This has become even more important with the rapid emergence of wide bandgap power switching devices. This, however, leads to several process integration and reliability challenges that need to be systematically addressed.

Georgia Tech Packaging Research Center, under contract from PSMA systematically surveyed the recent advances in passives, active embedding and 3D passive-active integration to generate this report, with emphasis on 3D power packaging enabled by advances in passive components and embedding of actives in power packages. A detailed literature study was conducted on key advances in embedded passive technologies and related topics. Emerging nanomaterials, processes and technologies are described in detail for inductors, capacitors and resistors. Nanostructured materials provide additional degrees of freedoms in enhancing the properties to improve the performance metrics such as volumetric density and efficiency of the components. Key enabling building-blocks are described for each technology. The manufacturing challenges are also highlighted in advancing the components to improve performance. Industry leaders were surveyed to get the recent technology advances in each category. Roadmaps are projected for passive component advances and active embedding technologies. The trends and roadmaps in 3D power packaging are also described in three categories: low power (1-100 W), medium power (100-1000 W) and high power (10-100 kW). Integration in each category is classified into lead-frame-based, substrate-embedding based and traditional ceramic substrates. Active embedding with panel-scale substrate manufacturing is also reviewed in detail. Recent innovations in substrate materials and associated reliability challenges such as via cracking, dielectric cracking or electric breakdown are highlighted. Advances in die-attach solutions with sintered nanocopper are reviewed, highlighting the evolution of low-stress sintered copper-based die-attach solutions.

Co-chairs of the PSMA Packaging Committee, Ernie Parker of Crane Aerospace & Electronics and Brian Narveson of Narveson Consulting, described the report as “the first comprehensive document to discuss the challenges companies will face to implement embedded passives in 3D power packaging to create the significantly higher power densities.” The PSMA report on 3D packaging was provided free of charge to PSMA Regular and Associate Company members. Additional copies may be purchased at the member price of $290. PSMA Affiliate members may also purchase the report for $290. The report is available to non-members for purchase $3,490) on the PSMA website.

www.psma.com

# Electric Motors on the Rise

**The electrification of drives is gaining speed. For years, car manufacturers all over the world have been working with hybrid and all-electric vehicles, however a most recent trend is that electric high-performance drives, originating from motorsport technology are gaining increased relevance for the design and development of production vehicles.**

**Nearly all leading manufactures consider cobalt-iron alloys in their development approaches - whether to explore the limits of what is technically possible or to get to know the entire range of the product market. VAC's VACODUR® and VACOFLUX® continue to be the leading solution for highly efficient electric motors. In combination with rare-earth magnet systems, these materials enable a torque, i.e. performance increase of approx. 50 % compared to conventional materials or a weight reduction with constant performance. Motor performance and efficiency can be adapted specifically. Current developments are targeting an improvement of the product portfolio with associated cost neutrality and process-optimized alloys. This brings the use of premium products closer to the use in production vehicles. More at electronica 2018 in hall B4, booth 309.**

www.vacuumschmelze.com

# Electronics Drive the World

The internationally leading Electronics Event, electronica 2018, will take place in Munich from November 13 to 16. At electronica 2016 around 73,450 trade visitors and 2,913 exhibitors were satisfied. At conferences and forums 7,987 participants were registered. After expanding by one hall in 2016, electronica is continuing to grow, and will fill 17 halls, along with its co-located event SEMICON Europa.

"We now can announce the biggest electronica ever with more than 3,000 exhibitors plus 350 within the SEMICON hall", stated electronica general manager Falk Senger. The event is backed by a prosperous industrial environment with exceptional high growth rates, despite the uncertainties due to economical wars between the US and China and declining growth rates in the developing countries, as shown by statistics prepared by the German ZVEI.

After covering the automotive activities at electronica 2018 (PEE September, pages 16-17) other sectors as well as some exhibitors will be highlighted.

**Towards smart energy**

The switch to sustainable generation is bringing about increasing decentralization with huge ramifications for the entire value chain. Smart energy is the umbrella term for a wide range of technologies in this area relating to energy storage, consumption control, and energy conversion. Under the motto "Connecting everything–smart, safe & secure" products and services from a wide range of sectors, all with some connection to this broad topic, will be showcased. The "Power Electronics Forum" will focus on the power electronics, smart grid, and energy storage segments.

More and more customers are becoming "prosumers", i.e. consuming and producing electricity at the same time. Many small power

**Electronica general manager Falk Senger is proud to announce the biggest event ever with an exhibitor increase of five percent**



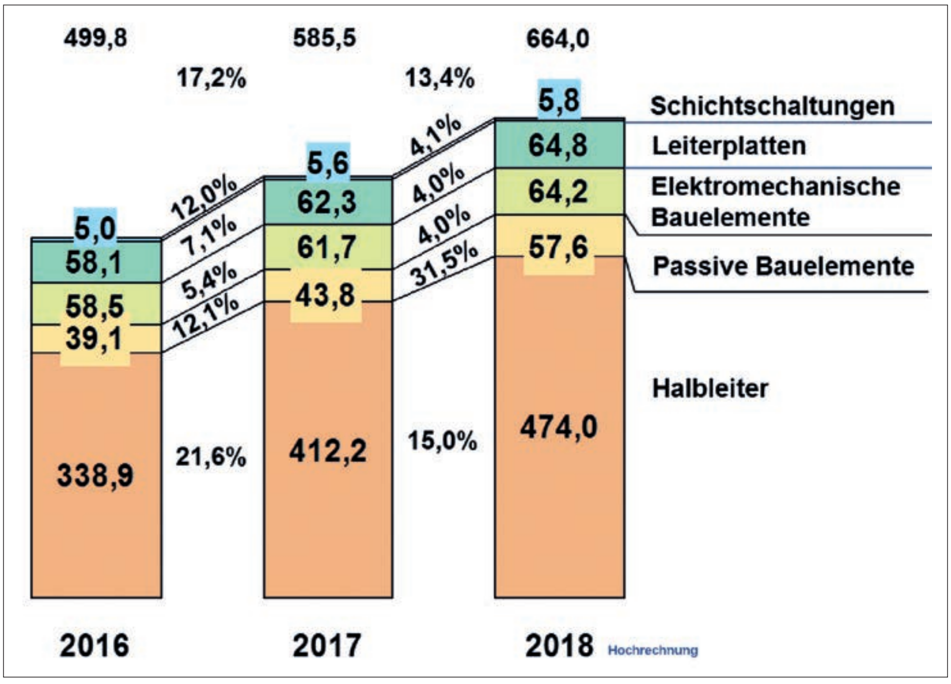
plants are also obtaining energy from renewable resources. This increasingly fragmented, bidirectional, and volatile supply structure urgently requires an intelligent load and generation management system—in other words, a smart grid.

Analysts from Grand View Research expect there to be 285 million smart meters in households, offices, and factories around the world by 2025. This will generate turnover of $50 billion, with coverage somewhere in excess of 50 % according to Navigant Research. But electricity meters are just one component of the smart energy concept. Smart-home and smart-city technologies also cover a whole range of sub-areas. That's why you will find the topic of "intelligent energy" covered in many segments at electronica 2018. These includes wireless and embedded as well as the Internet of Things and autonomous systems. Even electric vehicles have a role to play as flexible storage systems and grid stabilizers.

The Power Electronics Forum will specifically cater to the subject of smart energy. The forum will cover the whole spectrum of power supply units, power stores and power electronics, the last of which is among the key technologies for climate-friendly, resource-saving, yet competitive energy supply. This is because power electronics technology minimizes losses through the conversion, distribution, and consumption of electrical energy. For many applications, Silicon is no longer the first choice here. Wide-bandgap semiconductors such as SiC and GaN deliver higher efficiency in a high frequency and temperature range.

Passive components such as heat sinks, capacitors, and coils can therefore be smaller in size, which has a positive impact on the form factor of the overall system. This makes them important components for the smart grids of the future. In these intelligent power grids, decentralized distributed intelligence controls the generation, storage, and consumption of energy. As such, the performance fluctuations caused by fluctuating renewable energies must be compensated for. However, smart grids not only transport energy but also data from smart meters, sensors, and other devices. This is another industry segment where the Internet of Things can be found—in fact, electrical grids are even set to become the largest IoT installations of all. This process involves the networking of various components using modern information and communication technology. The topic is dealt with in detail in the Wireless Congress.

The Power Supplies exhibition area in halls A5




**Worldwide market growth in $billion of electronic components 2016 – 2018** **(Source: ZVEI)**

# Covering Analog Needs From Simple to Complex

## High-Performance Devices to Handle Every Design Challenge

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and A6 covers the full spectrum of transformers, power supplies, power supply units, and batteries. But that's not the only place where visitors will find smart energy components. Rohm (hall C3, stand 512), will be covering the entire production process from SiC wafers to components right through to packaging.

**Sensors & IoT**

With the advent of the "Internet of Things, IoT", the Internet is continuing to force its way deeper into all areas of private and professional life. Sensors play a key role in this development, as they turn every "thing" into a source of data. In doing so, they build bridges between the analogue and digital worlds in vehicles, smart cities, smart factories, smart homes, and in medicine. The sheer variety of applications is naturally leading to explosive growth in the number of different types of sensors available, all of them based on around a dozen basic measurement principles. The development of smart sensors plays a particularly important role in this context. In addition to acquisition, sensors now also combine preparation and processing in a single component. With the help of microprocessors, sensors become interfaces with higher-level systems without the need for an external computer.

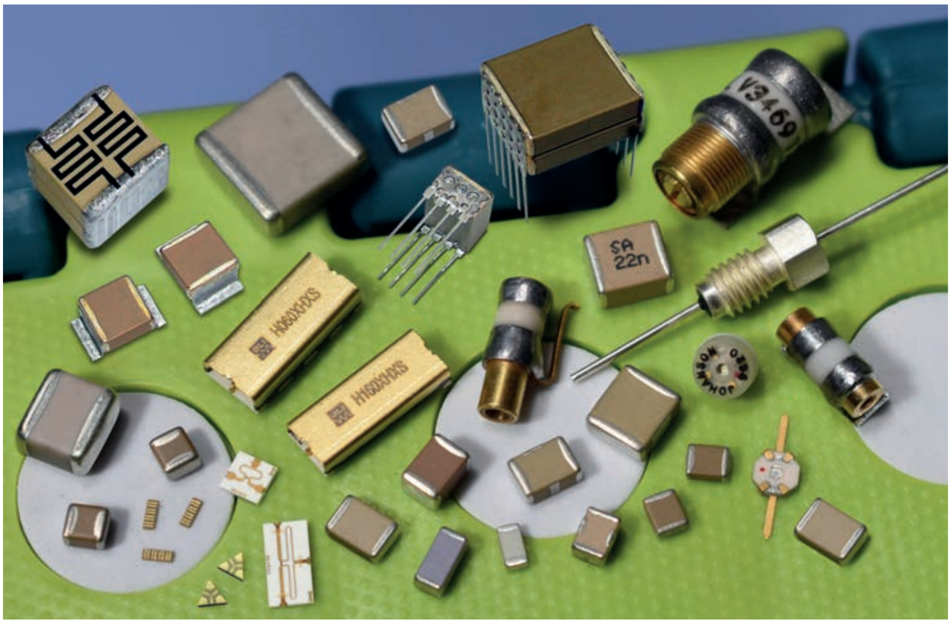
The VDE - a German electronics industry association - believes that the sensor market has enormous potential for growth. It predicts the number of sensors on the market will rise from 10 billion currently to one hundred trillion by 2030. Analysts from Zion Market Research believe that revenues from IoT sensors will grow to $27 billion by 2022, at a compound annual growth rate (CAGR) of over 24 %. High sale figures will come courtesy of Industry 4.0 and the automotive sector, as well as from medical electronics. That's why sensors play a leading role in many areas of the electronica 2018 exhibition, as well as in the electronica conferences.

Sensors are covered within the Automotive


**OnSemi's booth layout focuses on rapidly evolving markets of automotive, high performance power conversion (HPPC) and the Internet of Things (IoT)**

Conference. Driver assistance systems and comfort functions have led to an enormous increase in the number and variety of sensors on the market. The electrification of drive systems, autonomous driving and connectivity will accelerate this trend even further over the coming decade. Sensors are subject not only to demanding technical requirements, but also to increasingly high expectations regarding cost, miniaturization, strength, and reliability. Even so, meeting the safety requirements for autonomous driving requires the use of multi-sensor systems and combining the data from the widest possible range of sensors (sensor fusion).

Sensor technology will play a similarly crucial role at the Embedded Platforms Conference (eEPC) on November 14 and 15. In embedded systems, sensors no longer simply perceive the world around them; they process the measurements they take and increasingly act on them autonomously using machine learning algorithms . In Embedded Vision, sensors are opening up completely new fields for small, smart, image processing systems in the factory of the future, in traffic management, in medicine, and in consumer goods.




**Knowles Precision Devices products portfolio**

The inaugural Medical Electronics Conference (eMEC) on November 15, 2018 will host a range of sensor-based wireless systems designed to gather medical data. In the future, this technology will make individually tailored medical care both cheaper and more effective. To do so, however, it will have to meet the medical sector's stringent accuracy and reliability requirements. Applications for use close to the body require the development of additional bio-compatible sensor housings as well as secure, gas-tight encapsulations.

Alongside the conferences, manufacturers, specialists and technical managers can take a look at the latest trends in sensor technology and discuss the latest market and technological developments with experts and colleagues on all four days of the Automotive Forum (Hall B4), Embedded Forum (Hall B5) and IoT Forum (Hall C5). A new addition this year is "TechTalks"—a format focusing on technical depth and explicitly targeted at engineers and developers.

**On the exhibition floor**

Theory discussed within conferences and forums will be on display in practice on the exhibition floor, following a few examples.

KEMET (**www.kemet.com**) will use Electronica 2018 to begin its 100-year celebrations. The company will also showcase its latest technologies in hall B6, stand 143, to address the needs of fast moving market sectors including the Internet of Things (IoT) and the electrification of the powertrain and other systems in automotive. Founded in 1919, KEMET has played a leading role in driving passive component technology. The company offers a broad range of tantalum, ceramic, film and electrolytic capacitors. By acquiring TOKIN, the company also now offers complementary, adjacent, sensing, actuator and magnetic


**Panasonic's stand layout featuring the Hyperloop transportation system as an application example for various electronic devices**

components and technologies. A range of hands-on demonstrations will focus on the latest products for key target markets. A further interactive timeline feature will allow visitors to experience the company's 100-year journey and see how much technologies have evolved in that time.

Two years of innovating product lines and expansion through acquisitions sees a re-branded Knowles Precision Devices (**www.knowlescapacitors.com**) return to Electronica 2018 in hall B6 on stand 336. New and evolving markets, including automotive, defense, mobile, industrial, and internet of things (IoT) are creating surges in demand for passive components. As a result, some manufacturers are unable to fulfil orders, particularly in the electric vehicle (EV) market, and are ceasing production of mature lines or slimming down ranges in favor of newer and more profitable products. Knowles Precision Devices has continued to support a range of capacitor products for automotive applications, AEC-Q200 qualified, and is poised to offer solutions not considered catalog items. The HiT range of MLCCs are designed to meet the needs of high-voltage EV applications, with an operating temperature range of -55 to +200ºC. Specifications encompass both Stable (C0G) and ultra-stable (X7R) dielectric options in case sizes 0805 to 2220, with capacitance spread of 4.7 pF to 3.3 µF, and rated voltages of 16 to 630V DC. The specified max capacitor values for the 500/630 V parts has recently been increased to an upper limit of 68 nF, with the addition of an 0603 case size in X7R material.

Infineon Technologies (**www.infineon.com**) have a new stand position in hall C3 at booth 502. As the leader in power semiconductors in Si and SiC technologies, the company shows how it is empowering the automotive industry to make cars that are safer, smarter and more climate-friendly. A broad application spectrum spanning zero-emissions eMobility solutions, smart city infrastructures that build renewables into intelligent recharging grids, and automated driving features where the driver becomes a passenger will be addressed. Solutions for data centers, chargers and adapters fully leverage the performance gains of GaN for high-speed switching applications in consumer and industrial applications.

OnSemi's (**www.onsemi.com**) new products and enlightening demonstrations in hall C4, booth 101, are focused on solutions for the key and rapidly evolving markets of automotive, high performance power conversion (HPPC) and the Internet of Things (IoT). At the Automotive Conference the company will lead a discussion about how highly innovative and energy efficient semiconductor solutions will accelerate the path of vehicle manufacturers to their goal of autonomous driving. In the automotive world, the company's semiconductor and sensing technologies will address megatrends within vehicle electrification, autonomous driving and lighting technology. Demos will showcase components and system solutions including SiC devices, IGBTs, MOSFETs and power modules for vehicle electrification, imaging, radar and LiDAR for ADAS and autonomous driving, and energy-efficient power management and control for front, rear and internal lighting applications. Addressing energy infrastructure, ON Semiconductor will demonstrate highly reliable and efficient devices housed in innovative packaging concepts that support applications such as solar power, energy storage and EV charging. In addition, a range of MOSFETs, IGBTs, Power Integrated Modules (PIMs), and Intelligent Power Modules (IPMs) as well as fully integrated drivers for all motor types will offer a solution to most factory automation challenges. In cloud applications, power conversion systems solutions will show space and energy savings, which translates to significant cost reductions for server farm operators and other end users. New materials, such as SiC diodes, will continue to advance the energy revolution.

On stand B5-564, Panasonic (**http://industry.panasonic.eu**) will be highlighting innovations and components, as well as its core competencies as a design accelerator. In transportation the company is showcasing its involvement and sponsorship with the Hyperloop transportation concept, as well as its other projects in the field of e-mobility. Hyperloop is a new transportation concept where a high-speed train travels in a near-vacuum tube which allows the capsule to travel at supersonic speed – faster than any commercial train or car will be able to in the foreseeable future. In pursuit of this vision, SpaceX founder Elon Musk launched the "Hyperloop Pod Competition". The WARR Hyperloop team from the Technical University in Munich (TUM) won the latest international annual SpaceX Hyperloop Pod Competition this year. The WARR Hyperloop Pod, as well as the levitation demo will be on display, demonstrating how Panasonic Industry's sensor, resistor and relay portfolio played a significant role in achieving the goals of miniaturization and increased efficiency. For mobility Panasonic delivers many products, from passive components to all in-car electrical applications such as airbags, brake systems, lighting systems, and control panels. In addition, input devices for radio, navigation, steering wheels and human-machine-interface are on display. Sensors are used primarily for monitoring and detecting, while semiconductors focus on power electronics and battery management solutions.

ROHM (**www.rohm.com/eu**) will present in hall C3, stand 512, new solutions for power and energy management in the automotive and industrial sectors as well as its commitment to Formula E. Highlights include demonstrations from


**ROHM's stand layout featuring various power & SiC technology as well as the Venturi Formula E racing car**


**Vacuumschmelze exhibits a line of nanocrystalline magnetic materials also for automotive applications**

updates of new power devices such as 1700 V SiC module and other SiC devices, Power Management ICs and sensor technologies for the automotive and industrial market. For automotive applications, the company will show the latest generation of SiC-based inverters, human interface solution, car infotainment, PMIC and high reliability discrete components. New solutions for the industry sector will be presented including 99 % efficiency SiC inverters, application example of a solar inverter, on-board charger, power supply and EV charging station. Further applications showcase AC/DC and DC/DC converter ICs, motor drivers and sensors together with new IGBTs and high-speed switching MOSFET (Presto MOS Series) devices. SiC power modules for the Formula E Venturi racing car inverter block, forms the core of the drive system. The latest generation of inverters and the Formula E racing car of the fifth season as an application example for SiC power modules will be shown.

Vacuumschmelze (**www.vacuumschmelze.com**) will exhibit in hall B4, booth 309, a new series of highly permeable cores. The highly permeable nanocrystalline toroidal and oval cores are offered in different dimensions and with different permeability levels betwenn 30,000 and 100,000. Due to the high saturation flux density, they are ideally suited for damping common mode interference. Further benefits include AECQ200 qualification and technical cleanliness in accordance with VDA Volume 19. The combination of rotor-stator systems made of cobalt-iron and Vacomax 262 HR permanent magnet systems, also contributes to the wide range of products for automotive applications. The unique high-performance materials enable torque increases of typically up to 30 % as well as an associated weight reduction of the overall system. Vacomax 262 HRP allows torque and acceleration to be maximized in the smallest and most reliable size at application temperatures exceeding 130°C. Due to the low temperature coefficient of remanence, this alloy offers higher flux values than any other NdFeB magnet available today, as underlined by Norman Lemm, Director of Business Intelligence & Marketing. The differential current sensor "benvac" will also be on display. Benvac is a joint development of Bender GmbH & Co. KG and VACUUMSCHMELZE. This sensor is used in the safety shut-off of the IC-CPD (In-cable Control and Protection Device), which is used when charging electric vehicles.

Wolfspeed (**www.wolfspeed.com**) will showcase at the MEV booth 536 in hall C3 the E-Series™, a new family of robust SiC semiconductor devices for the EV and renewable energy markets. The E-Series family is the first commercial family of SiC MOSFETs and diodes to be automotive AEC-Q101 qualified and PPAP capable. The designation makes it the only commercially available family of SiC MOSFETs and diodes that meet high-humidity and automotive qualifications to deliver some of the most reliable and corrosion-resistant components. Among others the 900V SiC MOSFET is optimized for use in EV battery chargers and high voltage DC/DC converters and is featured in Wolfspeed's 6.6kW B-Directional On-Board Charger reference design. The new E-Series Merged-PIN Schottky Diodes (MPS) deliver high reliability for on-board power conversion systems and solar inverters, complementing the existing AEC-Q101 qualified 650 V SiC diode portfolio. The diodes deliver a 1200 V blocking capability with a current rating up to 20 A at 175?C junction temperature.


**Würth Elektronik eiSos presents among others a new resistor family for current measurements**

Würth Elektronik eiSos (**www.we-online.com**) is represented with four booths: B6-404, C3-151, A6-314 and hall C6-200. The highlights include the launch of the new product groups - resistors, sensors as well as quartz crystals and oscillators. The Resistors product group is unveiled or the first time at electronica 2018, namely: firstly resistors for current measurement applications. These include metal plate resistors, which, with their very low resistance values down to 10 mΩ, are used to measure currents up to 50 A. The second resistor group, the thick film resistors, are used to measure low currents in the hundredth-Ampere range. The resistance values in the low to medium range are from 100 mΩ to 270 Ω. The focal point of the Würth Elektronik eiSos trade show presence is the main booth no. 404 in Hall B6 with its twelve thematic areas. Here the group of companies demonstrates its innovative strength on the basis of typical examples. Horticulture LEDs are to be seen on the "Optoelectronic Solutions" thematic area, for instance, which can be matched to special plant breeding requirements in a greenhouse. The theme of "EMC Shielding and Cable Solutions" is promoted with interesting experimental setups on suppression and the filter effect of components. Other thematic areas are dedicated to "EMC Onboard Solutions", "Connector Solutions", "Electromechanical Solutions", "RF & Frequency Solutions", "Signal & Communications Solutions", as well as two stations with Power Management Solutions. Reference designs with IC partners at the "Design & Support" thematic are also presented. Within automotive standard products a rrich portfolio of EC-Q-qualified products is shown, like the WE-CHSA high current inductor with up to 57 A saturation current. Power modules – a 4-channel MagI?C module LED driver solution with microcontroller and a MagI?C module as supercap charger - these are example applications for DC/DC converters with integrated controller IC, inductor and capacitors. **AS**

175 °C for 2,000 hours at rated voltage
High performance, high temperature capacitor
Withstands vibrations up to 20G's
TAKES THE HEAT. SHAKES OFF THE G'S.
Our HHT capacitor goes where others can't. At 175 °C, it's rated for 2,000 hours and withstands vibrations up to 20G's. And at 150°C, the HHT is rated at an industry-best 5,000 hours. That's 3,000 hours longer than the competition. For extreme off-highway applications, the HHT capacitor is the obvious choice.
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# LiDAR and TOF Applications Low-Side GaN Driver

Distributor Mouser Electronics is now stocking the LMG1020 GaN driver from Texas Instruments. The single, low-side driver enables efficient, high-performance designs in speed-critical applications such as LiDAR (Light Detection And Ranging), time-of-flight (TOF) laser drivers, facial recognition, augmented reality, and class E wireless chargers.

LMG1020 is a low-side 5-V gate driver for GaN and logic-level Silicon power transistors. While it is designed for high-speed applications, such as wireless power transmission and LiDAR applications, it is a high-performance solution for any other low-side driving applications. The drive is optimized to provide the lowest propagation delay to the power transistor.

To operate GaN transistors at very high switching frequencies and to reduce associated switching losses, a powerful gate driver is employed between the PWM output of controller and the gates of the GaN transistor. Also, gate drivers are indispensable when the outputs of the PWM controller do not meet the voltage or current levels needed to directly drive the gates of the switching devices.


LMG1020 package

With the advent of digital power, this situation is often encountered because the PWM signal from the digital controller is often a 3.3 V logic signal, which cannot effectively turn on a power switch. A level-shift circuit is needed to boost the 3.3 V signal to the gate-drive voltage (such as 5 V) in order to fully turn on the power device and minimize conduction losses.

Gate drivers effectively provide the buffer-drive functions. Gate drivers also address other needs such as minimizing the effect of high-frequency switching noise (by placing the high-current driver IC physically close to the power switch), reducing power dissipation and thermal stress in controllers by moving gate charge power losses from the controller into the driver.

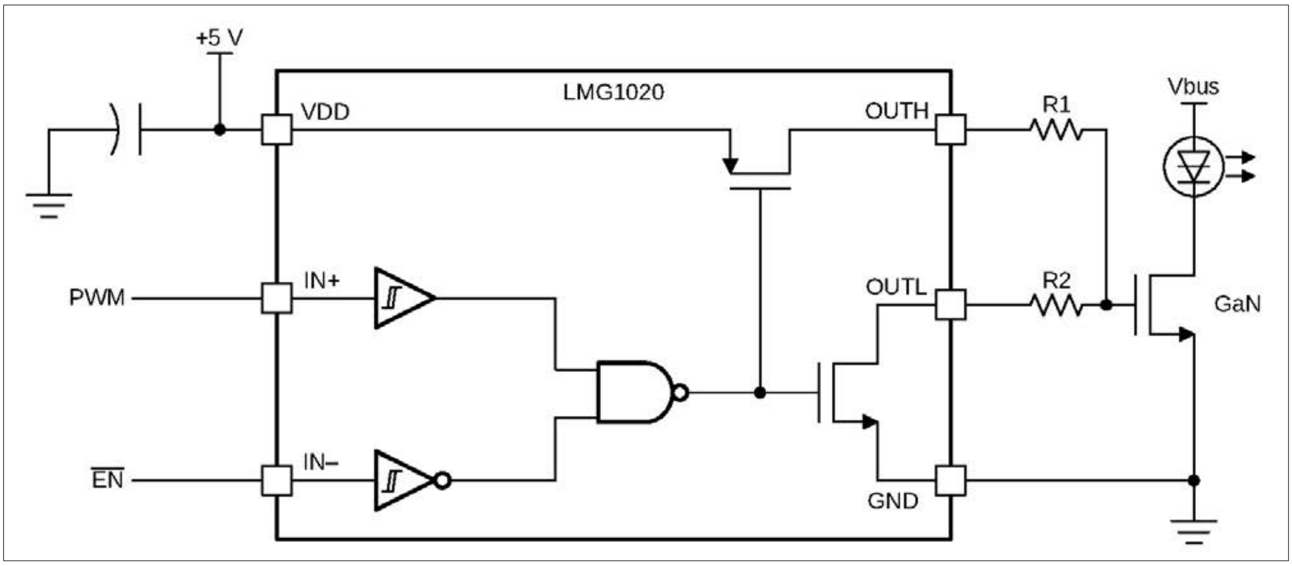
**GaN gate driver specifications**

LMG1020 is in a small 0.8 mm × 1.2 mm WCSP ball-grid array package in order to minimize its parasitic inductance. This low inductance design helps achieve high current, low ringing performance in very high frequency operation when driving power FETs.

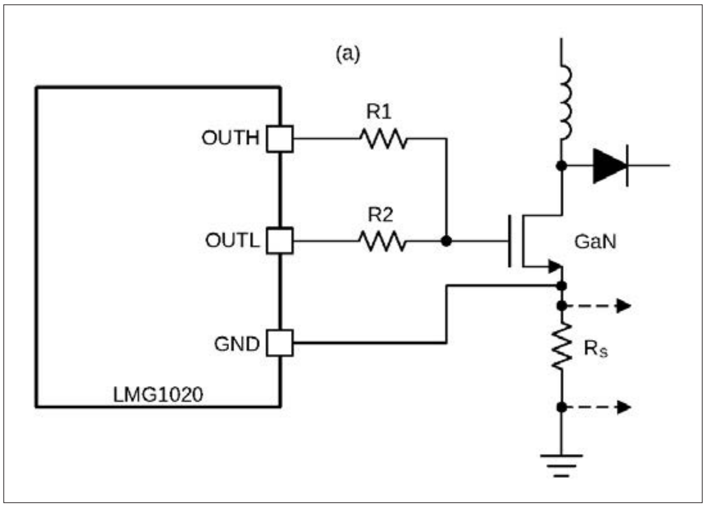
The input stage features two Schmitt-triggers at the pins IN+ and IN– to reduce sensitivity to noise on the inputs. IN+ signal and the inverted IN– signal are both sent to an AND gate. IN+ is connected with a pull-down resistor while IN– is connected with a pull-up resistor to prevent unintended turn-on. The output signal will follow the difference between IN+ and IN–. Both IN+ and IN– are single ended inputs, and these two pins cannot be used as a differential input pair.

The driver provides 7-A source, 5-A sink (asymmetrical drive) peak-drive current capability, and features a split output configuration. The OUTH and OUTL outputs allow to use independent resistors connecting to the gate. The two resistors allow the user to independently adjust the turn-on and turn-off drive strengths to control slew rate and EMI, and to control ringing on the gate signal. For GaN FETs, controlling ringing is important to reduce stress on the GaN FET and driver. The output stage OUTL is also pulled down in under-voltage condition, which prevents the unintended charge accumulation of device $C_{iss}$.

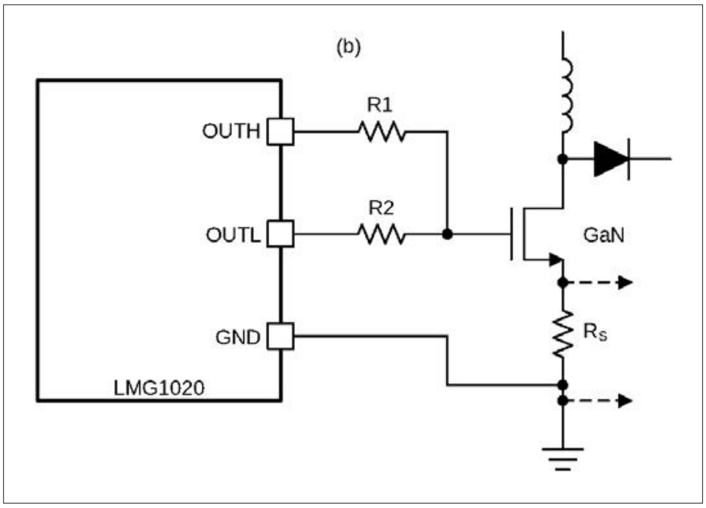
The driver features nominal 5 V and maximum 5.25 V of supply voltage, and its absolute maximum supply voltage is 5.75 V. In the design, it is recommended to limit the variability of the power supply to be within 5 % (0.25V), and the overshoot voltage during switching transient not to exceed




Typical LMG1020 implementation




Source resistor current sense a) configuration




Source resistor current sense b) configuration

the absolute maximum voltage.

LMG1020 also features internal undervoltage lockout (UVLO) to protect the driver and circuit in case of fault conditions. The UVLO point is setup between 4.1 V and 4.2 V with a hysteresis of 85 mV. This UVLO level is specifically designed to guarantee that GaN power devices can be switched at a low RDS(ON) region. During UVLO condition, the OUTL is pulled down to ground.

LMG1020 features over-temperature protection (OTP) function by having a rising edge trigger point at around 170°C. With a hysteresis of 20 K, the device can restart to operate when junction temperature is below 150°C.

**Typical applications**

The LMG1020 is a 60-MHz low-side gate driver for enhancement mode GaN FETs and Si FETs in a single-ended configuration. The split-gate outputs with strong source and sink capability provides flexibility to adjust the turn-on and turn-off strength independently. As a low side driver, LMG1020 can be used in a variety of applications, including different power converters, LiDAR, time-of-flight laser drivers, class-E wireless chargers, synchronous rectifiers, and augmented reality. LMG1020 can also be used as a high frequency low current laser diode driver, or as a signal buffer with very fast rise/fall time.

The LMG1020 is designed to be used with a single low-side, ground-referenced GaN or logic-level Si FET, as shown in the typical implementation. Independent gate drive resistors, R1 and R2, are used to independently control the turn-on and turn-off drive strengths, respectively. For fast and strong turn-off, R2 can be shorted and OUTL directly connected to the transistor's gate. For symmetric drive strengths, it is acceptable to short OUTH and OUTL and use a single gate-drive resistor. It is recommended using at least a 2 Ω resistor at each OUTH and OUTL to avoid voltage over-stress due to inductive ringing. Ringing overshoot must not exceed the maximum absolute supply voltage.

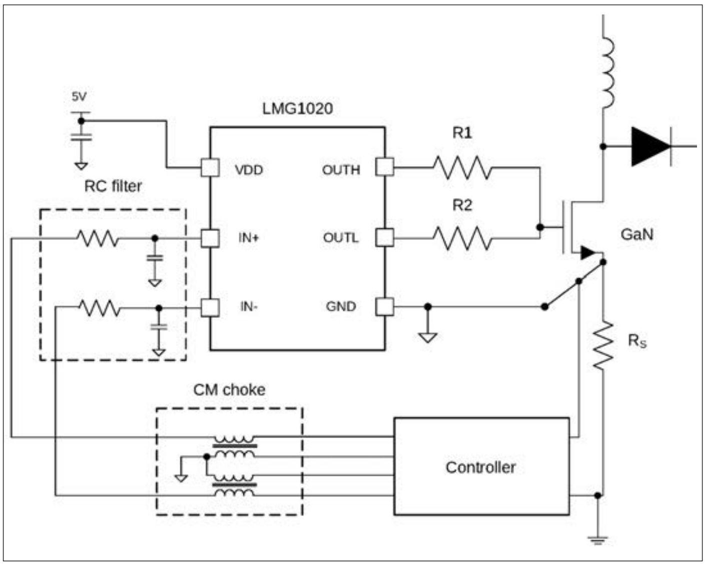
When designing a multi-MHz (or nano-second pulse) application that incorporates the LMG1020 gate driver and GaN power FETs, some design considerations must be evaluated first to make the most appropriate selection. Among these considerations are layout optimization, circuit voltages, passive components, operating frequency, and controller selection.

For the best switching performance and gate loop with lowest parasitics, it is recommended to connect the ground return pin of LMG1020 as close as possible to the source of the low-side FET in a low inductance manner. However, doing so can cause the ground of LMG1020 to bounce relative to the system or controller ground and lead to erroneous switching logic on the input so as mis-turn on/off on the output.

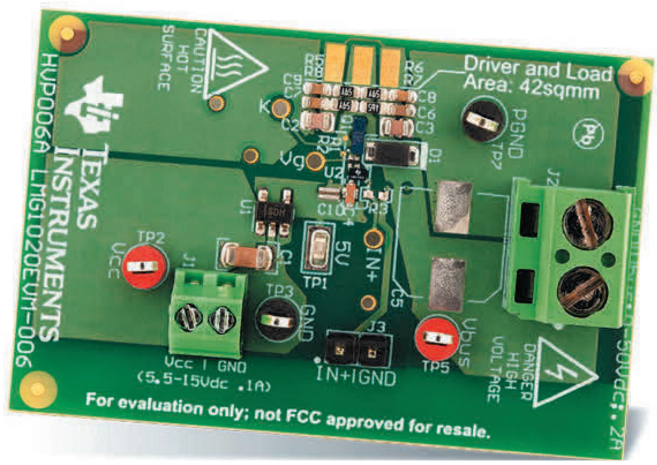
For an assumed parasitic inductance of 0.5 nH and a minimum hysteresis of 0.5 V, the maximum slew rate is 1 A/ns. Many applications would exhibit higher current slew rates, up to the 10 A/ns range, which would make this approach impractical. The stability of this approach can be improved by using the IN– input for the PWM signal and locally tying IN+ to VDD. By using the inverting input, the transient voltage applied to the input pin reinforces the PWM signal in a positive feedback loop. While this approach would reduce the probability of false pulses or oscillation, the transient spikes due to high di/dt may overly stress the inputs to the LMG1020. A current-limiting, 100 Ω resistor can be placed right before the IN– input to limit excessive current spikes in the device.

Secondly, for moderate ground-bounce cases, a simple R-C filter can be built with a simple resistor in series with the inputs. By utilizing the input capacitance of LMG1020, the resistor could be close to its input pin. The addition of a small capacitor on the input as supplement can also be helpful. A small time constant of the R-C filter can can enough to filter out high frequency noises. This solution is acceptable for moderate cases in applications where extra delay is acceptable and the pulse width is not extremely short such as 1ns range. For more extreme cases, or where no delay is tolerable while pulse width is extremely short, using a common-mode choke provides the best results.

One example application where ground-bounce is particularly challenging is when using a current sense resistor. In configuration a (Source Resistor Current Sense) ground is connected to the source of GaN FET, while the controller ground is connected to the other side of the current sense resistor. Due to the fast switching and very fast current slew rates, the high ground potential bounce induced by inductance of the sense resistor can disrupt the operation of the circuit or even damage the part. To prevent this,




Filtering for ground bounce noise handling




**LMG1020-HB-EVM for LiDAR application**

a common-mode choke can be used for IN+ and IN–, respectively. Resistors can also added to the signal output line before LMG1020 depending on the input signal pulse width to provide additional RC filtering. Filtering For Ground Bounce Noise Handling presents the schematic using approach a with the preferred filtering method.

Approach b (Source Resistor Current Sense) places the current sense resistor within the gate drive loop path. In this case, the LMG1020 GND pin is connected to the signal ground, and with good ground plane connection, the ground bounce issue can be less severe than approach a. However, the inductance of the current sense resistor adds common-source inductance to the gate drive loop. The voltage generated across this parasitic inductance will subtract from the gate-drive voltage of the FET, slowing down the turn-on and turn-off di/dt of the FET, or even cause mis-turn on and off. Additional gate resistance will have to be added to ensure the loop is stable and ring-free. The slower rise may negate the advantage of the fast switching of the GaN FET and may cause additional losses in the circuit. Therefore, this approach is not recommended.

The driver can be used to drive pulses of nanoseconds duration on to a capacitive load. LMG1020 can be driven with a equivalently short pulse on one input pin. However, this takes a sufficiently strong digital driver and careful consideration of the routing parasitics from digital output to input of LMG1020. Two inputs and included AND gate in LMG1020 provide an alternate method to create a short pulse at the LMG1020 output. Starting with both IN+ and IN– at low, taking IN+ high will cause the output to go high. Now if IN– is taken high as well, output will be pulled low. So a digital signal and its delayed version can be applied to IN+ and IN– respectively to create a pulse at the output with width corresponding to the delay between the signals.

## LiDAR EVM

The LMG1020-HB-EVM is designed to evaluate the LMG1020 driver for GaN FETs, it consists of one GaN eFET driven by one LMG1020 and with the source connected to a resistive load emulating a laser diode for LiDAR applications. This board is not intended to be used as a standalone product but it intended to evaluate the switching performance of LMG1020.

The LMG1020-EVM is a small, easy-to-use power stage with integrated resistive load. It takes a short-pulse input that can either be buffered (and shorten further), or passed directly to the power stage. The input pulse is signal is used to pulse the current through the load, to achieve 1-2 ns wide current pulses, which are the state-of-the-art target for LiDAR systems. The EVM features a LMG1020 low side nanosecond driver, driving a single EPC2039 FET referenced to ground and with the drain connected to the resistive load. The load is split between two current loops to reduce the effective inductance. The board has larger pads on which a laser diode of choice can be mounted.

**www.mouser.com/ti-lmg1020-gan-driver**

# Why and How Isolated Gate Drivers

An IGBT/power MOSFET is a voltage-controlled device which is used as a switching element in power supply circuits or motor drives. 'Gate' is the electrically isolated control terminal for each device. Other terminals of a MOSFET are source and drain; as are emitter and collector for an IGBT. To operate a MOSFET/IGBT, typically a voltage has to be applied to the gate relative to the source/emitter of the device. Dedicated drivers are used to apply voltage and provide drive current to the gate of the power device. This article discusses what these gate drivers are, why they are required and how their fundamental parameters such as timing, drive strength, isolation are defined. **Sanket Sapre, Applications Engineer, Analog Devices, Norwood, USA**

**Structure of an IGBT/power MOSFET is** such that the gate forms a non-linear capacitor. Charging the gate capacitor turns the power device on and allows current flow between its drain and source terminals while discharging it turns the device off and a large voltage may then be blocked across the drain and source terminals. The minimum voltage when the gate capacitor is charged and the device can just about conduct is the threshold voltage $V_{TH}$). For operating an IGBT/power MOSFET as a switch, a voltage sufficiently larger than $V_{TH}$ should be applied between the gate and source/emitter terminals.

Consider a digital logic system with a microcontroller which can output a PWM signal of 0-5 V on one of its I/O pins. This PWM would not be enough to fully turn on a power device used in power systems as its overdrive voltage generally exceeds the standard CMOS/TTL logic voltage. Thus, an interface is needed between the logic/control circuitry and the high power device. This can be implemented by driving a logic level n-channel MOSFET which in turn can drive a power MOSFET as seen in Figure 1a.

As in Figure 1a, when IO1 sends out a low signal, $V_{GSQ1} < V_{THQ1}$ and thus MOSFET Q1 remains off. As a result, a positive voltage is applied at the gate of power MOSFET Q2. The gate capacitor of Q2 ($C_{GQ2}$) charges through pull up resistor R1 and the gate voltage is pulled to the rail voltage of $V_{DD}$. Given $V_{DD} > V_{THQ2}$, Q2 turns on and can conduct. When IO1 outputs high, Q1 turns on and $C_{GQ2}$ discharges through Q1. $V_{DSQ1}$ ~ 0V such that $V_{GSQ2} <$ $V_{THQ2}$ and hence, Q2 turns off. One issue with this setup is of power dissipation in R1 during on state of Q1. To overcome this, pMOSFET Q3 can be used as a pull up to operate in a complementary fashion with Q1 as seen in Figure 1b. PMOS has a low on state resistance and with its very high resistance in the off state, power dissipation in the drive circuit is greatly reduced. To control edge rates during gate transition, a small resistor is externally added between drain of Q1 and gate of Q2. Another advantage of using a MOSFET is the ease of fabricating it on a die as opposed to fabricating a resistor. This distinct interface to drive the gate of a power switch can be created in the form of a monolithic IC which accepts a logic level voltage and generates a higher power output. This 'gate driver' IC will almost always have additional internal circuits for greater functionality but it primarily works as a power amplifier and a level shifter.

## Key parameters of a gate driver

Drive Strength: The issue of providing appropriate gate voltage is addressed by using a gate driver which does the job of a level shifter. The gate capacitor though, cannot change its voltage instantaneously. Thus, a power FET or IGBT has a non-

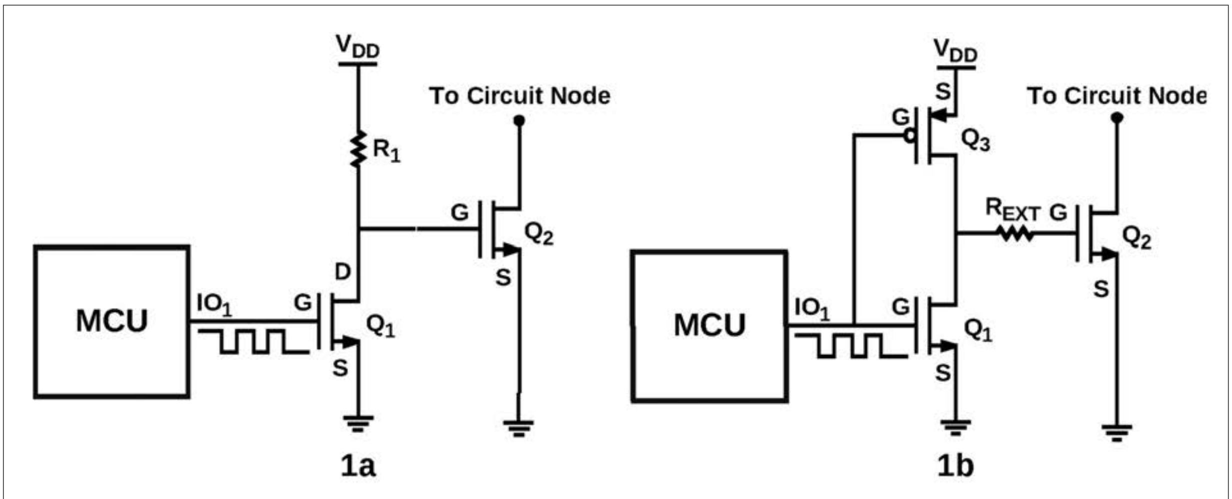



**Figure 1: Power MOSFET driven with inverted logic**

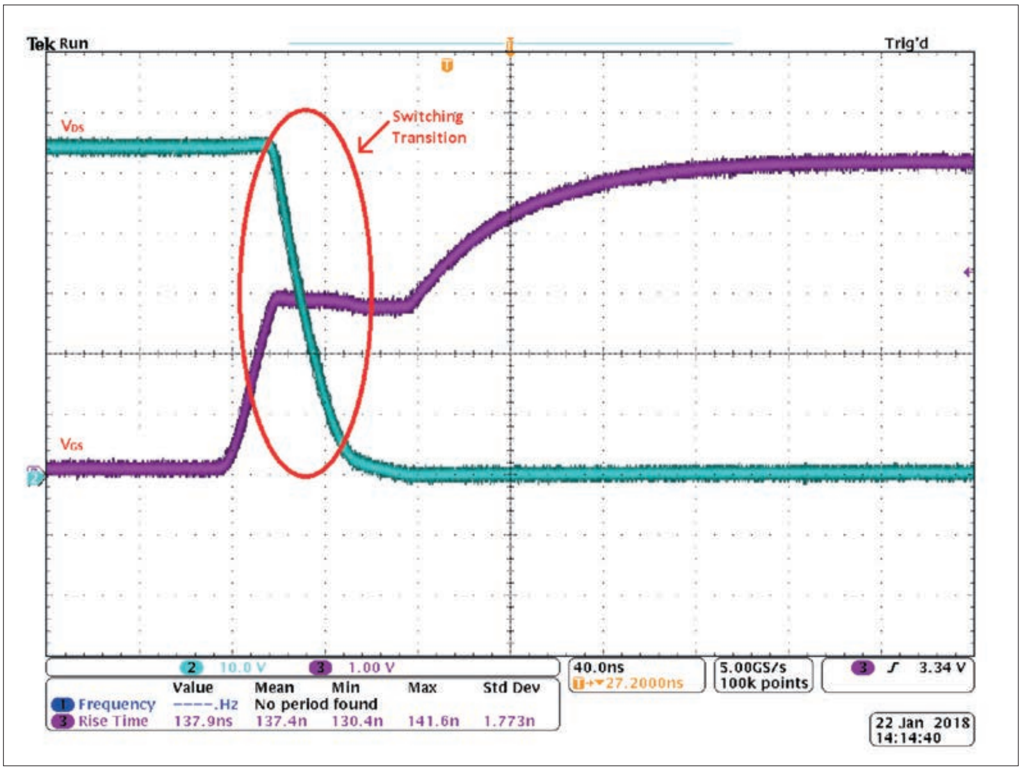



**Figure 2: MOSFET turn on transition without a gate driver**

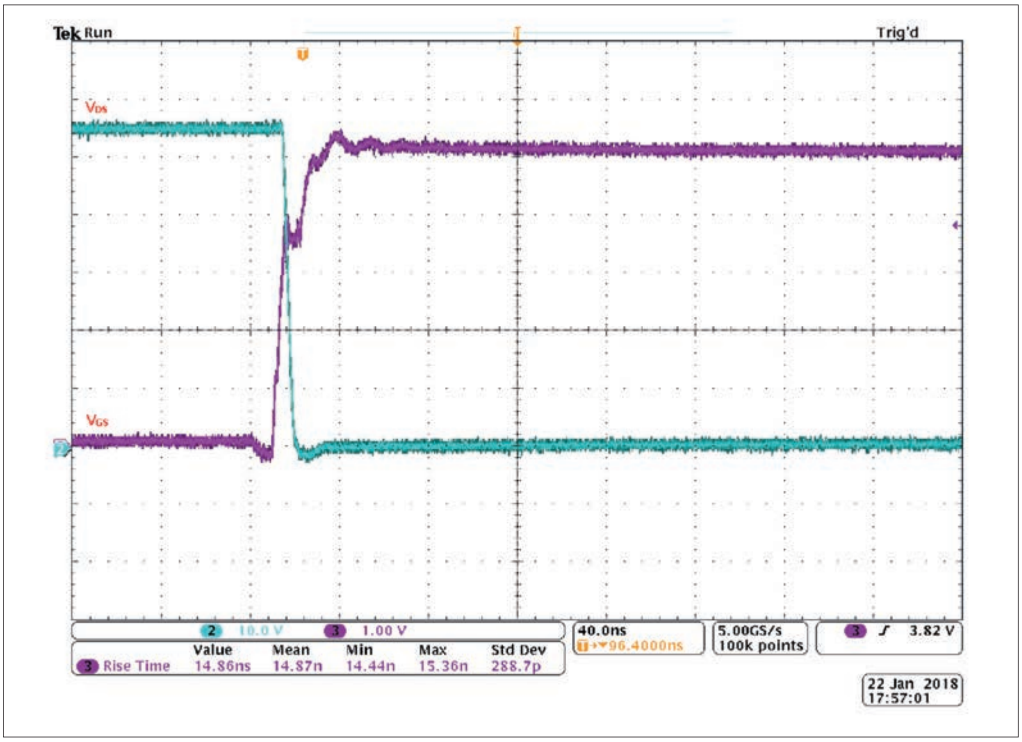



**Figure 3: MOSFET turn on transition with a gate driver**

zero, finite switching interval. During switching, the device may be in high current and high voltage state which results in power dissipation in the form of heat. Thus, transition from one state to another needs to be fast so as to minimize switching time. To achieve this, a high transient current is needed to charge and discharge the gate capacitor quickly.

A driver which can source/sink higher gate current for a longer time span produces lower switching time and thus lower switching power loss within the transistor it drives.

The source and sink current rating for the I/O pins of a microcontroller is typically up to tens of milliamps whereas gate drivers can provide much higher current. In Figure 2, a long switching interval is observed when a power MOSFET is driven by a microcontroller I/O pin at its maximum rated source current. As seen in Figure 3, transition time reduces significantly when ADuM4121 isolated gate driver which provides much higher drive current than a microcontroller I/O pin drives the same power MOSFET. In many cases though, driving a larger power MOSFET/IGBT directly with a microcontroller might overheat and damage the control due to a possible current overdraw in the digital circuit. A gate driver, with higher drive capability, enables fast switching with rise and fall times of a few nanoseconds. This reduces the switching power loss and leads to a more efficient system. Hence, 'drive current' is usually considered to be

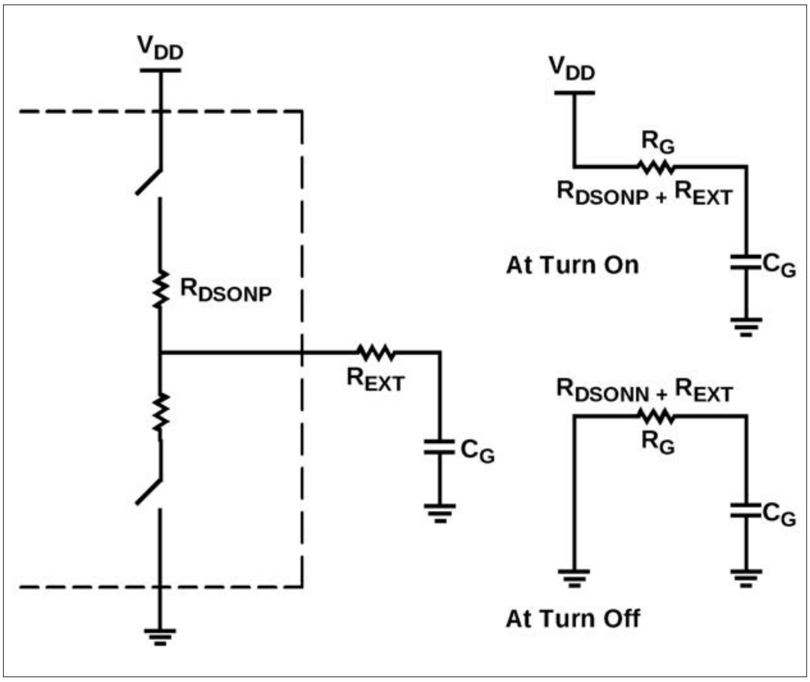



**Figure 4:** **RC circuit model for a gate driver with MOSFET output stage and power device as a capacitor**

an important metric in selection of gate drivers.

Corresponding to the drive current rating is the Drain-Source On Resistance termed $R_{DS(ON)}$ metric of a gate driver. While ideally $R_{DS(ON)}$ value should be zero for a MOSFET when fully on, it is generally in the range of a few Ohms due to its physical structure. This takes into account the total series resistance in the current flow path from drain to source.

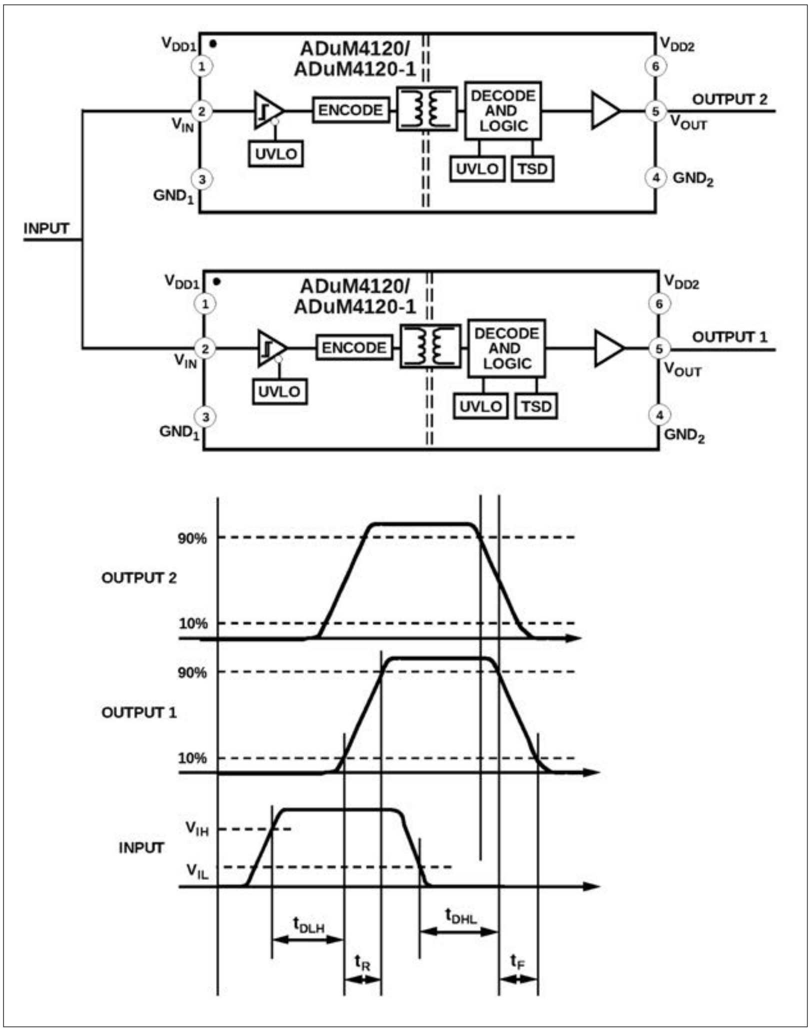
$R_{DS(ON)}$ is the true basis for maximum drive strength rating of a gate driver as it limits the gate current that can be provided by the driver. $R_{DS(ON)}$ of the internal switches determines sink and source current but external series resistors are used to reduce drive current and thus affect edge rates. As seen in Figure 4, high side on resistance and external series resistor $R_{EXT}$ form the gate resistor in the charging path and low side on resistance with $R_{EXT}$ forms the gate resistor in the discharging path.

$R_{DS(ON)}$ also directly affects power dissipation internal to the driver. For a specific drive current, lower value of $R_{DS(ON)}$ allows higher $R_{EXT}$ to be used. As power dissipation is distributed between $R_{EXT}$ and $R_{DS(ON)}$, higher value of $R_{EXT}$ implies more power is dissipated external to the driver. Hence, to improve system efficiency and to relax any thermal regulation requirement within the driver, lower value of $R_{DS(ON)}$ is preferred for the given die area and size of the IC.

Timing: Gate driver timing parameters are essential to evaluate its performance. A common timing specification for all gate drivers including ADuM4120 shown in Figure 5, is the propagation delay ($t_D$) of the driver which is defined as the time it takes an input edge to propagate to the output. As in Figure 5, rising propagation delay ($t_{DLH}$) may be defined as the time between input edge rising above input high threshold $V_{IH}$ to the output rising above 10 % of its final value. Similarly, falling propagation delay ($t_{DHL}$) can be stated as the time from input edge falling below input low threshold $V_{IL}$ to the time output falls below 90 % of its high level. The propagation delay for output transition can be different for a rising edge and a falling edge.

Figure 5 also shows the rise and fall times of the signal. These edge rates are affected by the drive current that a part can deliver but they are also dependent on the load being driven and hence are not accounted for in propagation delay calculation. Another timing parameter is pulse width distortion which is the difference between rising and falling propagation delay on the same part. Thus, pulse width distortion (PWD) = $|t_{DLH} - t_{DHL}|$.

Due to mismatch between transistors within different parts, the propagation delay on two parts will never exactly be same. This results in propagation delay




**RIGHT Figure 5:** **ADuM4120 Gate drivers and timing waveforms**

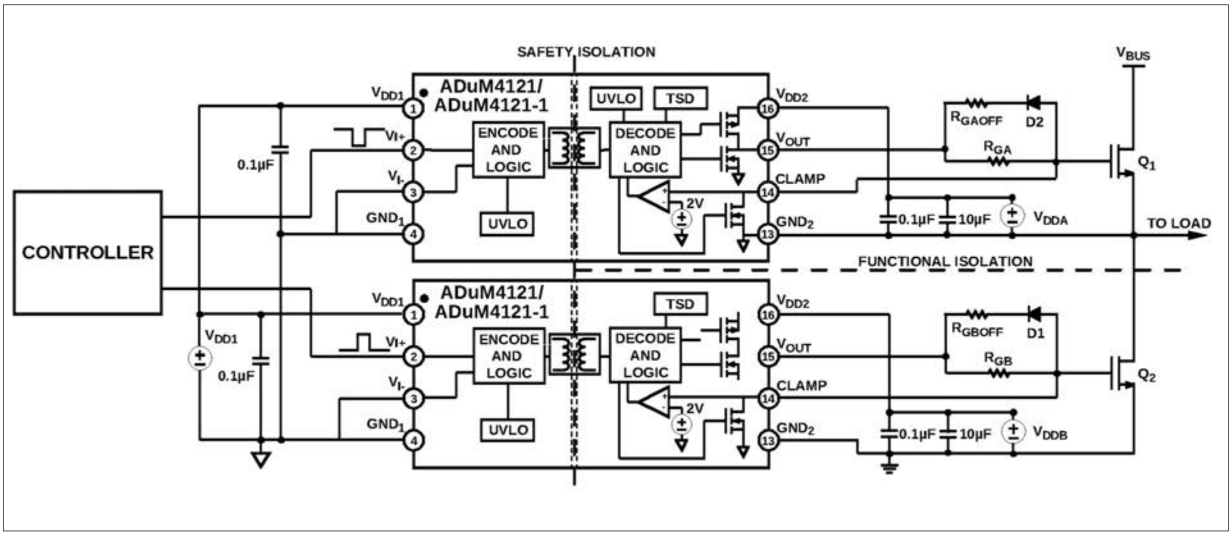



Figure 6: **Isolation barriers in a half bridge setup with ADuM4121 isolated gate drivers**

skew (tSKEW) which is defined as the time difference between output transitions on two different parts when reacting to the same input in the same operating conditions. As seen in Figure 5, propagation delay skew is defined as part to part. For parts which have more than one output channel, this spec is stated in the same way but is noted as channel to channel skew. Propagation delay skew cannot usually be accounted for in the control circuit.

Figure 6 shows a typical setup of ADuM4121 gate drivers used with power MOSFETs in a half bridge configuration for power supplies and motor drive applications. In such a setup, if both Q1 and Q2 are on at the same time, there is a chance of shoot-through due to the shorting of supply and ground terminals. This can permanently damage the switches and even the drive circuit. To avoid shoot-through, a 'dead-time' must be inserted in the system so that the chance of both switches being on at once is greatly reduced. During dead-time interval, gate signal to both switches is low and thus the switches are ideally in off state.

If propagation delay skew is lower, dead-time required is lower and control becomes more predictable. Having lower skew and lower dead-time results in smoother and more efficient system operation. Thus, timing characteristics are important as they affect speed of operation of the power switch and understanding these parameters leads to an easier and more accurate control circuit design.

Isolation: It is the electrical separation between various functional circuits in a system such that there is no direct conduction path available between them. This allows individual circuits to possess different ground potentials. Signal and/or power can still pass between isolated circuits using inductive, capacitive or optical methods. For a system with gate drivers, isolation may be necessary for functional purposes and it might also be a safety requirement. In Figure 6, we could have VBUS of hundreds of volts with tens of amperes of current passing through Q1 or Q2 at a given time. In case of any fault in this system if the damage is limited to electronic components, then safety isolation may not be necessary, but galvanic isolation is a requirement between the high power side and low voltage control circuit if there is any human involvement on the control side. It provides protection against any fault on the high voltage side as the isolation barrier blocks electrical power from reaching the user in spite of component damage or failure.

Isolation is mandated by regulatory and safety certification agencies in order to prevent shock hazard. It also protects low voltage electronics from any damage due to faults on the high power side. There are various ways to describe safety isolation, but at a fundamental level, they all relate to the voltage at which the isolation barrier breaks down. This voltage rating is generally given across lifetime of the driver as well as for voltage transients of a specific duration and profile. These voltage levels also correspond to the physical dimensions of the driver IC and the minimum distance between pins across the isolation barrier.

Apart from safety reasons, isolation may also be essential for correct system operation. Figure 6 shows a half bridge topology commonly used in motor drive circuits where only one switch is on at a given time. At the high power side, low side transistor Q2 has its source connected to ground. The gate-source voltage of Q2 ($V_{GSQ2}$) is thus directly referenced to ground and the design of the drive circuit is relatively straightforward. This is not the case with high side transistor Q1 as its source is the switching node which is pulled to either the bus voltage or ground depending on which switch is on. To turn on Q1, a positive gate to source voltage ($V_{GSQ1}$) which exceeds its threshold voltage should be applied. Thus, gate voltage of Q1 would be higher than $V_{BUS}$ when it is in on state as the source connects to $V_{BUS}$. If the drive circuit has no isolation for ground reference, a voltage larger than $V_{BUS}$ will be required to drive Q1. This is a cumbersome solution that is not practical for an efficient system. Thus, control signals that are level shifted and referenced to the source of the high side transistor are required. This is known as functional isolation and it can be implemented using an isolated gate driver such as ADuM4223.

Noise Immunity: Gate drivers are used in industrial environment which inherently has a lot of noise sources. Noise can corrupt data and make the system unreliable leading to degraded performance. Thus, gate drivers are required to have good immunity to noise to ensure data integrity. Noise immunity pertains to how well the driver rejects Electromagnetic Interference (EMI) or RF Noise and Common Mode Transients.

EMI is any electrical noise or magnetic interference which disrupts the expected working of the electronic device. EMI which affects gate drivers is a result of high frequency switching circuits and is mainly created due to the magnetic field from large industrial motors. EMI may be radiated or conducted and can couple into other nearby circuits. Hence, immunity to EMI or RF Immunity is a metric which refers to the ability of a gate driver to reject electromagnetic interference and maintain robust operation without errors. Having high EMI immunity allows drivers to be used in close proximity to large motors without introducing any faults in data transmission.

As seen in Figure 6, the isolation barrier is expected to provide high voltage isolation across grounds at different potentials. But, high frequency switching results in short edges for voltage transitions on the secondary side. These fast transients are coupled from one side to the other due to parasitic capacitance between the isolation boundary which can lead to data corruption. This can be in the form of introducing jitter in the gate drive signal or inverting the signal altogether leading to poor efficiency or even shoot-through in some cases. Thus, a defining metric for gate drivers is Common Mode Transient Immunity (CMTI) which quantitatively describes the ability of an isolated gate driver to reject large common mode transients between its input and output. The immunity of a driver needs to be high if the slew rates in the system are high. Thus, CMTI numbers are particularly significant when operating at high frequencies and large bus voltages.

## Conclusion

This article is intended to provide an introduction to gate drivers and thus the parameters discussed so far do not form an exhaustive list with regards to isolated gate driver specifications. There are other driver metrics such as supply voltage, allowable temperature, pinout, etc. which are a common consideration as with every electronic part. Some drivers such as ADuM4135 and ADuM4136 also incorporate protection features or advanced sensing or control mechanism.

The variety of isolated gate drivers available in the market make it imperative for a system designer to understand all these specifications and features to make an informed decision about using appropriate drivers in relevant applications.

## Literature

*Analog Devices, Inc., "ADuM4120", data sheet, http://www.analog.com/media/en/technical-documentation/data-sheets/ADuM4120-4120-1.pdf*

*Analog Devices, Inc., "ADuM4121", data sheet, http://www.analog.com/media/en/technical-documentation/data-sheets/ADuM4121_4121-1.pdf*

# Optimized High-Voltage Diodes

In the constant quest for smaller sizes, better performance, and lower costs, Dean Technology, Inc. (DTI) has developed a new technology for producing high voltage diodes that enables the future of the product type, without introducing new materials. XOE™, eXtreme Optimized Efficiency diodes, allow users to upgrade their performance in devices of the same size made from the same materials.

**Pedro H. Gonzalez, Technical Product Manager; and Griffin Caruolo, Director International Business Development, Dean Technology, Dallas, USA**

Every engineer and product manager involved in electronics is familiar with the issue; new designs need to be smaller than before, have better performance than the last version, and shouldn't cost more. While accomplishing those goals is never simple, it is marginally more realistic with newer products or technologies where there is still room for large advancement through the benefits of experience. When working with legacy commodities, however, this kind of progress becomes extremely rare. Normally the only way to move performance forward or reduce size is by incorporating new materials, methods, or equipment.

High-voltage diodes are no different, they have been made using the same basic materials and processes for decades, and there has not been much overall improvement in the performance of the devices. Certainly, some new package types like surface mount have been introduced. Better quality control has allowed for slight improvements in speed, current handling, and overall voltage ratings, but neither of these have been minor steps and not a true leap forward.

## High-voltage diode processing

Since the beginning of high-voltage diode fabrication, the philosophy has been to use stacked silicon to achieve the necessary high voltage characteristics essential for reliable device performance. The idea is to arrange doped silicon in a "sandwich-like" structure (as seen in Figure 1) so that the collective pieces of silicon can handle the electric field stresses which occur during device operation. This arrangement distributes the electrical stresses across the individual silicon "slices", and the method works well but has an inherent drawback which hampers efficiency.

Each slice of Silicon represents an active semiconductor voltage drop which must be overcome for proper device operation. As more slices are added to the "sandwich" the cumulative drop in voltage increases at a rate proportional to the number of slices. When the operating voltage is more than the total voltage drop a current begins to flow. It is this combination of cumulative voltage drop and current flow that affects efficiency. Such a combination produces heating in the device during operation. The heating impacts device reliability as well as limiting the operating current of the device.

Other efforts at addressing efficiency in high-voltage diodes have been attempted, through methods that replace the base Silicon semiconductor, or using far more exotic and expensive packaging materials. While these do offer performance and size benefits, the associated costs have kept them out of mainstream use.

The research and development team at Dean Technology discovered a substantially different approach. With the mindset of mitigating the inherent loss in the device and without introducing new materials or expensive equipment, they went through the production process step by step, identifying how to make corrections along the way. Diode performance is a delicate balance between many variables, each having a direct impact on the performance of the other. The team discovered that by tightly controlling all of these variables and individually designing all elements of each diode it is possible to dramatically increase the overall performance over similarly sized products using the same raw materials. This technology is called XOE™, eXtreme Optimized Efficiency.

## XOE - how it is done

The performance advancements of XOE are accomplished through three main design approaches: maximizing the die size, minimizing the number of die in the diode stack, and tightly controlling the Silicon diffusion process to ensure the highest possible consistency and overall performance of each wafer. Each of these elements impacts the other two, so device

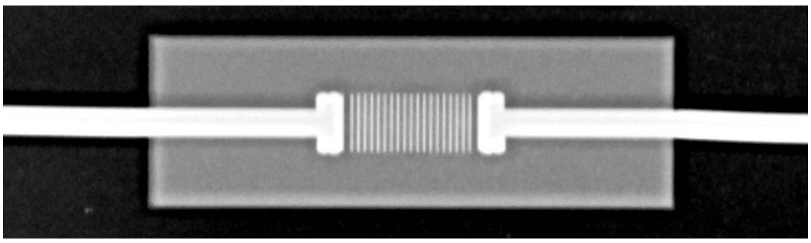


**Figure 1: X-ray of common high-voltage diode**

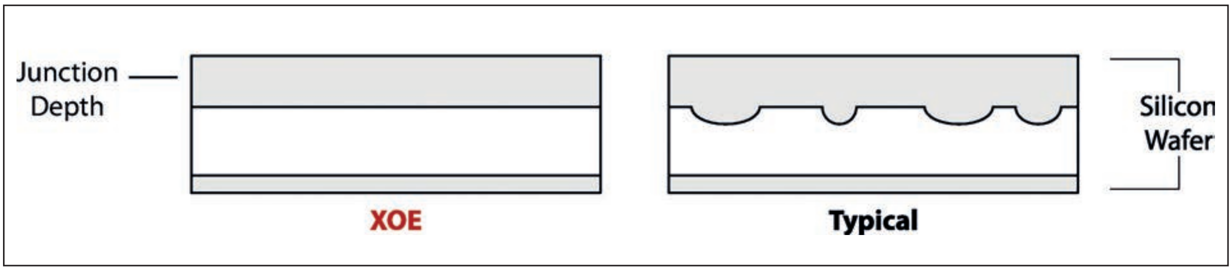
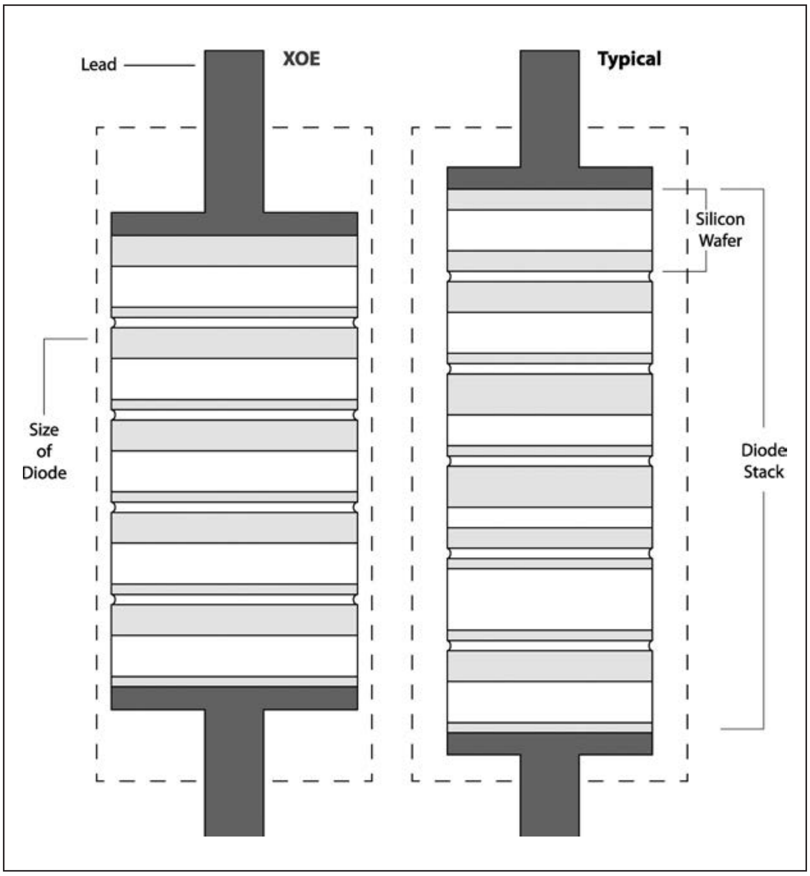



**Figure 2: XOE junction depth vs. typical HV diodes**




**LEFT Figure 3: XOE diode construction vs. typical HV diodes**

| Specification | Conditions | G15FS | XGF15 |
|---|---|---|---|
| **Physical Size** | Body Length x Body Diameter | 10 mm x 3 mm | |
| **Peak Inverse Voltage ($V_{RRM}$)** | | 15,000 V | |
| **Maximum Forward Voltage Drop ($V_F$)** | At 10 mA | 25 V | 10 V |
| | At 100 mA | - | 16.5 V |
| | At 160 mA | - | 18.5 V |
| **Maximum Average Forward Current ($I_{FAVM}$)** | At 55°C | 25 mA | 80 mA |
| **Maximum Leakage Current ($I_R$)** | At $V_{RRM}$ | 0.2 µA | |
| **Maximum Surge Current ($I_{FSM}$)** | At 8.3 mS | 3 A | 15 A |
| **Maximum Reverse Recovery Time ($T_{RR}$)** | At Approx $I_F$ = 0.5 $I_{FAVM}$; $I_R$ = -$I_{FAVM}$; $I_{RR}$ = -0.25 $I_{FAVM}$ | 100 nS | 80 nS |
| **Maximum Reverse Energy Withstand ($E_{RSM}$)** | | - | 500 mJ |
| **Operating Temperature Range** | | -55 to 125°C | -55 to 125°C |

designs are done to achieve the best balance and to produce an end product that sits right in the performance sweet spot.

The first two design criteria are reasonably straight forward, though require an exceptional attention to detail. Putting as large a Silicon die as possible in the final package gives XOE products increased surface area and maximizes the current handling. Minimizing the number of die in the diode stacks leads directly to lower loss by reducing the cumulative voltage drop in the device. All of this is made possible by the third element, Silicon wafer diffusion that is focused keenly on producing the most consistent junction depth across the wafer, and consistent final thickness of each individual die.

In standard Silicon wafer diffusion for high-voltage diodes small irregularities will occur in the junction depth as dopant is diffused into the base Silicon material. This creates peaks or "weak spots" in the Silicon that have an emmense effect on the final performance. The diffusion process used in XOE creates a far more consistent junction depth, as shown in Figure 2. Limiting these weak spots in the Silicon ensures more consistent performance of each layer in the final diode stack and enables the removal of extra slices.

The consistancy that results from the XOE diffusion method also creates stacks that have more consistent performance from slice to slice. This allows for better sharing across each die in the stack, allowing the final product to produce more total voltage withstand with a lower number of slices.

The combination of these three elements allows DTI to produce a final diode product with a die stack that is far more consistent in performance and quality, offers significant performance benefits, and as illustrated in Figure 3, fits in the same size package as a typical high-voltage diode.

## XOE benefits

All of this careful design, consistent quality, and predictable performance lead to truly astonishing results. Using all of the same materials, built on the same production line, and produced with the same average overall yield, DTI produces it's standard G15FS axial lead high voltage diode, and the XGF15 the XOE counterpart. Specifications for both parts are show in in Table 1 and a G15FS vs. XGF15,

**LEFT Table 1: G15FS vs. XGF15 specification comparison**

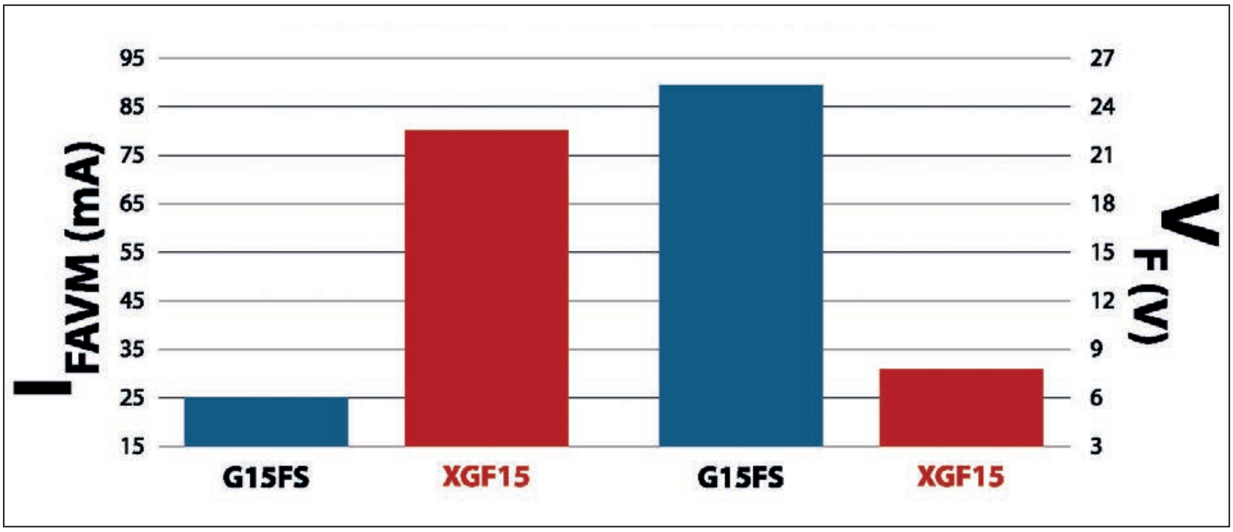



Figure 4: **Comparison of G15FS vs. XGF15, IFAVM and Vf at 10 mA**

$I_{FAVM}$ and $V_f$ at 10 mA comparison in Figure 4.

These two parts are the same physical size, have an identical voltage rating, maximum leakage current, and operating temperatures. That is where the performance similarities end. The XGF15 is significantly more efficient, showing less than half the loss of the G15FS at the same operating current, and is able to withstand a far greater forward surge current.

The lower loss of XOE diodes reduces the heat created while operating. Beyond contributing to the increased performance, this provides a more reliable product.

The consistency of the Silicon diffusion in XOE also allows DTI to rate and provide accurate maximum reverse energy withstand (ERSM) ratings for these products. The reverse energy withstand parameter is based on the ability of the diode to be driven into its avalanche region where at that point the diode will begin to flow reverse current beyond the normal leakage current. The resulting transient effect can damage a device if subjected to a prolonged duration in avalanche. The XOE platform is designed to aid in defining that parameter value due to the consistency found in the Silicon processing.

DTI has many axial lead high-voltage diodes built with XOE Technology currently available (Figure 5) and plans to release upgraded versions of all of its discrete diodes in the near future. This will include all axial lead and surface mount configurations, in all currently offered package sizes. Custom parts can also be produced using this technology to meet individual design needs for all applications that require high voltage.

## Summary

By fully understanding the design and production of high voltage diodes and designing with a focus on minimizing loss and maximizing efficiency, Dean Technology is able to offer upgraded performance from similarly sized devices using the same materials. The benefits of XOE include higher current capabilities, lower voltage drop, reduced heat dissipation, better breakdown immunity from transitions into the avalanche region, and enhanced reliability for end user products and a cost effective and easy migration path for existing circuit board platforms.

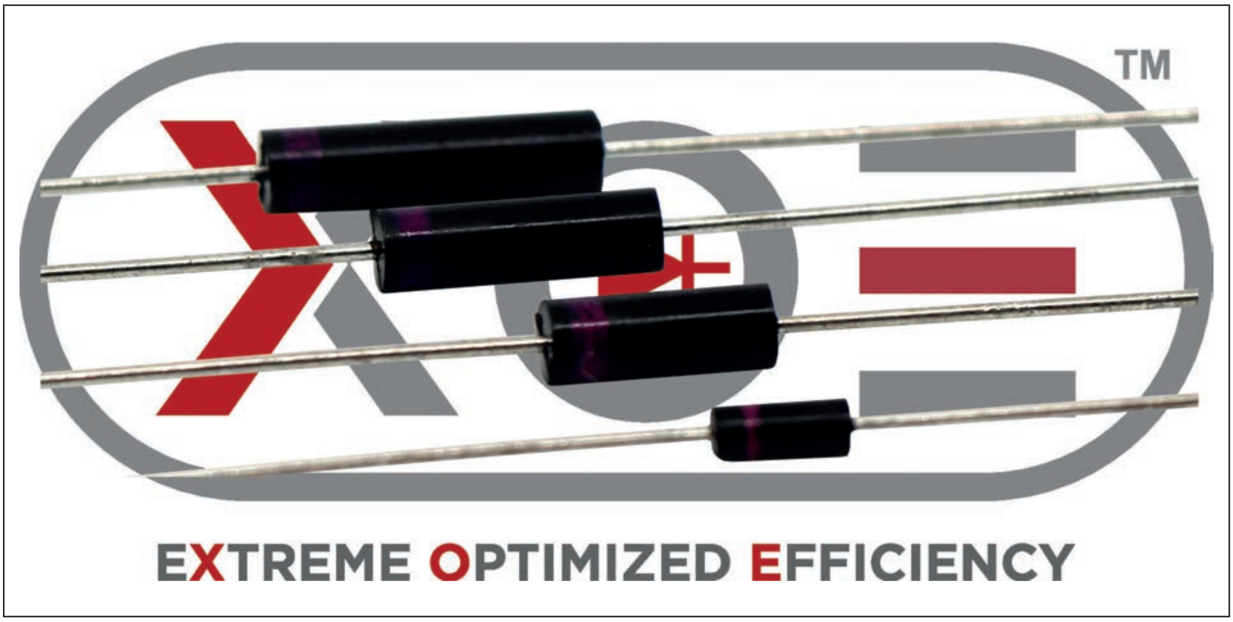



Figure 5: **XOE axial lead high-voltage diodes**

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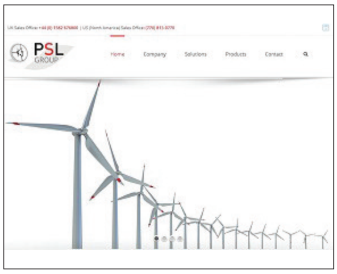

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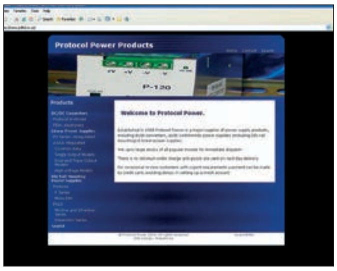

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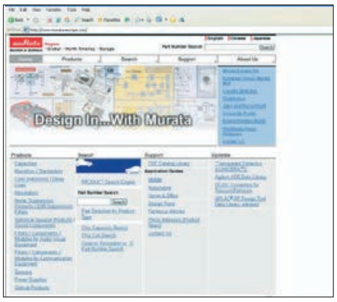

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