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POWER SUPPLY DESIGN

Doing More with Buck Regulator ICs

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Also inside this issue

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COVER STORY

Doing More with Buck Regulator ICs

Switching regulators are widely used and one of the most popular switching regulator topologies is the buck converter (also known as a step-down converter). Manufacturers typically offer buck regulator ICs with built-in controller and integrated FETs. Such buck regulators primarily implement step-down voltage conversion. Nevertheless, they can also be used to create many other designs, such as inverting power supplies, bipolar power supplies, and isolated power supplies with single or multiple isolated voltage rails. Renesas' ISL8541x family of buck regulator ICs feature integrated high-side and low-side FETs, internal boot diode, and internal compensation, which minimizes the amount of external components and enables very small total solution size. In addition, this family of regulator ICs has a wide input voltage range of 3 V to 40 V to support a multi-cell battery and a variety of regulated voltage rails. In this article, the ISL85410 buck regulator IC is used to illustrate various application designs. This article introduces a variety of designs using buck regulator ICs, explains their operational principles, and discusses the practical considerations to implement these designs. More details on page 22.

Cover supplied by Renesas Electronics Corporation

High Power next Core (HPnC)

with Fuji Electric's X-Series - 7G IGBT

X series 7G

MAIN FEATURES

Latest chip technology
- Fuji X-series IGBT and FWD

High reliability
- CTI>600 for higher anti-tracking
- High thermal cycling capability with ultra sonic welded terminals and MgSiC base plate
- High thermal cycling capability with ultra sonic welded terminals and MgSiC base plate
- CTI>600 for higher anti-tracking
- Improvement of delta Tj power cycle capability by using 7G Package technology
- Tj operation target is 175 °C

RoHS compliance
- Ultra sonic welded terminals

Over temperature protection
- Thermal sensor installed

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Fuji Electric
Innovating Energy Technology

Reducing Carbon Emissions by Power Electronics

Legislators in the European Union are imposing a new passenger car fleet CO2 emissions target of 95 g/km, to be phased in during 2020, with 100 % application in 2021 on Worldwide Harmonized Light Vehicle Test Procedure (WLTP). New passenger car fleets that fail to meet compliance are set for potentially substantial fines in both 2020 and 2021. IHS suggests that the EU28 sales-weighted passenger car phased (best 95 %) fleet CO_2 average in 2020 is likely to reach 102 g/km (NEDC). This includes 4 g/km of CO_2 reduction derived from super credits and a further 2 g/km of CO_2 reduction from forecasted eco-innovation technology deployment. In 2020, fines paid by OEMs could amount to € 11 billion. Furthermore, with a 2021 target set at 115 g/km (as the 95 g/km New European Driving Cycle (NEDC) target is adjusted to an equivalent WLTP value), IHS forecasts that the sales-weighted passenger car fleet CO2 average will reach 123 g/km (WLTP). Once in 2021 and subject to full WLTP regulatory monitoring, only a seismic shift in consumer demand for BEV (Electric-Plug-In) and PHEV (Hybrid-Full Plug-In) will result in the full mitigation of EU28 fleet level excess emissions premiums. And this is the time for power electronics.

The automotive industry is undergoing a dramatic transformation. By 2025, it is forecasted that a quarter of all cars worldwide will be electrically powered. On top of that, manufacturers and suppliers are currently responding to increasing demands for "next-generation" technologies including autonomous and connected vehicles, as well as developing completely new data-generated business models. Thus the value of semiconductor devices is also increasing, as underlineded by the microelectronic trend analysis carried out by the German ZVEI. Last year's worldwide average of $477 billion is set to increase to $535 billion by 2022. Car production worldwide will simultaneously rise from 99 million units to 110 million units over the same time period. Both increases mean that 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 %.

According to Yole's analysts SiC adoption by automotive players, over the next 5-10 years, differs depending on where SiC is being used. That could be in the main inverter, in OBC or in the DC/DC converter. By 2018, more than 20 automotive companies are already using SiC SBDs or SiC MOSFET transistors for OBC, which will lead to 44 % CAGR through to 2023. Yole expects SiC adoption in the main inverter by some pioneers, with an inspiring 108% market CAGR for 2017-2023. This will be possible because nearly all carmakers have projects to implement SiC in the main inverter in coming years. In particular, Chinese automotive players are strongly considering the adoption of SiC.

Upcoming events such as EPE in September and Electronica in November will highlight these trends. An EPE keynote by Rik W. De Doncker, RWTH Aachen, will highlight the Fast Charging Infrastructure in the Urban Environment. Charging of electric vehicles, in particular fast charging, in cities is a major challenge for the existing AC infrastructure. Even charging multiple vehicles overnight quickly overloads the low-voltage distribution grid. In addition, as the automotive industry launches the proposition that fast charging up to 350 kW is a customer requirement, offering fast-charging stations could become a business opportunity. He will present solid state solutions that build on existing AC infrastructure to accommodate high-power charging.

The electronica Automotive Conference will show what the future of mobility could look like. Among other things, the focus will be on emission-free driving and its effects on the automotive industry. The organization of transportation in cities will also play an important role. Among those taking part are key players from the automotive industry including suppliers (Tier 1 to 3), OEMs, component manufacturers and software developers. Prominent speakers will address both managers and technicians. Alongside their presentations, they will also be discussing current technology trends and strategies for the worldwide automotive industry. As well as emission-free and autonomous driving up to level 5, a focal point for the conference will be the interesting topic of so-called last-mile vehicles as part of the overall mobility mix. Highlights of the conference will be the opening speeches, including those by Rainer Müller-Finkeldei, Director of Mechatronic Development for Daimler and Jürgen Bortolazzi, Director of Driver Assistance Systems for Porsche. Dr. Reinhard Ploss, CEO of Infineon Technologies, will talk about Semiconductors as a key enabler for the transition of the automotive industry.

For automotive applications, ROHM Semiconductors i. e. 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. Motor sports Formula E is attracting increasing attention worldwide as a platform for further innovation in the electric car sector. As official technology partner of the VENTURI racing team SiC power modules for the inverter block, which forms the core of the drive system of electric vehicles, as well as 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 showcased.

Thus fall is an exciting time for Power Electronics.

Enjoy reading this issue!

Achim Scharf
PEE Editor

X-Rays Aid Better Understanding Of Electron Mobility

In HEMT devices – high-electron-mobility transistors – based on gallium nitride (GaN), electrons can move freely in a layer one-millionth of a millimetre thick between two semiconductors. In their experiment at the ADRESS-Beamline of the Swiss Light Source SLS,, PSI researcher Vladimir Strocov and his colleagues looked into the question of how one might, through clever construction of a HEMT, contribute to an optimal flow of electrons. Their finding: When going into the high power regime of the gallium nitride transistor, in specific directions the electrons move more efficiently.

The Paul Scherrer Institute PSI develops, builds and operates large, complex research facilities and makes them available to the national and international research community. The institute's own key research priorities are in the fields of matter and materials, energy and environment and human health. PSI is committed to the training of future generations. Therefore about one quarter of our staff are post-docs, post-graduates or apprentices. Altogether PSI employs 2100 people, thus being the largest research institute in Switzerland. The annual budget amounts to approximately CHF 390 million. PSI is part of the ETH Domain, with the other members being the two Swiss Federal Institutes of Technology, ETH Zurich and EPFL Lausanne, as well as Eawag (Swiss Federal Institute of Aquatic Science and Technology), Empa (Swiss Federal Laboratories for Materials Science and Technology) and WSL (Swiss Federal Institute for Forest, Snow and Landscape Research).

Freedom for electrons

Semiconductors are the basic building blocks of all miniaturized circuitry and power chips. They conduct electricity only when they are skillfully prepared. In classical semiconductor components such as transistors, that is accomplished through selective incorporation of atoms of a complementary chemical element. The problem is that these foreign atoms slow down the electron motion. In the HEMT, this problem is solved in an elegant way. Here, in something like a sandwich, a suitable combination of pure semiconductor materials is brought into contact so that, at the boundary, a conducting layer one-millionth of a millimeter thick is formed. That makes it possible to do without the foreign atoms. This idea, first proposed in the early 1980s by the Japanese scientist Takashi Mimura, is already used today.

In practice, however, it is also relevant that the atoms in a semiconductor are always arranged in a specific periodic crystal structure. For example, the HEMT that Strocov and his team studied, made from aluminium nitride and gallium nitride, has a six-fold symmetry in its interface layer: There are six equivalent orientations along the atomic chains.

The samples were grown on c-oriented sapphire substrate . The 500 nm-thick Ga-polar GaN layer was grown on top of an AlGaN buffer layer required to suppress the crystal defects and promote growth of a smooth uniform film. The GaN layer was overgrown by a barrier layer consisting of 2 nm of AlN and 1 nm of $Al_{0.5}Ga_{0.5}N$.

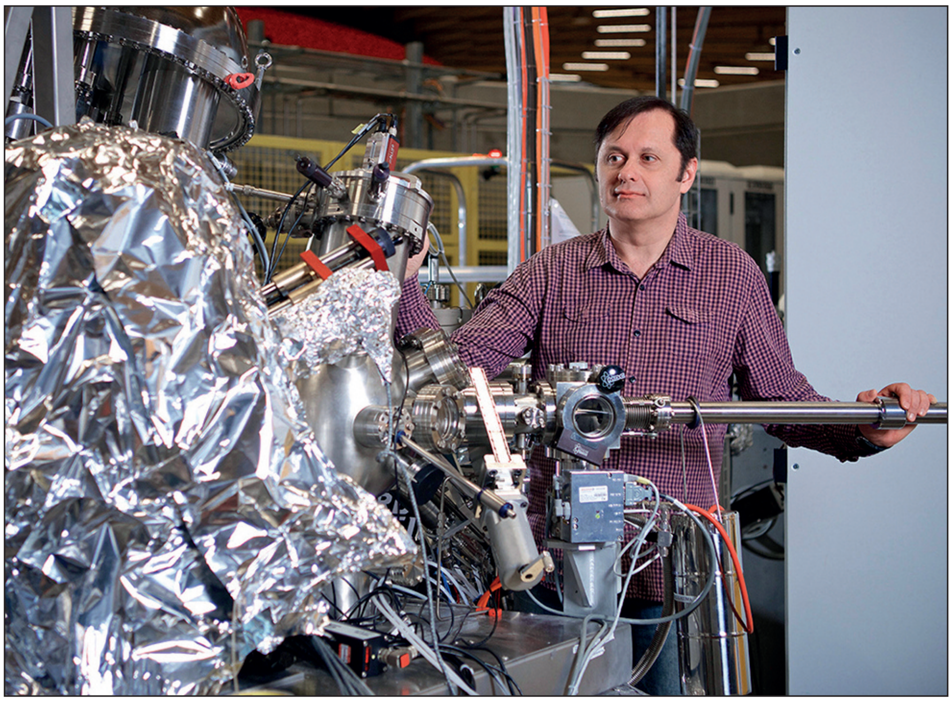
To investigate the flow of electrons within the interface layer, the researchers placed their HEMT under a very special "microscope" – one that does not examine the positions, but rather the propagation speeds of the electrons: the ADRESS beamline of the Swiss Light Source SLS, one of the world's most intense source for soft X-ray radiation.

Experiment on a living transistor

The technical concept of this examination method is called angle-resolved photoelectron spectroscopy, or ARPES. Up to now it has been carried out with light sources in the ultraviolet range. Now Strocov and his team have used the high-energy X-ray light of SLS to do it. With it, the researchers were able to lift out electrons from deep inside the conducting layer of the HEMT and then guide them into a measuring instrument that determined their energy, speed, and direction: an experiment on a "living" transistor, so to speak. "That is the first time it has been possible to make the fundamental properties of electrons in a semiconductor heterostructure visible", says Vladimir Strocov.

The high intensity of the X-rays at SLS – which far outperforms comparable facilities – was crucially important for this, acknowledge Leonid Lev and Ivan Maiboroda of the Kurchatov Institute in Russia, where the HEMT devices were fabricated: "The unique instrumentation of SLS provided us with extremely important scientific results. It showed us ways in which HEMT structures with higher operating frequencies and performance could be developed." The fact that the electrons prefer a particular direction of flow can be exploited technically, Strocov explains: "If we orient the atoms in the gallium nitride HEMT so that they match the electrons' direction of flow, we get a significantly faster and more powerful transistor."

https://www.psi.ch



Vladimir Strocov at the ADRESS-Beamline of the Swiss Light Source SLS, where the experiments took place. This is one of the world's best sources for soft X-ray radiation **Photo: Paul Scherrer Institute/Markus Fischer**

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MPLAB® Mindi™ Analog Simulator reduces circuit design time and design risk by simulating analog circuits prior to hardware prototyping. The simulation tool uses a SIMetrix/SIMPLIS simulation environment, with options to use SPICE or piecewise linear modeling, that can cover a very wide set of possible simulation needs. This capable simulation interface is paired with proprietary model files from Microchip, to model specific Microchip analog components, in addition to generic circuit devices. Finally, this simulation tool installs and runs locally, on your own PC. Once downloaded, no internet connection is required, and the simulation run time is not dependent on a remotely located server. The result is fast, accurate analog circuit simulations.

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CMBT Capacitor Technology for Next Generation Power Electronics

Capacitors are an essential component found in all electrical and electronic systems and represent a $23 billion market. They are used for bypassing, decoupling, DC and AC filtering and energy storage/discharge circuits in modern power supplies. The trend towards the continued electrification of the automotive, energy and consumer electronics sectors is expected to generate significant demand for such capacitors for the foreseeable future.

EEStor Corporation has developed a proprietary ceramic dielectric material (Composition Modified Barium Titanatethat, CMBT), when used as a capacitor dielectric demonstrates a significant higher relative permittivity than commercially-available Y5V type ceramic capacitors. "Y5V dielectrics in general have high capacitance per unit volume, and have a wide temperature characteristic of +22 % –82 % capacitance change over the operating temperature range of –30°C to +85°C. These characteristics make Y5V ideal for decoupling applications within limited temperature ranges", stated Ian Clifford, EEStor founder and CEO. "Our CMBT-glass hybrid Y5V series capacitors have higher volumetric efficiency, lower dissipation factors and better frequency stability than current commercial Y5V dielectrics making them ideally suited for circuits requiring greater volumetric efficiency or greater capacitance at high voltage." Y5V capacitors represent $1.5 billion of the $23 billion global capacitor market in 2018.

MRA Laboratories tested the dielectric capacitor layers for thermal performance and measured the Temperature Coefficient of Capacitance (TCC). TCC describes the maximum change in capacitance over a specified temperature range. EEStor dielectrics can be classified in the Electronic Industries Alliance (EIA) RS-198 standards as a Y5V or Y6V designation based on the following data:

- Y5V because at -30°C it has a TCC of -80.4%, and at 85°C it has a TCC of -66.7%
- Y6V because at -30°C it has a TCC of -80.4%, and at 105°C it has a TCC of -71.9%

400 V AC disc capacitor

Based upon the test results above, EEStor has designed a CMBT-based capacitor that can compete against commercially available Y5V 400 V AC ceramic disc capacitors which are over four times the volume. This size difference translates directly to a lower cost per farad, as significantly less material will be used for the smaller volume CMBT component. In addition to having higher capacitance per unit volume and lower cost per farad, the CMBT Y5V disc capacitor has a lower dissipation factor, higher insulation resistance, and a higher breakdown strength than the comparable commercial capacitor, Clifford said.

A CMBT-based capacitor can compete against commercially available Y5V 400 V AC ceramic disc capacitors over four times the volume **Photo: EEStor**

The data sheet for a 400 V 1 nF 125LD10-R capacitor (**www.vishay.com/capacitors/list/product-23106**) indicates that the package has a diameter of 8.4 mm and a thickness of 2.4 mm. That's an area of π x 4.22 = 55.418 mm^2. And thus, a volume of 55.418 mm^2 x 2.4 mm = 133 mm^3 for the whole package.

Assuming the capacitor has an internal active area equal to the diameter of the finished part, we are surely overestimating the size of the active area, as the area of the capacitor would include the non-zero thickness of the insulation for the layer. The dielectric thickness will also be less than that of the finished part as there is some non-zero value for thickness of the electrodes and packaging.

One can't know for sure how much of the Vishay package volume is used by the dielectric. But the data sheet gives some idea how the size grows: The 5 nF Vishay capacitor package diameter grows to 11 mm from 8.4 mm for the 1 nF capacitor. So, the area (and thus volume) grows 5.52 / 4.22 = 1.7 times. Similarly, the 10 nF Vishay capacitor diameter grows to 14.3 mm from 8.4 mm for the 1 nF capacitor. So, the area (and thus volume) grows 7.152 / 4.22 = 2.9 times.

This suggests that the volume of the packaging doesn't grow proportionally with that of the dielectric but stays at about the same thickness as the dielectric grows (which would make sense for a given voltage rating) so that the proportion of the capacitor volume attributed to packaging is reduced as the dielectric volume grows. A rough mathematic regression suggests that at 1 nF, the dielectric would use at least 25 % of the volume of the capacitor package. Therefore, with the dielectric using about 25 % of the Vishay whole package volume, that would represent 133 mm^3 / 4 = 33.25 mm^3.

That EEStor sample was 640 µm thick with an electrode area of 41.737 mm^2 and had a capacitance of 3.666 nF at 400 V. It also demonstrated a breakdown strength of over 2400 V AC.

To build a 1 nF capacitor out of this dielectric material using the same thickness, the area can be reduced to 41.737 mm^2 x 1 nF / 3.666 nF = 11.385 mm^2.

The dielectric volume (area x thickness) would then be: 11.385 mm^2 x 0.64 mm = 7.3 mm^3.

That's a diameter of (11.385 / π)1/2 x 2 = 3.8 mm, for a thickness of 640 µm.

MRA roughly evaluated above that the dielectric of the Vishay capacitor was using at least 25 % of its package volume, which is 133 mm^3 / 4 = 33.25 mm^3.

Considering the EEStor dielectric volume of 7.3 mm^3, Vishay would use 33.25 / 7.3 = 4.5 times the dielectric volume. In addition to having higher capacitance per unit volume and thus lower cost per farad, the EEStor capacitor has a lower dissipation factor, higher insulation resistance, and a higher breakdown strength than the commercial capacitor.

50 V DC MLCC

Another example of the benefits of an CMBT capacitor over existing technologies is also apparent when compared with commercial Y5V 50 V DC multi-layer ceramic capacitors (MLCC).

Commercial Y5V MLCCs have 8 % less capacitance for the same size as the CMBT 50 V DC Y5V MLCC. It also has higher insulation resistance, 8 % more capacitance, and better DC bias characteristics than the commercially available Y5V MLCC.

www.eestorcorp.com

Power Electronics Academia and Industry Meet in Riga

From 17 to 21 September 2018 the EPE'18 ECCE Europe, the well recognized academic/industrial conference on power electronics, will be held in RIGA, Latvia.

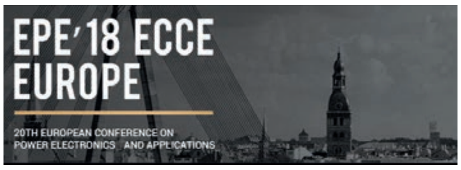
Five keynotes until September 20 will highlight important trends, performed by well-known researchers and industry.

Keynote 1, Tuesday 18 September 2018, 9h30, will be given by Prof. Frede Blaabjerg, Aalborg University, Denmark, is entitled **Design for reliability in Power Electronic Systems.**

In recent years, the automotive and aerospace industries have brought stringent reliability constraints on power electronic converters because of safety requirements. Today customers of many power electronic products expect up to 20 years (or even longer) of lifetime and they also want to have a "failure free period" and all with focus on the financials. The renewable energy sectors are also following the same trend, and more and more efforts are being devoted to improving power electronic converters to account for reliability with cost-effective and sustainable solutions. This presentation will introduce the recent progress in the reliability aspect study of power electronic converters for power electronic applications with special focus on renewables. It will cover the following contents: the motivations for highly reliable electric energy conversion in renewables; the reliability requirements of typical power electronic systems; failure mechanisms and lifetime models of key power electronic components (e.g., power semiconductor switches, capacitors, and fans); long-term mission profiles in renewable applications and their components; reliability analysis methods for more complicated systems, tools to be applied, and improvement strategies of power electronic converters in their applications. A few case studies will be given.

Keynote 2, Wednesday 19 September 2018, 9h00, by Daniel RADU, Director of Technology Power Systems Center, Building & IT Business, Schneider Electric, France, is entitled **Emergency of the DC microgrids in electro-intensive applications.**

Nowadays the increasing of the cost of the energy (electricity, oil, fuel, ...) and his availability (e.g. limited available power in nationals grids) conduct the electro-intensive applications owners to look to a drastically improvement of energy efficiency. One investigated option is the use of DC electrical distribution architectures in order to avoid unnecessary power losses. This was allowable due to the development of the power electronics bringing higher efficiency, higher reliability, lower cost and easy maintenance. The keynote will discuss the investigations done for the DC microgrids in a marine application (onboard vessels) as well for the large data centers.



Keynote 3, Wednesday 19 September 2018, 9h30, by Prof. Dr. ir. Dr. h.c. T.U.Riga, Rik W. De Doncker, RWTH Aachen, Germany, will highlight the **Fast Charging Infrastructure in the Urban Environment - Challenges and Opportunities.**

Charging of electric vehicles, in particular fast charging, in cities is a major challenge for the existing AC infrastructure. Even charging multiple vehicles overnight quickly overloads the low-voltage distribution grid. In addition, as the automotive industry launches the proposition that fast charging up to 350 kW is a customer requirement, offering fast-charging stations could become a business opportunity. In this presentation, solid state solutions are presented that build on existing AC infrastructure to accommodate high-power charging.

Keynote 4, Thursday 20 September 2018, 9h00, by Dr. Alireza Nami, ABB Corporate Research Sweden, will cover **Power Electronics for future power grids: drivers and challenges.**

Currently, electric power systems start to shift toward more environment friendly energy productions to limit the climate change and reduce pollutions. The major focus is the variability of the new energy sources, and reliability of the supply. The challenge for the future electric power grids is how to integrate a widespread addition of renewable sources with intermittent nature in both transmission and distribution grids without compromising reliability, stability and cost of the service to the consumers. A system that can handle a generation mix with a high percentage of renewables will become a necessity which requires solutions as increased transmission capacity through AC and DC solutions, and/or a larger energy storage capacity in the grids. Grid-connected converter technologies have had a truly revolutionary impact on the way that electrical energy is delivered to consumers all over the world, and has become an indispensable part of the electric power systems today. It is anticipated that by 2030 all electric power generated utilizes power electronics somewhere between the point of generation and its end. Power electronics contribute in many ways to more efficient use of energy, which allows for energy savings, which in turn leads to reduced environmental impact. The R&D in this field aims at optimizing complex decisions and solutions that are required for the design of these power electronic converters to deliver innovation for the future conversion, processing, transmission, distribution as well as storage of energy across a wide range of applications.

Keynote 5, Thursday 20 September, 9h30, will be given by Bruno Luscan, Supergrid Institute, France, under the title **Power Grids Control: drivers and trends.**

The energy transition objectives can't be achieved without a massive integration of renewable energy sources into power grids. On one hand, this integration requires to reinforce large scale transmission system capacity, and interconnections between countries, in order to create an electricity market and the conditions for renewable energy trading. On another hand, conventional generation connected to the grid through synchronous generators is replaced by renewable generation which is connected to the grid through power-electronics converters.

This trend leads to three major changes for the grid: HVDC transmission is becoming an important part of the grid, AC system inertia is reducing and system dynamics are modified, Grid-connected power electronics converters can be controlled in order to support grid operation.

The presentation will cover the following aspects of power grid controls: The well-established principles of AC power system control, The principles of HVDC control, in a PtP link or in a multi-terminal system, The impact of AC system inertia reduction on power system stability, The contribution of Grid-connected power electronics converter to power system stability, The contribution of HVDC transmission to AC stability control. Starting from the physics of the system, a selection of key control challenges will be explained, and some major evolutions in power grid control will be put into perspective.

The Technical Programme is available under **https://wd.cborg.info/EPE2018/program_preliminary.html** and covers: POWER ELECTRONICS COMPONENTS AND CONVERTERS with Devices, components, packaging and system integration; Power converters topologies and design and Measurement and control.

POWER ELECTRONICS APPLICATIONS with Electrical machines and drive systems; Renewable energy power systems; and Grids, smart grids.

AC & DC with Power supplies; Electric vehicle propulsion systems and their energy storage; Industry specific energy conversion and conditioning technologies.

Exhibitors include dSPACE, ECPE, Egston, HIOKI EUROPE GmbH, imperix , Leclanché Capacitors, Linksium, MathWorks – Speedgoat, Mersen, OMICRON Lab, Opal-RT, Plexim, Power Electronics Measurements LTD, Powersys, Rohde & Schwarz, Teledyne LeCroy, TRIPHASE, Typhoon HIL, and Yokogawa.

Automakers Adopt SiC Technology

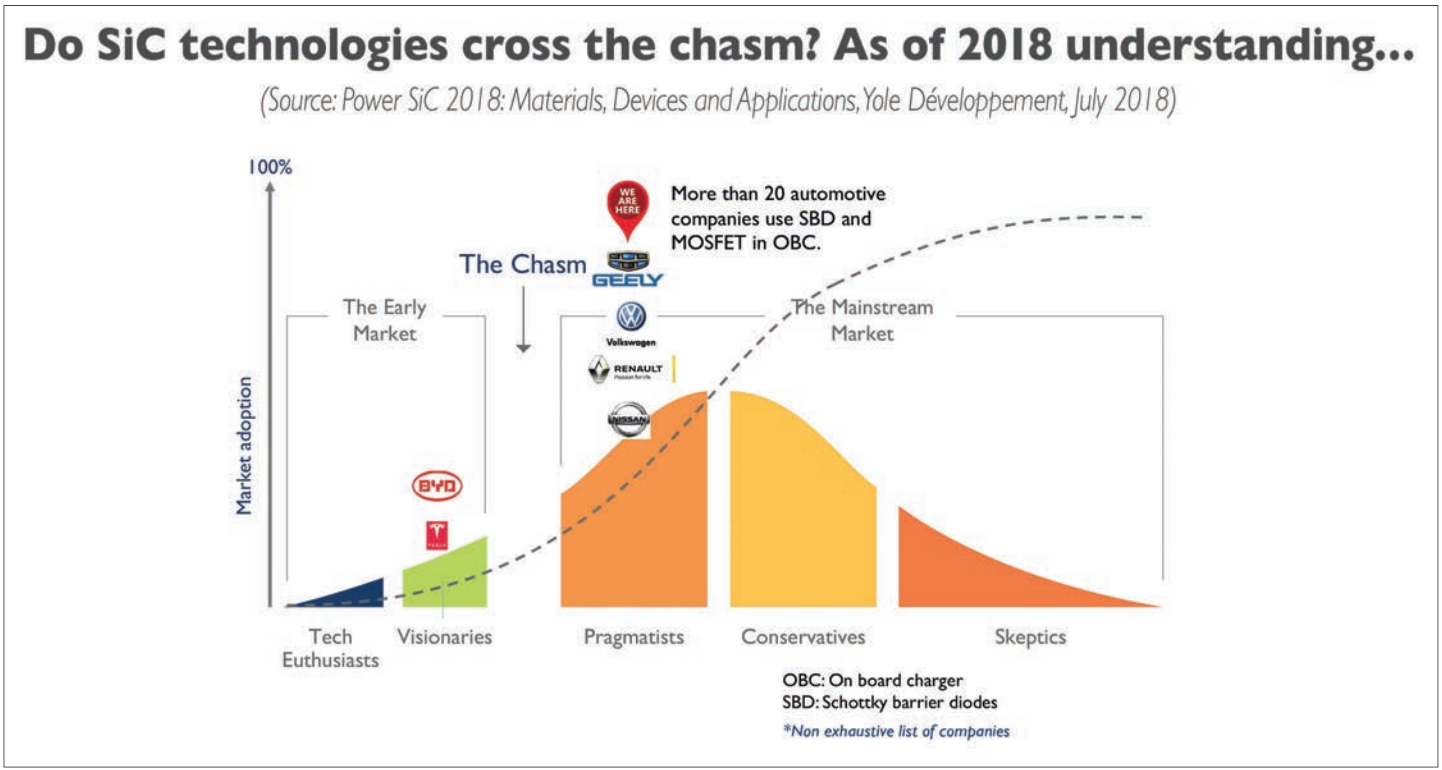
Today, SiC transistors are clearly being adopted, penetrating smoothly into different applications. Yole's analysts forecast a $1.4 billion SiC power semiconductor market by 2023, this market is showing a 29 % CAGR between 2017 and 2023.

The SiC market is still being driven by diodes used in PFC and PV applications. However Yole expects that in five years from now the main SiC device market driver will be transistors, with an impressive 50 % CAGR for 2017-2023. This adoption is partially thanks to the improvement of the transistor performance and reliability compared to the first generation of products, which gives confidence to customers for implementation. Another key trend revealed by Yole's analysts is the SiC adoption by automotive players, over the next 5-10 years. "Its implementation rate differs depending on where SiC is being used," comments Dr. Hong Lin, Technology and Market Analyst. "That could be in the main inverter, in OBC or in the DC/DC converter. By 2018, more than 20 automotive companies are already using SiC SBDs or SiC MOSFET transistors for OBC, which will lead to 44 % CAGR through to 2023." Yole expects SiC adoption in the main inverter by some pioneers, with an inspiring 108% market CAGR for 2017-2023. This will be possible because nearly all carmakers have projects to implement SiC in the main inverter in coming years. In particular, Chinese automotive players are strongly considering the adoption of SiC. Also the recent SiC module developed by STMicroelectronics for Tesla and its Model 3 is a good example of this early adoption.

PV has also caught the attention of Yole's analysts during recent months. China claimed almost the half of the world's installations in the last year. However due to new governmental regulations, Yole sees a slow down of the PV market in short term and has lowered its expectation of SiC penetration for the segment. In general, system manufacturers are interested in implementing cost effective systems which are reliable, without any technology choice, either silicon or SiC. Today, even if it's certified that SiC performs better than Silicon, system manufacturers still get questions about long term reliability and the total cost of the SiC inverter.

Yole and System Plus Consulting teams will attend Electronica/SEMICON Europa 2018 (Munich, November 13-16). During the leading trade show, Dr. Milan Rosina, Senior Technology & Market Analyst, Power Electronics & Batteries at Yole proposes a dedicated WBG presentation on November 15 at 2:30 pm.

www.yole.fr



WLTP Poses Challenges to Automakers

Automakers failing to meet 2021 fleet CO_2 emissions compliance, for passenger vehicles sold in the European Union could be fined more than €14 billion in 2021, based on new analysis from business information provider IHS Markit.

Legislators in the European Union (EU) are imposing a new passenger car fleet CO_2 emissions target of 95 g/km, to be phased in during 2020, with 100 % application in 2021 on Worldwide Harmonized Light Vehicle Test Procedure (WLTP). New passenger car fleets that fail to meet compliance are set for potentially substantial fines in both 2020 and 2021. The IHS baseline scenario (one of various scenarios) suggests that the EU28 sales-weighted passenger car phased (best 95 %) fleet CO2 average in 2020 is likely to reach 102 g/km (NEDC). This includes 4 g/km of CO_2 reduction derived from super credits and a further 2 g/km of CO2 reduction from forecasted eco-innovation technology deployment. In 2020, fines paid by OEMs could amount to €11 billion.

Furthermore, with a 2021 target set at 115 g/km (as the 95 g/km New European Driving Cycle (NEDC) target is adjusted to an equivalent WLTP value), IHS forecasts that the sales-weighted passenger car fleet CO_2 average will reach 123 g/km (WLTP). If this level of excess emission is unable to be curtailed, it could lead to a total of €14 billion in excess emission premiums. "The current expectation considers each OEM we expect to be selling cars in the region during the forecast horizon. As we continue to follow OEM technology developments and any regulatory adjustments, our forecasts may be adjusted accordingly," said analyst Vijay Subramanian. The analysis shows that 25 OEMs are however, on course to meet targets in 2020 and 2021, given developments and initiatives toward electrification and hybridization of their fleets.

The analysis shows that 25 OEMs are however, on course to meet targets in 2020 and 2021, given developments and initiatives toward electrification and hybridization of their fleets. Despite the continued collapse of the European diesel passenger car market, a technology that is generally helpful in CO_2 abatement, the implementation of other impactful technologies, including LED lighting, thermal encapsulation, highly efficient alternators and other relevant technologies are proving to be helpful in offsetting some, it not all, of the diesel headwind effect in the 2020 and 2021 periods.

Once in 2021 and subject to full WLTP regulatory monitoring, only a seismic shift (over the baseline) in consumer demand for BEV (Electric-Plug-In) and PHEV (Hybrid-Full Plug-In) will result in the full mitigation of EU28 fleet level excess emissions premiums.

Infineon Remains Power Semi Market Leader

For 2017, IHS Markit confirms Infineon Technologies AG position as the global market leader for power semiconductors (Power Semiconductor Market Share Database 2017, August 2018). In the overall market ($42.4 billion), which also includes power ICs, Infineon remained the lead and achieved the biggest organic growth across the industry. In the submarket for discretes and modules ($18.5 billion), the company has been confirmed number one for the fifteenth time in a row, increased its market share and is now more than double the size of the company in second place. In the market for discrete IGBTs ($1.1 billion), it is now more than three times the size of the next competitor. In IPMs ($1.6 billion) the company increased its market share by 1.4 % (Number 3; market share 10.3%). In total Infineon grew faster (39 %) than the market (20 %).

www.ihsmarkit.com

Funding for US WBG Projects

The PowerAmerica Institute at N.C. State University, a member of Manufacturing USA, recently awarded funding to six new member projects that will enhance wide bandgap technologies in the USA. In addition, PowerAmerica awarded funding for 20 projects to be led by existing members for a total of $20 million in project funding for this cycle.

"These projects are instrumental in fulfilling our mission of accelerating the adoption of wide bandgap technologies into power electronics systems. To date, the institute has funded scores of projects that have contributed to the development of more efficient power electronics, which will benefit a range of applications – from electric vehicles to data centers," said PowerAmerica Deputy Executive Director and CTO Victor Veliadis. The new member projects receiving funding include: Design and Manufacturing of Advanced, Reliable and Wide Bandgap Power Modules by GE Aviation Systems + National Renewable Energy Laboratory; Dual-Inductor Hybrid Converter for Direct 48 V to sub-1V PoL DC/DC Module by University of Colorado, Boulder; Solid-State Circuit Breaking at the Medium Voltage Level by University of North Carolina, Charlotte; and 600 V GaN Bi-Directional Switch by Infineon Technologies. The company will develop a low-cost, 600 V bidirectional 70 mΩ switch based on the company's CoolGaN HEMT technology, capitalizing on the unique bidirectional nature of the GaN HEMT. The project will validate both the dual gate concept and a solution for substrate voltage stabilization, and will make the GaN switch more economically attractive.

https://poweramericainstitute.org/

PowerSphyr and GaN Systems Join Forces in Wireless Charging

California-based PowerSphyr and Canadian GaN Systems announced an agreement to bring state-of-the-art GaN-based wireless power systems to market for high powered applications across consumer, industrial, and automotive applications.

Working together to develop hardware and firmware solutions, PowerSphyr and GaN Systems are committed to delivering solutions that adhere to wireless charging standards, while developing next generation power and functional capabilities. GaN transistors are the best means for higher power level applications from 30 W up to several kilowatts – much greater than achieved with traditional Silicon solutions and provide the building block to achieve higher power, higher efficiency, and lower cost in wireless power transmitters. GaN-based wireless power solutions have enabled faster charging, higher power transfer, and new system designs that are removing the limitations of distance and power and moving charging beyond phones including power tools, robots, drones, and ebikes. "We selected GaN Systems on the basis of our strategic vision for delivering fast, flexible, and complete wireless charging solutions, and their ability to rapidly deliver a complete family of robust, reliable, best-in-class semiconductors," said Neil Ganz, CEO and Chairman of PowerSphyr. The company is experienced in magnetic induction; magnetic resonance; and RF energy harvesting. "A world without cords is becoming a reality because of collaboration with visionary companies like PowerSphyr, whose technology, approach, and expertise is uniquely positioned to accelerate the wireless power transfer and charging marketplace," added Jim Witham, GaN Systems CEO. The company recently launched a 100 W power amplifier with ranges from 70 W to 100 W and a 300 W power amplifier with ranges from 150 W to 1 kW.

www.powersphyr.com, www.gansystems.com

"A world without cords is becoming a reality," expects GaN Systems CEO Jim Witham

Evolution of the smart grid

Japan faces a unique power delivery challenge because of its two entirely incompatible power grids. The odd system is a legacy from the 19th Century, when local providers In Osaka used 60 Hz generators, while German equipment purchased in Tokyo worked on a frequency of 50 Hz.

By the early 20th century, local grids worldwide were growing, driven by the demands of the industrial revolution. Alongside the less-than ideal billing options, the growing request for power meant supply sometimes outstripped demand, particularly at peak times and power quality became affected. Between the 1970s and 1990s, events such as blackouts, power cuts and brownouts, where voltage is dropped for minutes or hours, were not uncommon in many developed countries. More recently, from the turn of the century, technology has advanced to a stage where many of these limitations have been overcome. Peak power prices no longer need to be averaged out and passed on to domestic and commercial customers equally. However, new challenges, including the instability of renewable power, have also become apparent. Concerns over environmental damage from fossil fired power stations and a reluctance to uptake nuclear power has resulted in the use of renewable energy technologies on a large scale.

According to REN21's Global Status Report, 19 % of the global final energy consumed was provided by renewable energy, with modern renewables increasing their share to approximately 10 %. Renewable energy capacity grew through the use of solar photovoltaic cells, while hydropower continued to represent the majority of generation. "Renewable energy is key to fighting climate change, but it does produce highly variable power, which could lead to lower energy margins and potentially even blackouts on cloudy, still days. These risks, combined with a need for a highly distributed grid with power generated and consumed throughout, has led to the development of smart grids," explains Nick Boughton, sales manager at UK-based systems integrator, Boulting Technology.

"The first step in a smart grid upgrade is to improve infrastructure, to produce what China has coined a Strong Grid. Next is the addition of the digital layer, making the grid smart, followed by business process transformation, which is necessary to capitalize on the investment," Boughton

" Smart grids are a natural evolution of the power grid for most countries and an obvious choice for developing countries," explains Nick Boughton, sales manager at UK-based Boulting Technology

underlines. Nowadays, much of this work is grouped as smart grid upgrades. The smart grid is the end goal to take advantage of the full suite of features available for power grids. These include state estimation technology, which improves fault detection and allows self-healing and multiple power routes that improve reliability, resilience and flexibility. Modern smart grids can also handle bidirectional energy flow, pushing further toward the goal of distributed generation. This is achieved by allowing power from photovoltaic cells, fuel cells and charge from the batteries of electric cars to reverse flow. Two directional flow increases safety while reducing reliability issues in an intelligent manner.

Algorithms can use data fed back to the system to predict how many standby generators will be needed to cope with rapid increases in grid load. This promotes load reduction that can eliminate stability issues. Smart grids are a natural evolution of the power grid for most countries and an obvious choice for developing countries investing in power infrastructure or upgrading cities to smart cities. "The benefits have brought about results in more stable power quality for commercial properties, manufacturers and other industries alike. Smart grids effectively eliminate or account for many power quality and reliability issues. Despite the many advantages of a smart grid upgrade, Japan's separate grids might require more work before becoming compatible", Boughton concludes.

www.boultingtechnology.co.uk/

Allegro MicroSystems Opens R&D Center in the Czech Republic

Allegro's new center is currently staffed with two dozen engineers located in Prague to accelerate development of ICs for both the automotive and industrial markets. The team will initially focus on developing sensor ICs for electrified vehicles, green energy, and high-efficiency industrial motor applications.

"We were fortunate to hire an excellent team of engineers accelerating our position in both the automotive and industrial markets," said Michael Doogue, Vice President of Business Development. "We plan to hire an additional 20 to 30 engineers over the next few years. The Prague team is an important addition to our global product development team, and I am certain that they will have a positive impact on Allegro's product development velocity and our customer support levels for many years to come." The availability of highly skilled IC design, systems, and software engineers was a major contributor to Allegro's decision to open this new R&D center. The area provides an optimum combination of experienced engineers and recent graduates from local universities.

www.allegromicro.com

Focus Automotive at Electronica 2018

The automotive industry is undergoing a dramatic transformation. By 2025, it is forecasted that a quarter of all cars worldwide will be electrically powered. On top of that, manufacturers and suppliers are currently responding to increasing demands for "next-generation" technologies including autonomous and connected vehicles, as well as developing completely new data-generated business models. At electronica from November 13 – 16 on Munich fairgrounds this complex automotive topic will be presented on the exhibition itself, by the Automotive Forum and by the full-day electronica Automotive Conference (eAC) already on November 12.

Electronics is the driving factor in all new functions in the automotive area. The growth rate of electronic components and systems is currently in the double-digit range. In addition, the range of electronic contents and components in cloud solutions "outside of the car" has also increased considerably. Industrial companies such as Google, IBM and Intel are investing significant budgets and resources to play an important role in the future of the automotive industry.

Thus the value of semiconductor devices is also increasing, as underlineded by the microelectronic trend analysis carried out by the German Central Association of the Electrical Engineering and Electronic Industries (ZVEI). Last year's worldwide average of $477 billion is set to increase to $535 billion by 2022. Car production worldwide will simultaneously rise from 99 million units to 110 million units over the same time period. Both increases mean that 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 %.

Automotive conference

The electronica Automotive Conference will show what the future of mobility could look like. Among other things, the focus will be on emission-free driving and its effects on the automotive industry. The organization of transportation in cities will also play an important role. Among those taking part are key players from the automotive industry including suppliers (Tier 1 to 3), OEMs, component manufacturers and software developers.

Prominent speakers will address both managers and technicians. Alongside their presentations, they will also be discussing current technology trends and strategies for the worldwide automotive industry. As well as emission-free and autonomous driving up to level 5, a focal point for the conference will be the interesting topic of so-called last-mile vehicles as part of the overall mobility mix. Highlights of the conference will be the opening speeches, including those by Rainer Müller-Finkeldei, Director of Mechatronic Development for Daimler and Jürgen Bortolazzi, Director of Driver Assistance Systems for Porsche. Dr. Reinhard Ploss, CEO of Infineon Technologies, will talk about Semiconductors as a key enabler for the transition of the automotive industry.

Automotive forum

Whether it comes to semi-autonomous or autonomous driving, new interior and exterior light functions or improved connectivity—the Automotive Forum presents the latest solutions and products in the industry's various sectors. Select examples illustrate the state of the art as well as interaction between various technologies. The forum also focuses on the challenges of increasingly interdisciplinary collaboration in the future.

From piloted driving and constant connectivity with the outside world to new comfort functions in the car's interior: New technology is changing the development and working world in the automotive industry. Networked systems, new light technologies featuring LEDs, OLEDs and laser light and improved sensors for driver-assistance systems call for increasingly stronger interaction between individual controllers and actuators. More efficient components ensure added comfort and safety when driving or during (partially) piloted driving, and more elaborate software and faster data buses guarantee networking within the automobile and beyond.

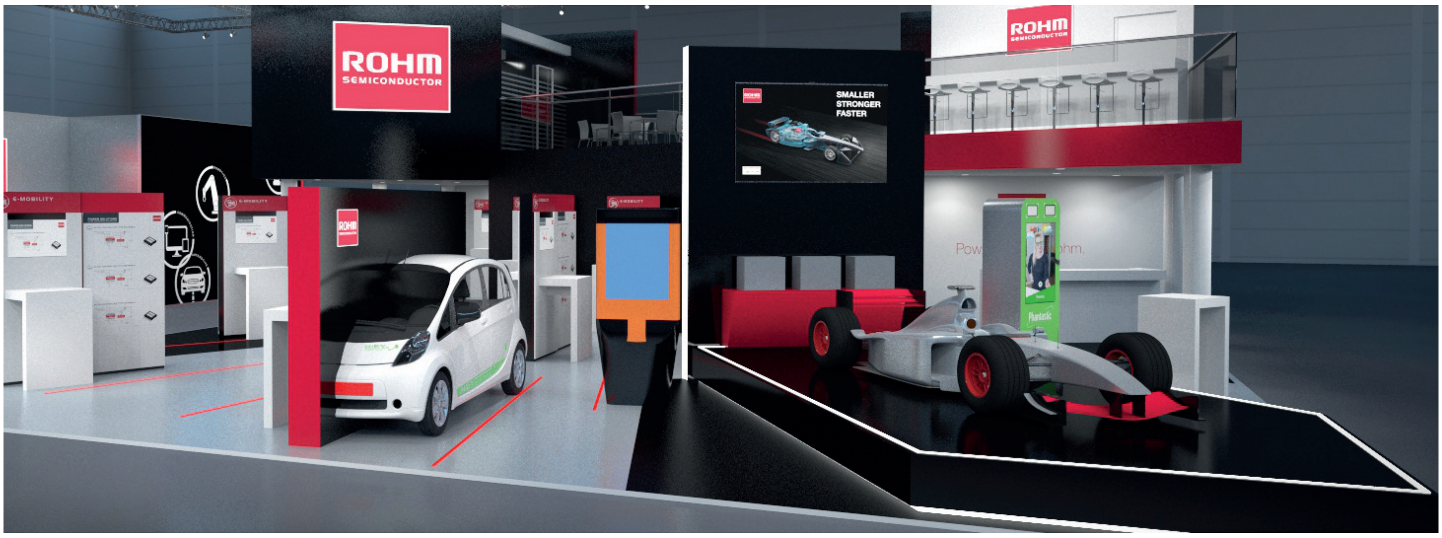
Presentations from expert speakers and panel discussions will be taking place across all four days of the trade fair. Sales engineers, electronics developers, system designers, project leaders, supply chain managers and anyone that works on automotive development projects should make their way to exhibition hall B4 where they can find out more about important trends and speak to experts and colleagues about the latest market and technology news. In addition, engineers work with other developers in expert discussion groups to develop solutions to specific technical requirements from their own day-to-day work.

Once again Falk Senger, Managing Director at Messe Muenchen, will open the electronica Automotive

Automotive exhibition area

The AKXY concept car from Japanese technology company Asahi Kasei (http://www.asahi-kasei.co.jp/) will celebrate its European premiere at electronica 2018. It consists of lithium-ion battery applications, CO_2 sensors and high-performance plastics. The car utilizes the SUV electric vehicle platform of GLM to achieve a drivable design with 225 kW motor output power. AKXY is equipped with a wide variety of Asahi Kasei materials, components, and systems, numbering 27 products in all, most of them available for adoption in mass-produced vehicles, including engineering plastics to replace metal and enable vehicle weight reduction, artificial suede for seats with superior comfort, and an in-car communication system utilizing various speech-processing technology. The car is additionally equipped with cutting-edge technology that has potential for commercialization in line with automotive industry trends for safe driving and accident prevention, including a contactless vital sign sensing system that is able to detect the pulse of drivers without their being aware of it, and CO_2 sensors to monitor the in-car environment.

Japanese Semiconductor manufacturer ROHM (**www.rohm.com/electronica**) presents 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 updates of new power devices such as 1700V SiC module and other SiC devices, Power Management ICs and sensor technologies for the automotive and industrial market. In addition, ROHM will highlight local support capabilities by presenting Power-Lab Test benches and sensing solutions by Finland Software Design Center. 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. Motor sports Formula E is attracting increasing attention worldwide as a platform for further innovation in the electric car sector. ROHM, official technology partner of the VENTURI racing team since the start of the third racing season in October 2016, contributes SiC power modules for the inverter block, which forms the core of the drive



Among others ROHM will showcase SiC power modules for FormulaE inverters

system of electric vehicles. ROHM will showcase the latest generation of inverters and the Formula E racing car of the fifth season as an application example for SiC power modules.

Wolfspeed's E-Series family (**www.wolfspeed.com/e-series**) is the first commercial family of SiC MOSFETs and diodes to be automotive AEC-Q101 qualified and PPAP capable. It features the third generation planar technology, which has more than 10 billion field hours. The E-Series 900 V MOSFET is optimized for use in EV battery chargers and high voltage DC/DC converters and is featured in a 6.6k W bidirectional OBC reference design. The E-Series 1200 V Merged-PIN Schottky Diodes (MPS) deliver high reliability for on-board power conversion systems and solar inverters, complementing Wolfspeed's existing AEC-Q101 qualified 650 V SiC diode portfolio.

This time round, electronica will be going way beyond the presentation of relevant components, systems, applications, and solutions. In addition to 17 halls, 13 forums, and four conferences, there will be a wide range of innovations on show. Exhibitors, visitors, established industry players and start-ups, not to mention employers and new talent, will therefore have extensive opportunities for making contacts and networking. Over 3000 companies from more than 50 countries will be present to provide a glimpse of the future.

5 kV Reinforced Digital Isolator

In high-voltage equipment, digital isolators provide signal isolation and level-shifting for proper operation of many circuits, while also protecting users from dangers such as electric shock. Yet, not all of these isolators are alike as many consume a large amount of power, generate significant heat and introduce large propagation delays, limiting system reliability and throughput.

To better protect industrial systems from the dangers of high-voltage signals, equipment designers can now turn to the new robust MAX22445 5 kVRMS four-channel reinforced digital isolator from Maxim Integrated Products. Delivering up to 2x greater throughput at 4x lower power consumption versus other solutions, the MAX22445 provides reliable communication across the isolation barrier to ensure safe operation of compact industrial, medical and other equipment. The IC, which mitigates the dangers of high-voltage power, transfers signals of up to 200 Mbps. It is available in a 16-pin wide-body SOIC package with 8 mm of creepage and clearance. The MAX22445 is available at Maxim's website for $3.49 (1000-up, FOB USA).

The MAX22444–MAX22446 family offers all possible unidirectional channel configurations to accommodate any 4-channel design, including SPI, RS-485, and digital I/O applications. Output enable for the A side of the MAX22445R/S/U/V is active-low, making them ideal for isolating a port on a shared SPI bus since the CS signal can directly enable the MISO signal on the isolator. All other output enables in the MAX22444-MAX22446 family are the traditional active-high.

Digital isolation

The MAX22444-MAX22446 provide reinforced galvanic isolation for digital signals that are transmitted between two ground domains. The devices withstand differences of up to 5 kV_{RMS} for up to 60 seconds, and up to 2121 V_{PEAK} of continuous isolation.

The wide supply voltage range of both V_{DDA} and V_{DDB} allows the MAX22444-MAX22446 to be used for level translation in addition to isolation. V_{DDA} and V_{DDB} can be independently set to any voltage from 1.71 V to 5.5 V. The supply voltage sets the logic level on the corresponding side of the isolator.

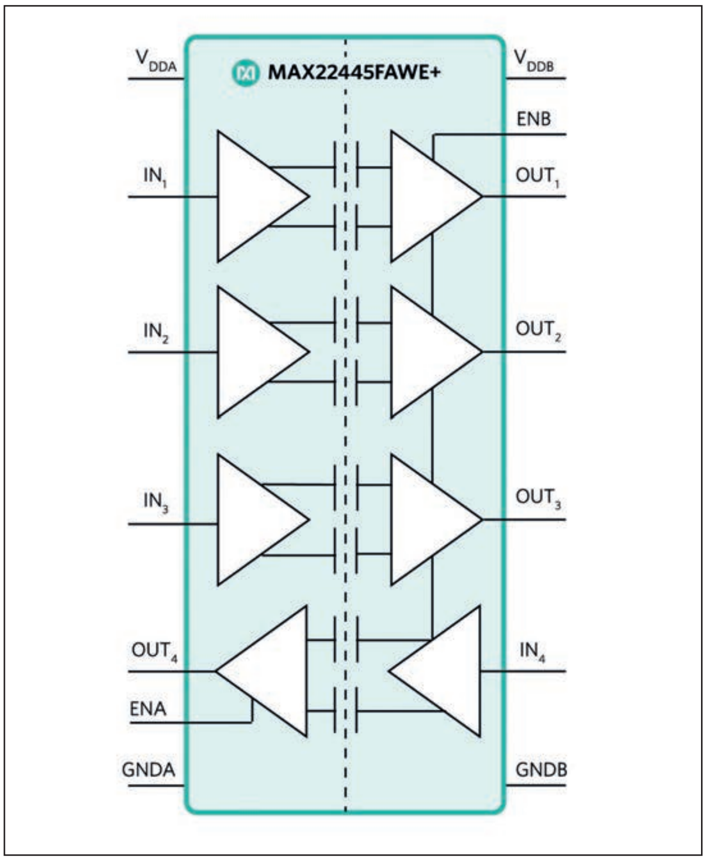
Each channel of the MAX22444-MAX22446 is unidirectional; it only passes data in one direction. Each device features four unidirectional channels that operate independently with guaranteed data rates from DC up to 25 Mbps (B/E/M/R/U versions), or from DC to 200 Mbps (C/F/N/S/V versions). The output driver of each channel is push-pull, eliminating the need for pullup resistors. The outputs are able to drive both TTL and CMOS logic inputs.

Power supply sequencing

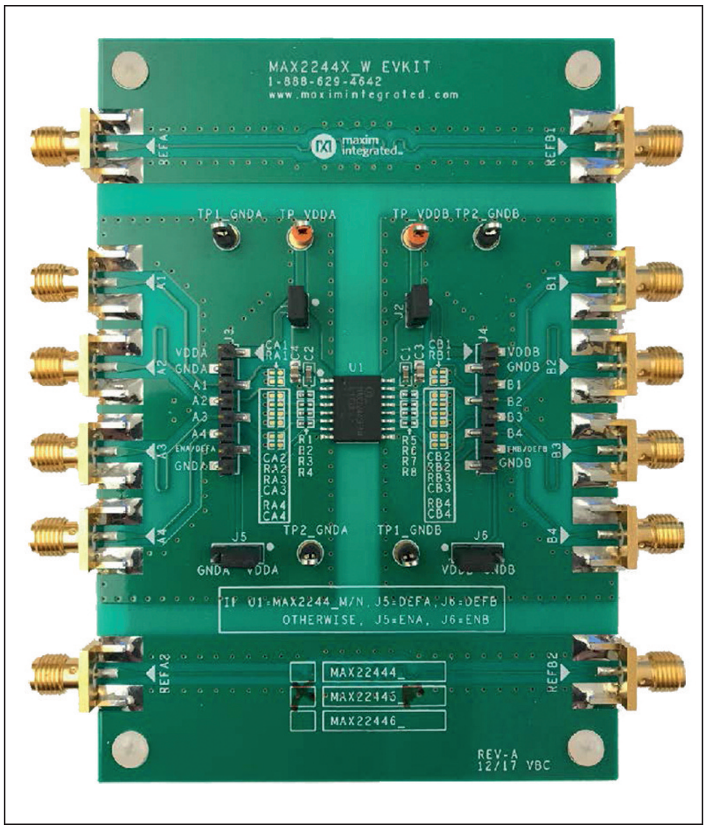
The MAX22444-MAX22446 do not require special power supply sequencing. The logic levels are set independently on either side by V_{DDA} and V_{DDB}. Each supply can be present over the entire specified range regardless of the level or presence of the other supply.

To reduce ripple and the chance of introducing data errors, V_{DDA} and V_{DDB} should be bypassed with 0.1µF low-ESR ceramic

Maxim's new digital isolaters enables safe, high data throughput and compact industrial automation systems



MAX22444-MAX22446 block diagram



MAX22445FW populated evaluation kit

capacitors to GNDA and GNDB as close to the power supply input pins as possible.

Safety limits

The V_{DDA} and V_{DDB} supplies are both internally monitored for undervoltage conditions. Undervoltage events can occur during power-up, power-down, or during normal operation due to a sagging supply voltage. When an undervoltage condition is detected on either supply while the outputs are enabled, all outputs go to their default states regardless of the state of the inputs.

Damage to the BiCMOS IC can result in a low-resistance path to ground or to the supply and, without current limiting, the MAX22444-MAX22446 could dissipate excessive amounts of power. Excessive power dissipation can damage the die and result in damage to the isolation barrier, potentially causing downstream issues.

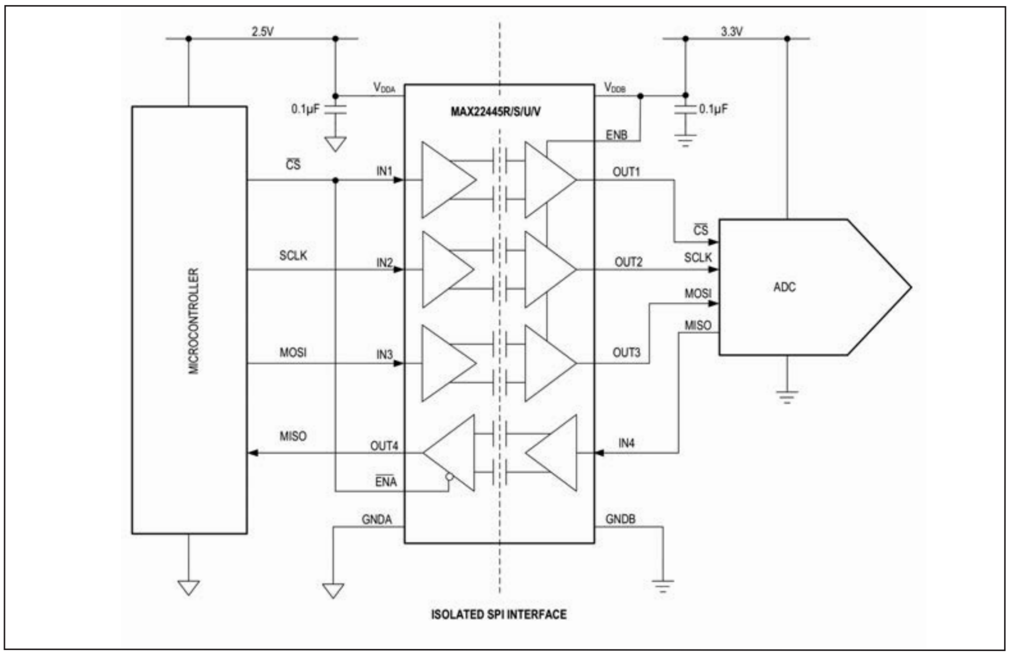
Evaluation kits

The MAX22444–MAX22446 EV kits provide a proven design to evaluate the digital isolators. Two types of evaluation boards are available to support different channel direction configurations, different ENA polarities and different output default settings. The MAX22445FWEVKIT# is fully assembled and tested, and comes populated with the MAX22445FAWE+. The MAX2244XWEVKIT# is a generic board which has U1 unpopulated allowing the user to select a device from the MAX22444-MAX22446 family. Both evaluation boards support the wide-body 16-pin SOIC package type.

The EV kits should be powered from two independent isolated power supplies with nominal output voltage in range from 1.71V to 5.5V. For evaluating the electrical parameters of the device without any isolation between the two sides, a single power supply can also be used.

Intended applications are Battery Management, Fieldbus Communications for Industrial Automation, Isolated RS-485/RS-422, CAN, Isolated SPI Interface, or Medical Systems. The MAX22445FWEVKIT# evaluation kit is available for $32 (FOB USA).

www.maximintegrated.com/products/MAX22445



RIGHT: MAX22445 SPI bus isolation schematic

FluxLink Now Automotive Qualified

SCALE-iDriver ICs now certified AEC-Q100 for automotive applications

Power Integrations released two members of its SCALE-iDriver™ gate-driver IC family certified to AEC-Q100 Grade Level 1 for automotive use. The two parts, SID1132KQ and SID1182KQ, are suitable for driving 650 V, 750 V and 1200 V automotive IGBT and SiC-MOSFET modules, and are rated for peak currents of +/-2.5 A and +/-8 A respectively. The SID1182KQ has the highest output current of any isolated gate driver available and is capable of driving a 600 A /1200 V and 820 A750 V switches.

The single-channel IGBT and SiC-MOSFET driver ICs features FluxLink™ magneto-inductive bi-directional communication technology which ensures reinforced galvanic isolation between the primary and secondary sides, setting a new standard in isolation integrity and stability. FluxLink technology eliminates the need for opto-electronics, which suffer parametric changes with age and relentless thermal degradation that limits operational lifetime. Use of magnetically-coupled conductors locked into a homogenous thermoset, high quality insulation greatly enhances operational stability and longevity. The devices utilize a compact eSOP package, which offers a CTI level of 600, 9.5 mm creepage and clearance distance, and meets automotive 5500 m requirements.

AEC-Q100 approval for the SCALE-iDriver gate-driver family enables automotive design engineers to increase system efficiency. The automotive DC/DC converter for the secondary-side supply voltage is greatly simplified as only a unipolar voltage is required. Built-in voltage and power management circuitry handles the necessary regulation of positive and negative gate-drive voltages. The IC features a full range of safety features including Advanced Soft Shut Down (ASSD) for short-circuit turn-off and under-voltage protection.

Short-circuit protection

The SCALE-iDriver uses the semiconductor desaturation effect to detect short-circuits and protects the device against damage by ASSD. Desaturation can be detected using two different circuits, either with diode sense circuitry or with resistors . With the help of a well stabilized V_{VISO} and a Schottky diode (DSTO) connected between semiconductor gate and VISO pin the short-circuit current value can be limited to a safe value.

During the off-state, the VCE pin is internally connected to the COM pin and C is discharged. When the power semiconductor switch receives a turn-on command, the collector-emitter voltage (V_{CE}) decreases from the off-state level same as the DC-link voltage to a normally much lower on-state level and C_{RES} begins to be charged up to the V_{CE} saturation level ($V_{CE\ SAT}$). C_{RES} charging time depends on the resistance of R_{VCEX}, DC-link voltage and C_{RES} and R_{VCE} value. The V_{CE} voltage during on-state is continuously observed and compared with a reference voltage, V_{DES}. The V_{DES} level is optimized for IGBT applications. As soon as V_{CE}>V_{DES}, the driver turns off the power semiconductor switch with a controlled collector current slope, limiting the V_{CE} over-voltage excursions to below the maximum collector-emitter voltage (V_{CES}). Turn-on commands during this time and during t_{SO} are ignored, and the SO pin is connected to GND.

The response time t_{RES} is the C_{RES} charging time and describes the delay between VCE asserting and the voltage on the V_{CE} pin rising. Response time should be long enough to avoid false tripping during semiconductor turn-on and is adjustable via R_{RES} and C_{RES} or R_{VCE} and C_{RES} values. It should not be longer than the period allowed by the semiconductor manufacturer.

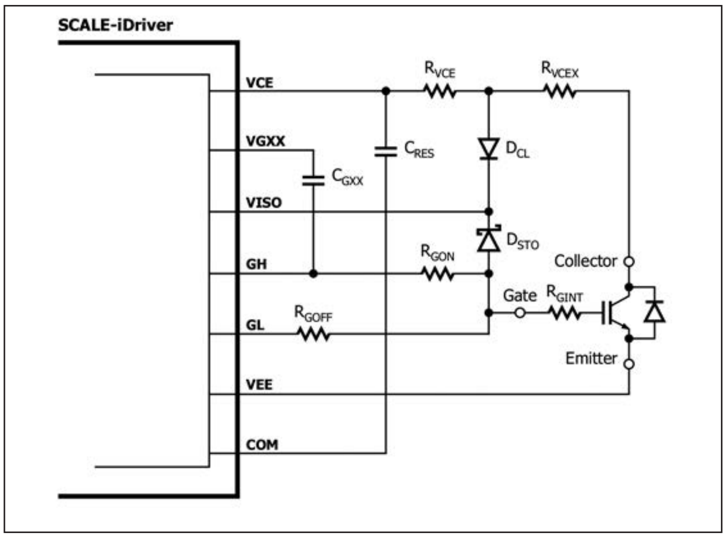
Application example

The schematic and typical components using a Resistor Network or Diodes for Desaturation Detection are shown below. In both cases the primary-side supply voltage (V_{VCC}) is connected between VCC and GND pins and supported through a supply bypass ceramic capacitor C1 (4.7 mF typically).

If the command signal voltage level is higher than the rated IN pin voltage (in this case 15 V) a resistive voltage divider should be used. Additional capacitor CF and Schmitt trigger IC1 can be used to provide input signal filtering. The SO output has 5 V logic and the RSO is selected so that it does not exceed absolute maximum rated ISO current.

The secondary-side isolated power supply (V_{TOT}) is connected between VISO and COM. The positive voltage rail (V_{VISO}) is supported through 4.7 µF ceramic capacitors C_{S21} and C_{S22} connected in parallel. The negative voltage rail (V_{VEE}) is similarly supported through capacitors C_{S11} and C_{S12}. The gate charge will vary according to the type of power semiconductor switch that is being driven. Typically, C_{S11} + C_{S12} should be at least 3 mF multiplied by the total gate charge of the power semiconductor switch (Q_{GATE}) divided by 1 mC. A 10 nF capacitor CG_{XX} is connected between the GH and VGXX pins.

The gate of the power semiconductor switch is



Short-circuit protection using a resistor chain R_{VCEX}

connected through resistor R to the GH pin and by R_{GOFF} to the GL pin. If the value of R_{GON} is the same as RGOFF the GH pin can be connected to the GL pin and a common gate resistor can be connected to the gate. In any case, proper consideration needs to be given to the power dissipation and temperature performance of the gate resistors.

The switch desaturation can be measured using resistors R_{VCE2} – R_{VCE11}. In this example all the resistors have a value of 100 kΩ using 1206 package. The total resistance is 1 MΩ. The resistors should be chosen to limit current to between 0.6 mA to 0.8 mA at maximum DC-link voltage. The sum of R_{VCE2} – R_{VCE11} should be approximately 1 MΩ for 1200 V semiconductors and 500 kΩ for 600 V semiconductors. In each case the resistor string must provide sufficient creepage and clearance distances between collector of the switch and SCALE-iDriver. The low leakage diode DCL keeps the short-circuit duration constant over a wide DC-link voltage range.

Response time is set up through R_{VCE} and C_{RES} (typically 120 kΩ and 33 pF respectively for 1200 V semiconductors). If short-circuit detection proves to be too sensitive, the C_{RES} value can be increased. The maximum short-circuit duration must be limited to the maximum value given in the semiconductor data sheet.

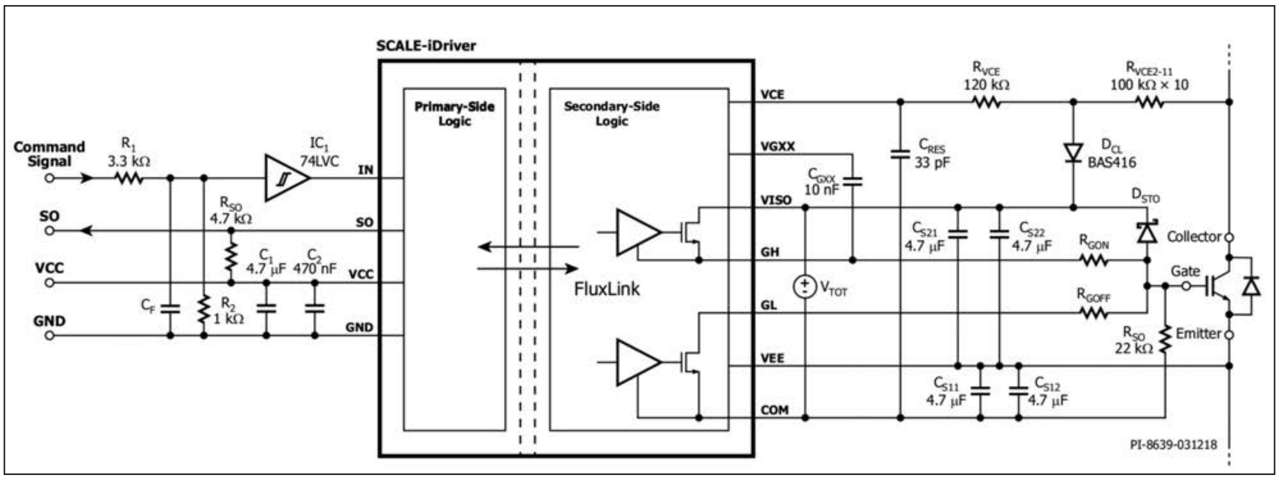
The second application example illustrates how diodes D_{VCE1} and D_{VCE2} may be used to measure switch desaturation. For insulation, two diodes in SMD packages are used (STTH212U for example). R_{RES} connected to VISO guarantees current flow through the diodes when the semiconductor is in the on-state. When the switch desaturates, C_{RES} starts to be charged through RRES. In this configuration the response time is controlled by R_{RES} and C_{RES}. In this application example CR_{ES} = 33 pF and R_{RES}= 62 kΩ; if desaturation is too sensitive or the short-circuit duration too long, both C_{RES} and R_{RES} can be adjusted.

It is important to ensure that PCB traces do not cover the area below the desaturation resistors or diodes D_{VCE1} and D_{VCE2}. This is a critical design requirement to avoid coupling capacitance with the SCALE-iDriver's VCE pin and isolation issues within the PCB. Gate resistors are located physically close to the power semiconductor switch. As these components can get hot, it is recommended that they are placed away from the SCALE-iDriver.

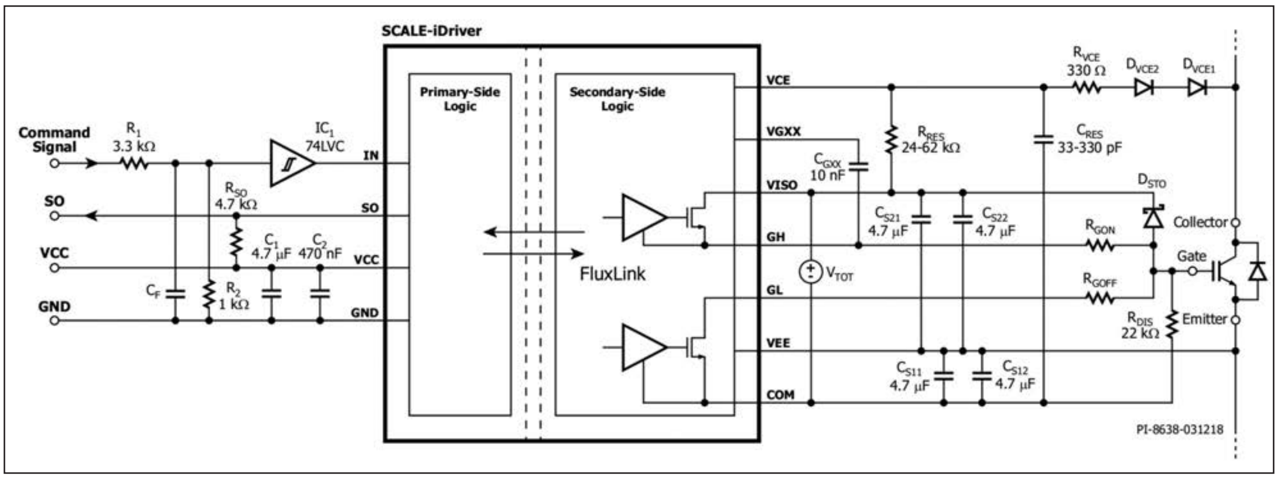
Literature

"New Isolation Technology Improves Reliability and Safety", Power Electronics Europe 3-2018, pages 31-32

www.power.com/products/scale-idriver-ic-family/sid11x2kq/



SCALE-iDriver application example using a resistor network for desaturation detection



SCALE-iDriver Application Example Using Diodes for Desaturation Detection

Doing More with Buck Regulator ICs

Switching regulators are widely used and one of the most popular switching regulator topologies is the buck converter (also known as a step-down converter). Manufacturers typically offer buck regulator ICs with built-in controller and integrated FETs. Such buck regulators primarily implement step-down voltage conversion. Nevertheless, they can also be used to create many other designs, such as inverting power supplies, bipolar power supplies, and isolated power supplies with single or multiple isolated voltage rails. This article introduces a variety of designs using buck regulator ICs, explains their operational principles, and discusses the practical considerations to implement these designs. **Sitthipong Angkititrakul, Applications Engineer, Renesas/Intersil Electronics Corporation, USA**

Renesas' ISL8541x family of buck regulator ICs feature integrated high-side and low-side FETs, internal boot diode, and internal compensation, which minimizes the amount of external components and enables very small total solution size. In addition, this family of regulator ICs has a wide input voltage range of 3 V to 40 V to support a multi-cell battery and a variety of regulated voltage rails. In this article, the ISL85410 buck regulator IC is used to illustrate various application designs.

Step-down converter with a buck regulator IC

A step-down converter is required when the desired voltage level is lower than the available voltage source in the system. For example, take a system that has a 12 V battery as input, but lower voltage rails such as 5 V, 3.3V , or 1.2 V are desired to power microcontrollers, I/O's, memory, and FPGAs. By efficiently converting a high voltage to a low voltage, the buck converter extends the system's battery life, reduces heat dissipation, and improves reliability. Figure 1 shows the simplified schematic of a step-down converter using the ISL85410 buck regulator IC.

The output voltage has the same polarity as the input voltage, and the voltage conversion ratio in continuous-conduction-mode (CCM) can be expressed as

$$V_{OUT} / V_{IN} = D \qquad (1)$$

where D is duty cycle and ranges from 0 to 1, which indicates the output voltage (V_{OUT}) is always less than or equal to the input voltage (V_{IN}).

Inverting power supply with a buck regulator

While positive voltages are commonly used and available in electronic systems, negative voltages are sometimes also required. In such cases, an inverting power supply will be required to generate a negative voltage from a positive input. The inverting buck-boost converter is one of the popular solutions to address these application needs.

Figure 2 compares the power stage of a buck converter with an inverting buck-boost converter, showing that an inverting buck-boost converter can be derived by switching FET Q2 and inductor L1. This

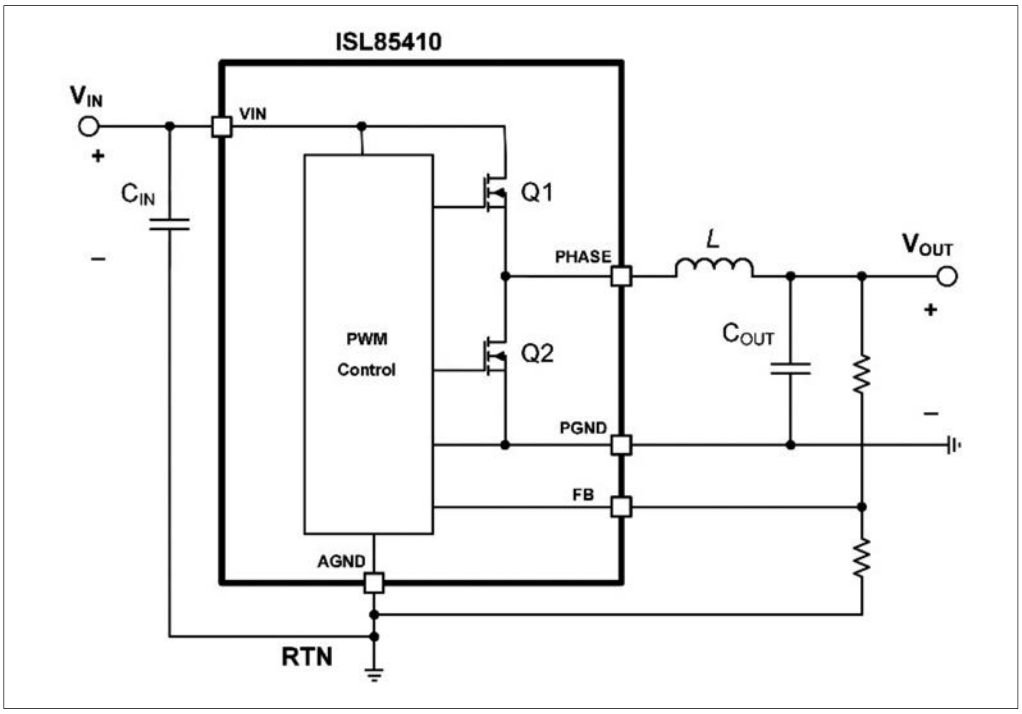


Figure 1: Simplified schematic of a step-down converter

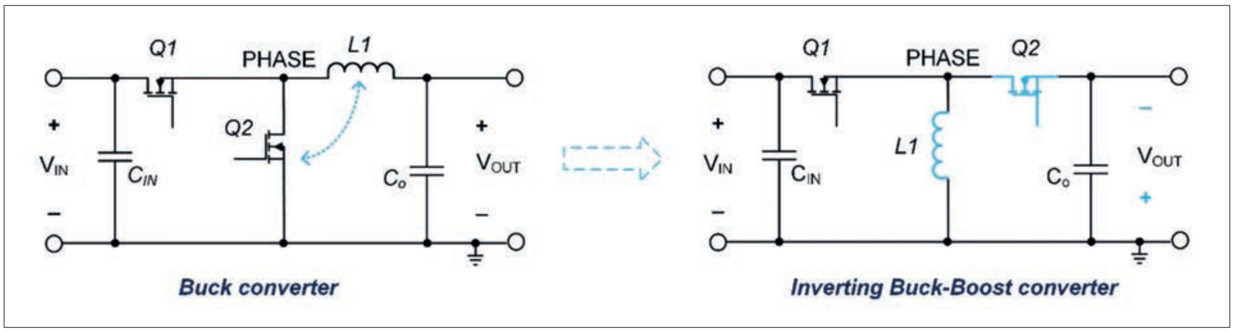


Figure 2: Power stages of buck converter and inverting buck-boost converter

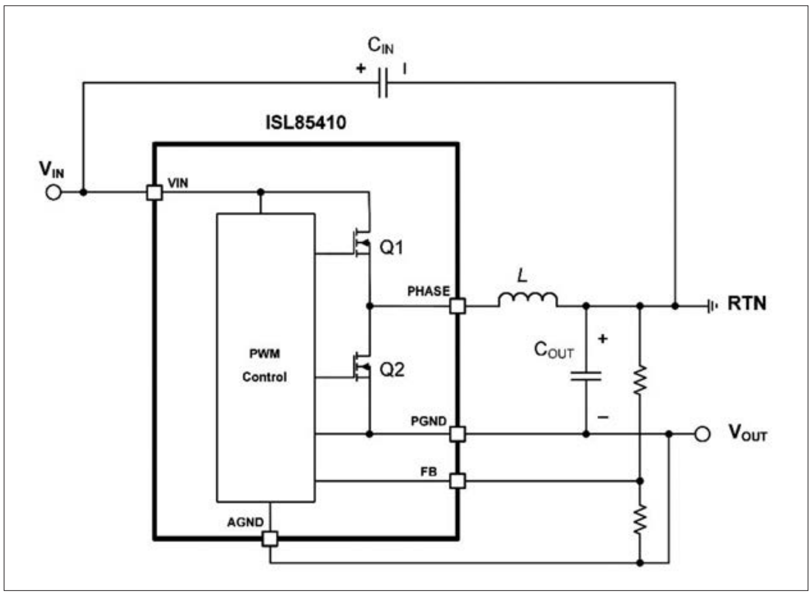


Figure 3: Simplified inverting buck-boost converter implementation

topology change results in different voltage conversion ratio and inverting polarity of the output voltage

$$V_{OUT} / V_{IN} = - D / 1 - D \qquad (2)$$

In an inverting buck-boost converter, the output voltage amplitude can be either higher or lower than the input voltage, and the output voltage is negative with respect to ground of the input voltage source.

The inverting buck-boost converter can be implemented with a highly integrated buck regulator IC. Figure 3 shows a simplified implementation example using the ISL85410 buck regulator. When configuring a buck regulator as an inverting buck-boost converter, power designers must pay attention to two major differences. The first difference is the connection of the return (RTN) of input voltage source (V_{IN}). In the buck converter shown in Figure 1, the RTN of input voltage source is also the device ground (i.e., the AGND/PGND pins of the buck regulator), while the RTN of the input voltage source and the device ground are no longer the same in an inverting buck-boost converter. Hence, the input voltage source must be applied across VIN pin and RTN instead of AGND/PGND pins when implementing an inverting buck-boost converter.

The second difference is the voltage stress on VIN pin with reference to AGND pin. This voltage in a buck converter is always equal to V_{IN} regardless of the output voltage. By contrast, the VIN pin in an inverting buck-boost converter has to tolerate the sum of input voltage and output voltage ($V_{IN}+V_{OUT}$). For instance, in a design converting 24 V to -5 V, the voltage stress on VIN pin is 29 V rather than 24 V. Keep in mind that the voltage stress on VIN pin should never exceed the absolute maximum voltage rating specified in the IC datasheet.

Bipolar power supply with a buck regulator IC

Many applications, including operational amplifiers and data acquisition systems, need a bipolar ±5 V or ±12 V power supply. One popular method is to use a single switching regulator along with a coupled inductor (also commonly called a transformer) to generate a negative voltage

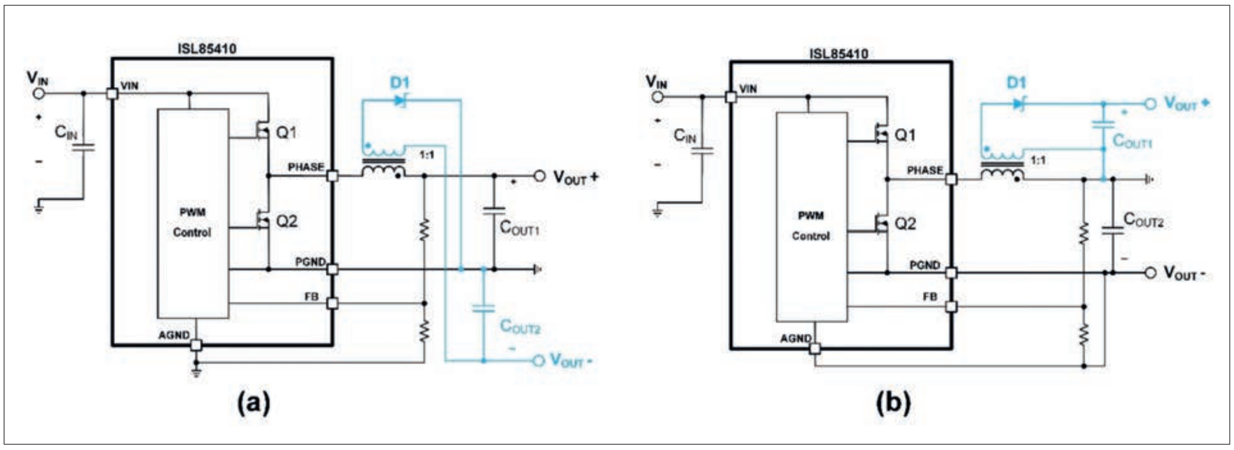


Figure 4: Simplified schematic of bipolar power supply using buck method (a) or inverting buck-boost method (b)

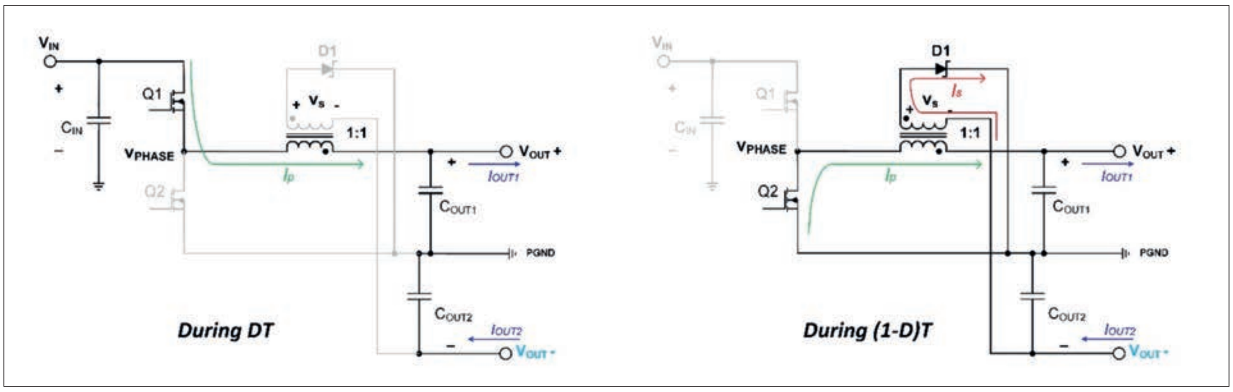


Figure 5: Equivalent circuit of a bipolar power supply using buck method

VIN	VOUT+	VOUT-	IOUT1	IOUT2	fSW
24V	5V	-5V	100mA	100mA	500kHz

Table 1: Key parameters of the bipolar power supply

rail and a positive voltage rail. Figure 4 shows how a buck converter and inverting buck-boost converter can be used to create bipolar power supplies.

As shown in Figure 4(a), the ISL85410 buck regulator is first configured as a buck regulator regulating the positive output V_{OUT+}, and then the negative output V_{OUT-} is generated by adding an additional coupled winding. The positive output V_{OUT+} is regulated as in a buck converter, while the negative output V_{OUT-} reflects V_{OUT+} (for simplicity purpose, forward voltage drop of the rectifier diode D1 is neglected) but with an opposite polarity.

Figure 5 shows the equivalent circuit of a bipolar power supply using the buck method during the time intervals of DT and (1-D)T. During DT, high side FET Q1 is on, which leads to reverse biased rectifier diode D1, and thus no current flows in the secondary winding. During (1-D)T, Q1 is off and the current Ip freewheels through low side FET Q2. The voltage across secondary winding (V_S) reflects V_{OUT+}, and consequently D1 is turned on to charge output capacitor C_{OUT2} and supply power to the load. It is highly recommended to configure the converter in forced CCM to achieve good voltage regulation for the negative output voltage (V_{OUT-}).

A SIMPLIS model of the bipolar power supply, using the ISL85410, was built and simulated to elaborate its operation principle. The key parameters are listed in Table 1.

The simulation waveforms are shown in Figure 6. During (1-D)T when Q2 is on, the reflected current of the secondary winding current (I_S) makes the total primary current (I_P) become negative. Through proper design, this negative current should be kept low enough to avoid triggering the negative current limit of the buck regulator under normal operation conditions.

Figure 4 (b) shows another approach, which uses the inverting buck-boost method to generate a bipolar power supply. In contrast with the approach using buck method, the inverting buck-boost method configures the buck regulator IC in an inverting buck-boost to create a negative voltage rail, while a positive voltage rail is generated using a coupled winding. Unlike the bipolar power supply using buck method, the inverting buck-boost method can regulate the output from an input voltage lower than the output (step-up conversion). However, the voltage stress seen by FETs in the inverting buck-boost method is higher than the buck method. Table 2 summarizes the comparison between these two methods, provides the design guidelines for choosing the best solution for a specific application.

Isolated power supply with a buck regulator IC

Isolated voltage rails often are required to provide galvanic isolation, enhance safety, and enhance noise immunity. Common applications examples include programmable logic controllers (PLCs), smart power metering, and IGBT driver power supplies. Flyback and push-pull converters are two of the popular and cost effective solutions. However, the flyback converter usually requires an optocoupler or an auxiliary winding to regulate output voltage. In addition, the switch in flyback suffers high voltage spikes and thus an RCD snubber is commonly required. The push-pull DC transformer operating with a fixed 50 % duty cycle either suffers bad output voltage regulation or needs an additional LDO for accurate output regulation.

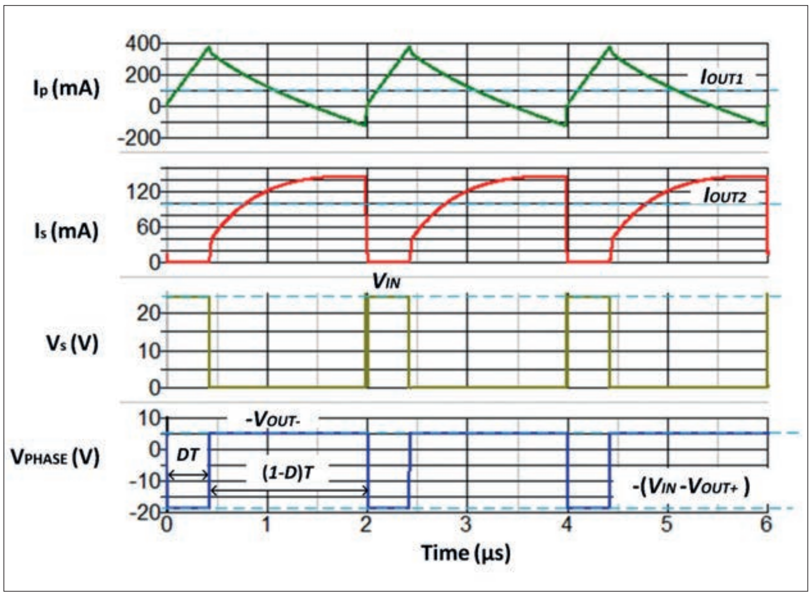


Figure 6: Simulation waveforms of a bipolar power supply using buck method

Bipolar Power Supply	Pros	Cons
Buck Method	Lower max voltage seen by VIN pin	Output cannot be higher than input
	Lower voltage stress on FETs	Higher duty cycle is required with same input
	Lower primary inductor current	
Inverting Buck-Boost Method	Output can be either higher or lower than input	Higher max voltage seen by VIN pin
	Lower duty cycle with same input	Higher voltage stress on FETs
		Higher primary inductor current

Table 2: Comparison of bipolar power supply using buck method versus inverting buck-boost method

In the aforementioned bipolar power supply (Figure 4), the additional output voltage rail is achieved by adding a magnetically coupled winding to the inductor in a buck or inverting buck-boost converter. By simply isolating the returns of these two outputs, an isolated voltage rail is achieved (see Figure 7). This approach has recently become very popular.

The two approaches for generating an isolated voltage rail using a buck regulator are shown in Figure 7. These configurations are similar to the bipolar power supply descried in Figure 4 except the returns (references) of the two outputs are separated. Unlike a bipolar power supply where the transformer turns ratio is 1:1, the turns ratio of an isolated power supply can be optimized to set the desired output voltage on the secondary side. Moreover, it can be adjusted to make the controller operate with an optimal duty cycle.

The isolated power supply with a buck regulator offers several advantages. The buck method shown in Figure 7(a) is widely adopted and will be used as an example to explain its benefits. First, it eliminates the optocoupler or tertiary winding required in a flyback converter. Secondly, the buck configuration on the primary side provides low voltage stress on the primary side FETs versus the flyback converter. Lower voltage FETs means lower on-resistance and higher efficiency. Thirdly, the primary side output (V_{OUT1}) is well regulated and the isolated output (V_{OUT2}) reflects V_{OUT1}, which gives good output voltage regulation on the secondary side over a wide input voltage range. Better voltage regulation can be achieved than a push-pull DC transformer without extra LDOs. Highly integrated buck regulator ICs such as the ISL85410 with internal compensation makes these approaches easy to use and attractive for power supply design.

Multiple isolated voltage rails can be realized by adding more coupled windings – two examples are shown in Figure 8. The operation principle is similar to the single isolated voltage rail.

Conclusion

Buck regulator ICs make it easy to implement buck converters for realizing step-down power conversion. We have shown how they can be employed to generate inverting power supplies, bipolar power supplies and isolated power supplies with single or multiple isolated voltage rails. The highly integrated ISL8541x family of buck regulator ICs features wide input voltage range, integrated boot diode, and internal compensation. The inverting, bipolar, and isolated power supply solutions implemented with these ICs offer several important benefits, including low external components count, small total solution size, and ease of use.

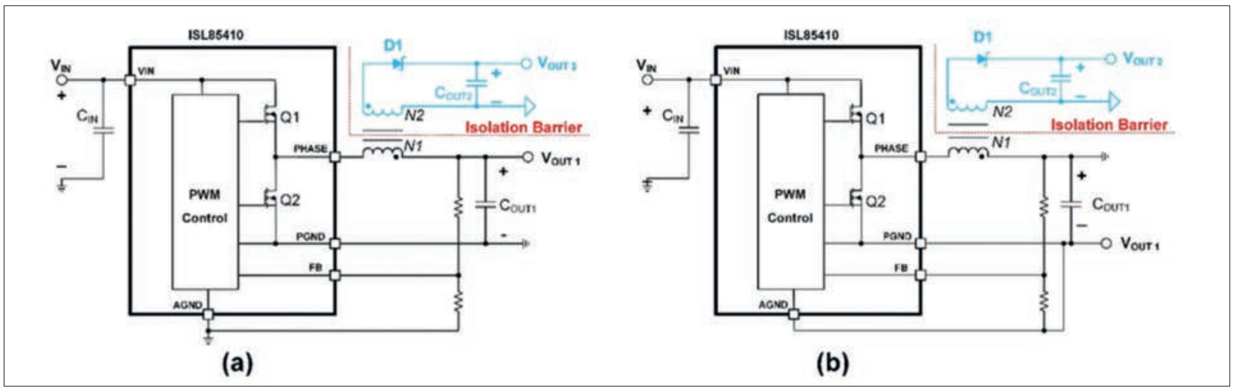


Figure 7: Simplified single isolated voltage rail using buck method (a) or inverting buck-boost method (b)

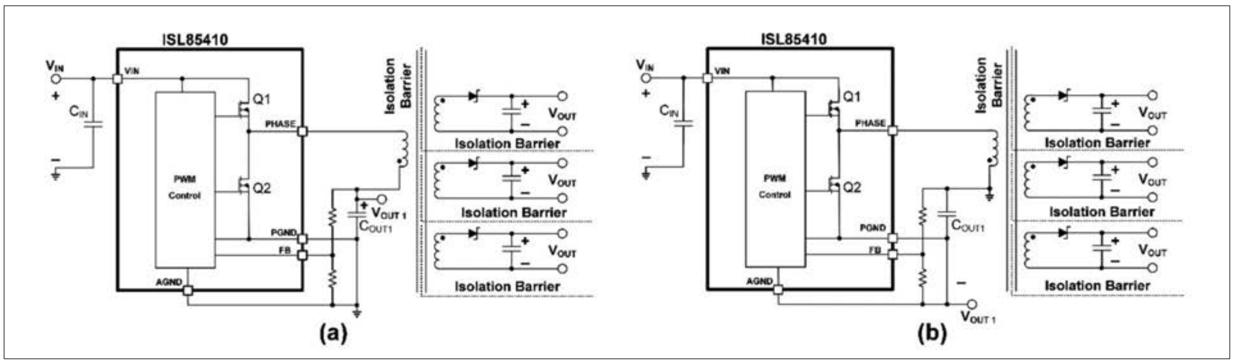


Figure 8: Multiple isolated voltage rails using buck method (a) or inverting buck-boost method (b)

Rapid Prototyping of Power Supplies By Programmable Power Modules

It is often overlooked, but the power supply is one of the most essential part of all hardware products. A high-efficiency power supply design directly benefits the overall system cooling requirement, thereby reducing the cost and volume of the final product. A low-noise power solution design ensures that the final products pass applicable EMI standards, such as IEC EN61000. In some applications, such as data transceivers and DAC/ADCs, the performance of a product is highly dependent on the design and noise level of the power supplies. To meet target specifications, power engineers may have to do a complete redesign of the power supply during the prototyping stage. Plug & play digital programmable power modules enable now rapid prototyping of power supplies. **Heng Yang, Sr. Applications Engineer, Monolithic Power Systems, USA**

The design cycle of a hardware system is an iterative process that involves design, prototyping, and verification (see Figure 1). Each iteration adds to the system development cost and time. If specifications of a project changes, a new prototype need to be developed. Besides, modern power management ICs have embedded more features, which increase the complexity in the power stage design and board layout. Consequently, it is not trivial to accurately predict the behavior of a power supply design in advance, considering the complex compensation network and parasitic elements introduced by PCB traces. If the power supply of a prototype fails to meet target specifications, the entire system may not function properly. Realistically, it is often required to modify the power stage. Therefore, a new prototype must be built to improve the power supply design. For example, an original stable power converter may become unstable at a larger load step due to an insufficient phase margin. To stabilize the power supply, the compensation network must be redesigned.

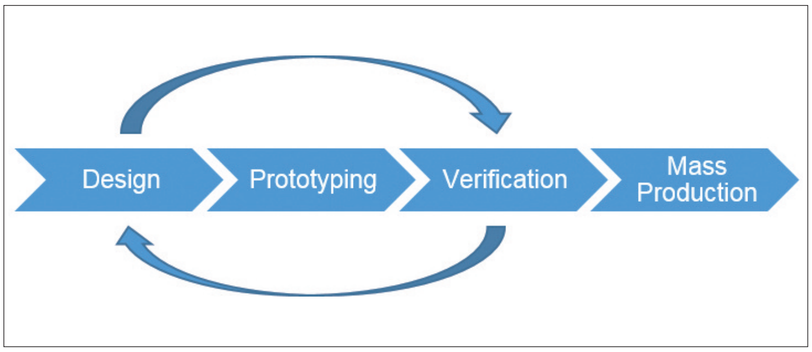


Figure 1: Iterative hardware system design process

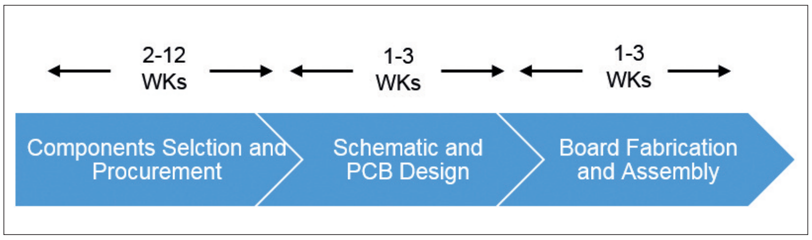


Figure 2: Steps involved in traditional power supply prototyping

Rapid power supply prototyping

The prototyping of a hardware system involves component procurement, schematic design, PCB layout, and board fabrication and assembly. Each of the steps below involved in the prototype development can be costly and time consuming (see Figure 2). The lead-time of component procurement can be very long and unpredictable. Complex systems require a wide variety of components. Customized parts and ICs require an even longer wait time?

The schematic and PCB design can be accelerated. However, a fast design service would require a higher price, which adds to the total development cost. Lead-time of board fabrication and assembly also correlate to their cost. A 3-day PCB fabrication turn-time can cost as much as two times a 7-day turnaround time.

As shown in Figure 2, the lead-time of a new prototype can be as long as 18 weeks. This delays the overall project schedule significantly. A rapid power supply prototyping solution can help power engineers control the schedule and budget of the any new product development (see Figure 3).

There are four key features of this solution. The entire power solution is integrated into a single standard DIP/LGA package. The integrated power solution enables cold swap of a power supply and significantly simplifies the PCB design – only the input and output copper planes

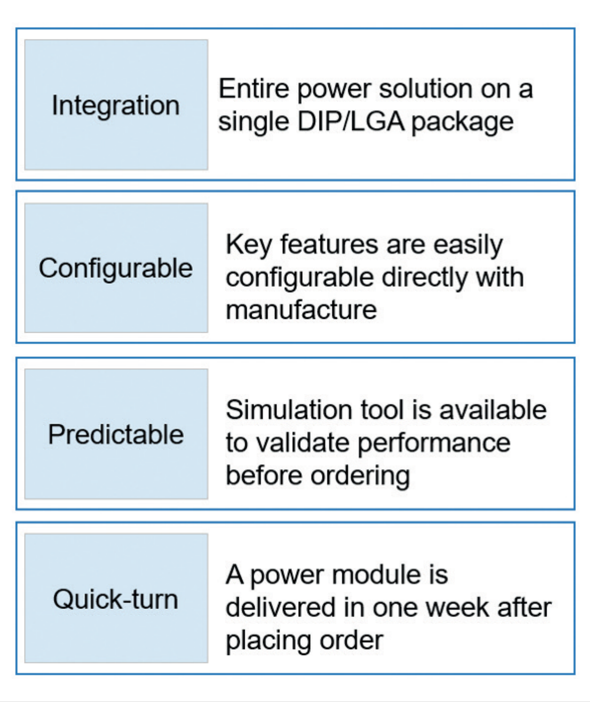


Figure 3: Rapid power supply prototyping solution

are needed. Furthermore, the integrated power solution eliminates the possibility of PCB routing errors. The parasitic elements are well controlled and predicable within the power solution package. Therefore, unexpected power supply behavior due to parasitic elements is eliminated.

The key features of the power supply can be configured online when ordering to satisfy an initial or revised specification. The configurable power solution eliminates the need for a complex power stage and compensation network design. The power supply is optimized by a vendor before shipping to meet the given specifications.

The power solution is modeled precisely. The exact behavior, including stability, output voltage ripple, power dissipation, fault limits, and soft-starting time, can be simulated in advance before ordering. The simulation minimizes the chance of falling to meet specifications.

The last key feature of the rapid prototyping solution is quick turnaround. The customized power solution can be delivered within one week after placing the order.

By employing the fast power supply prototyping solution, a power engineer can shorten the power supply prototype development time by as much as 95 % (see Figure 4). Additionally, the cost of non-power components and board fabrication and assembly are reduced, which reduces the overall cost of product development. The power engineer can leverage an existing hardware prototype by simply swapping the power solution with a new one if only the redesign of power stage is needed.

The process for prototyping development are simplified into three easy steps:

- Configure the integrated power solution online based on an initial or revised specification
- Simulate the configured power supply at rated operating condition to validate the performance of the power supply.
- Replace the power module on an existing prototype with the new one.

Field programmable power modules

Monolithic Power Systems' mEZ series of field programmable power modules is specifically developed to meet the rapid prototyping needs. Figure 5 shows an example of an mEZ field programmable module, the mEZDPD3603, which operates at a 4.5 V to 36 V input, 0.6 V to 12 V output, and provides up to 3A continuous current.

These programmable power modules offer three key advantages in system prototyping: They offer a complete power supply in a single package (standard DIP and LGA options are available). Power engineers can replace the entire power solution with a new design by swapping the power modules. They are fully configurable on the MPS website. The output voltage, compensation, switching frequency, output current limit, fault limits, soft-start time, and PWM mode are all able to be customized to customer specifications. The configuration parameters are transferred to the manufacturer after ordering, and the customized part will be delivered to the customer. The mEZ power modules provide a one-time programmable (OTP) memory for applications where an I^2C communication bus is available. When paired with the virtual bench graphical user interface (GUI), the key features of the power modules can be programmed once by customers.

The power supply rapid prototyping is simplified to three steps: Power engineers determine specifications for the power supply, such as input and output voltage, output current, required efficiency, load transient dynamics, and fault protection limits. Simulating the power solution using the web-based simulation tool, which generates simulated waveforms including

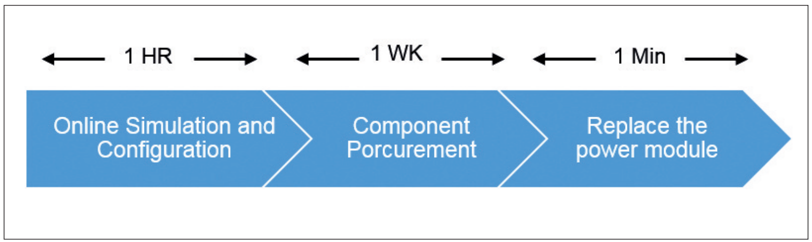


Figure 4: Fast prototyping development

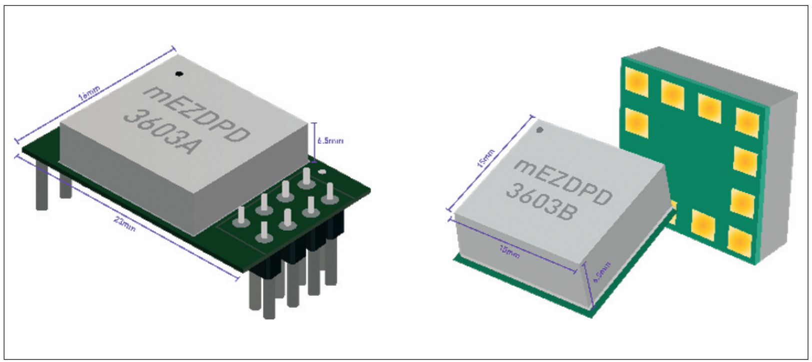


Figure 5: mEZDPD3603 power module with DIP and LGA packages

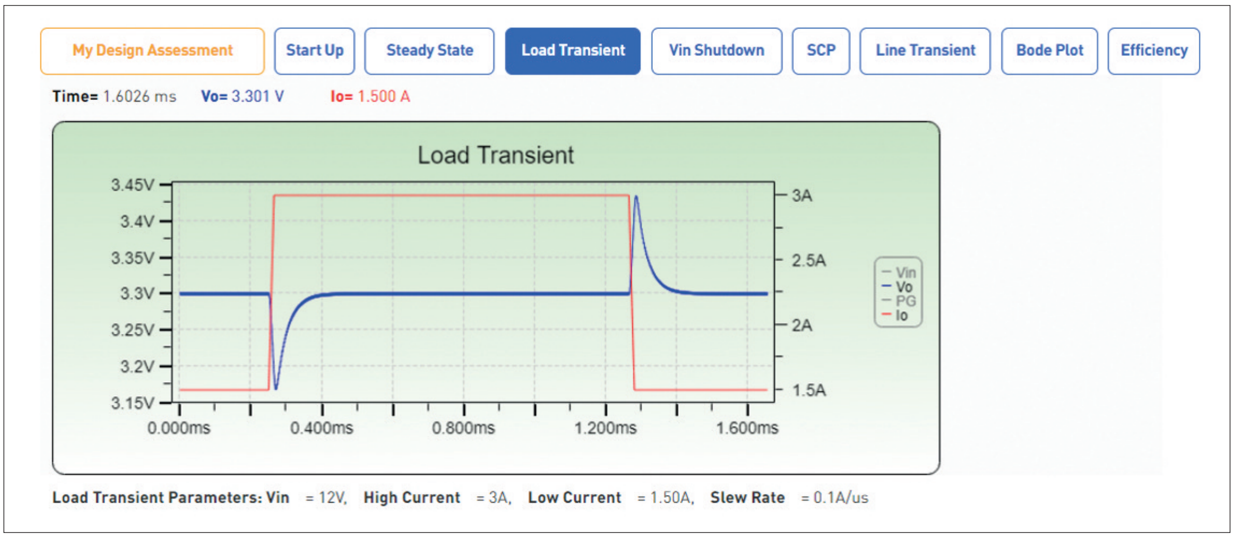


Figure 6: **Online simulation tool for mEZ field programmable power modules**

start-up and shutdown, steady state, load and line transient, short-circuit protection, and Bode plot (see Figure 6). Power designers can leverage the simulation tool to fully verify the configuration before placing their order to ensure that the performance meets the specification. Once the performance is satisfied, entering the configuration into the system. The manufacturer will ship the customized part to customer.

Conclusion

Power engineers can utilize the power supply rapid prototyping solution to help them deliver a product on time and within budget. The rapid prototyping solution requires an integrated power solution that is swappable on prototype, configurable with the manufacturer, predictable before procurement, and deliverable in a quick turnaround. The mEZ field programmable power modules align with the concept of power supply rapid prototyping. A power engineer can simply configure a power module online to meet their specifications, simulate the power solution to validate the design, and receive the customized part quickly and easily.

High-Side Current Sensing Questions

Ask any experienced electrical engineer - for example Gureux, an applications engineer with 30 years of experience in our story - about what to put in front of a MOSFET gate and you will probably hear "a resistor, approximately 100 Ω." Despite this certainty, one still wonders why and questions the utility and the resistance value. Because of that curiosity, these questions will be examined in the following example. Neubean, a young applications engineer, looks to test if it is actually necessary to place a 100 Ω resistor in front of a MOSFET gate for stabilization. Gureux, monitors his experiments and gives his expert opinion along the way in the technical discussion. **Aaron Schultz, Applications Engineering Manager, Analog Devices/Linear Technology, USA**

The circuit in Figure 1 shows a typical example of high-side current sense. Negative feedback tries to force the voltage VSENSE upon gain resistor R_{GAIN}. The current through R_{GAIN} flows through P-channel MOSFET (PMOS) to resistor R_{OUT}, which develops a ground referenced output voltage. The overall gain is according to equation 1:

$$V_{OUT} = I_{SENSE} \times R_{SENSE} \times \frac{R_{OUT}}{R_{GAIN}}$$

Optional capacitance C_{OUT} across the resistor R_{OUT} serves to filter the output voltage. Even if the drain current of the PMOS quickly follows the sensed current, the output voltage will exhibit a single-pole exponential trajectory. The resistor R_{GATE} in the schematic separates the amplifier from the PMOS gate. What is the value? "100 Ω, of course!" the experienced applications engineer might say.

Trying out the appropriate resistance

Neubean, a student of Gureux's, thinks that with enough capacitance from the gate to the source, or with enough gate resistance, he should be able to cause stability problems. Once it is clear that R_{GATE} and C_{GATE} interact detrimentally, then it will be possible to debunk the myth that 100 Ω, or in fact any gate resistance, is automatically appropriate.

Figure 2 shows an example of an LTspice simulation used to highlight the circuit behavior. Neubean runs simulations to show the stability problems that he believes will occur as R_{GATE} increases. After all, the pole from R_{GATE} and C_{GATE} ought to erode the phase margin associated with the open loop. Yet, no value of R_{GATE} shows any sort of problems in the time domain response.

In looking at the frequency response, Neubean needs to take care of identifying what the open loop response is. The forward path that forms the loop, when combining the unity negative feedback, starts from the difference and ends at the resulting negative input terminal. Neubean then simulates and plots $V_S/(V_P - V_S)$, or V_S/V_E. Figure 3 shows a plot's frequency domain plot for this open-loop response. In the Bode plot of Figure 3, there is very little DC gain and no evidence of phase margin problems at the crossover. In fact, the plot overall looks very strange as the crossover frequency is less than 0.001 Hz.

The decomposition of the circuit into a control system appears in Figure 4. The LTC2063, like almost all voltage feedback op amps, starts with high dc gain and a single pole. The op amp gains the error signal and drives the PMOS gate through

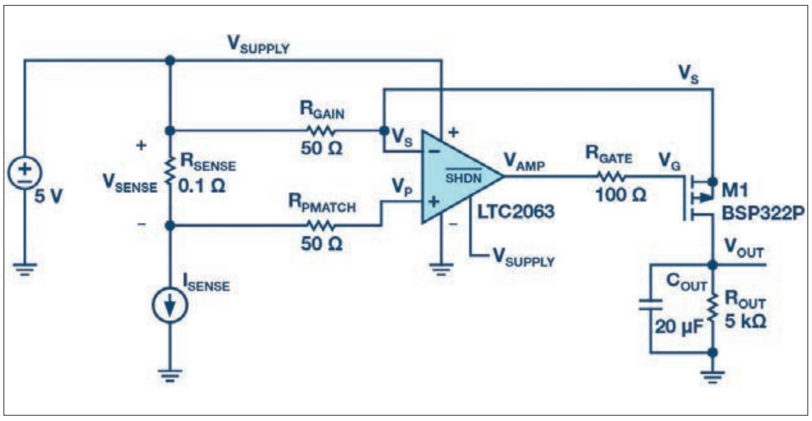


Figure 1: High-side current sense

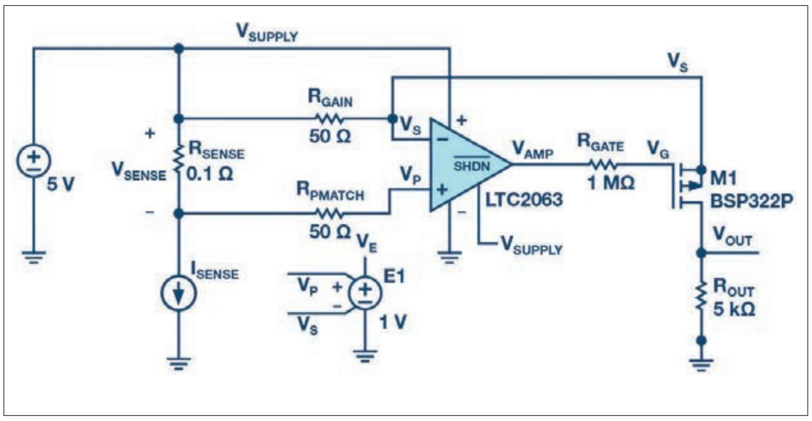


Figure 2: High-side current sense simulation

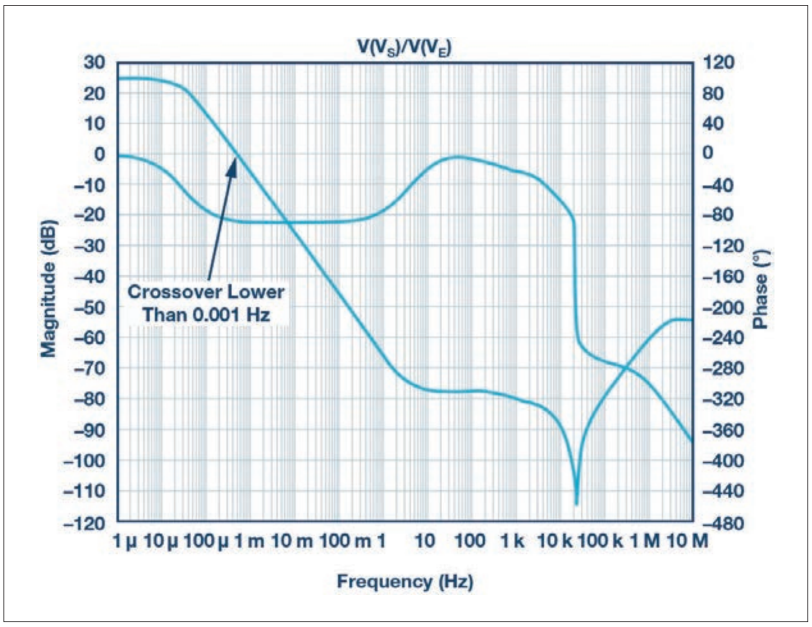


Figure 3: Frequency response from the error voltage to the source voltage

the R_{GATE} – C_{GATE} filter. The CGATE and PMOS source connect together to the –IN input of the op amp. R_{GAIN} connects from that node to the low impedance source. Even in Figure 4, it might appear that the RG_{ATE} – C_{GATE} filter should cause stability problems, particularly if R_{GATE} is much larger than R_{GAIN}. After all, the C_{GATE} voltage, which directly affects the R_{GAIN} current in the system, lags op amp output changes.

Neubean offers one explanation to why perhaps R_{GATE} and C_{GATE} do not cause instability: The gate source is a fixed voltage, so then the R_{GATE} – C_{GATE} circuit is irrelevant. Adjust the gate and the source follows - it's a source follower. His more experienced colleague notes - actually, no. This is only valid when the PMOS operates normally as a gain block in the circuit. Thus Neubean writes the following equations:

$$\frac{V_S}{V_E} = \frac{A}{(1+\frac{s}{\omega_A})} \times \frac{gm \times R_1 + s \times R_1 \times C_G}{gm \times R_1 + s \times R_1 \times C_G + (1+\frac{s}{\omega_G})}$$

with

$$\omega_G = \frac{1}{R_G \times C_G}$$

op amp gain A, and op amp pole ωA.

$$\frac{V_S}{V_G} = \frac{gm + s \times C_G}{gm + s \times C_G + \frac{1}{R_1}}$$

so, what is the important term gm for a MOSFET?

$$gm = \sqrt{2 \times Kn \times Id}$$

Looking at the circuit back in Figure 1, with zero current through R_{SENSE}, the current through the PMOS ought to be zero. With zero current, gm is zero, because the PMOS is effectively off, not being used, unbiased, and has no gain. When gm = 0, V_S/V_E is 0 at 0 Hz and V_S/V_G is 0 at 0 Hz, so there is no gain at all and the plots in Figure 3 may be valid after all.

Try to Go unstable with the LTC2063

Armed with this revelation, a few simulations with non-zero I_{SENSE} have been tried.

Figure 5 shows what looks like a much more normal gain/phase plot of the response from V_E to V_S, crossing from >0 dB to <0 dB. Figure 5 should show about 2 kHz, with lots of PM at 100 Ω, a bit less PM at 100 kΩ, and even less with 1 MΩ, but not unstable.

In the lab a sense current with the high-side sense circuit LTC2063 of 100 kΩ and 1 MΩ have been inserted, expecting to see unstable behavior or at least some kind of ringing. Unfortunately, not. By increasing the drain current in the MOSFET first by using more I_{SENSE} and then by using a smaller R_{GAIN} resistance, no destabilization can be observed. Also in the simulation by filling a phase margin with non-zero I_{SENSE}, it seems difficult, if not impossible, to find instability or low phase margin.

Neubean asks Gureux why he is failing to destabilize the circuit. Gureux advises him to do the numbers. Neubean examines what might be the actual pole associated with R_{GATE} and the total gate capacitance. With 100 Ω and 250 pF, the

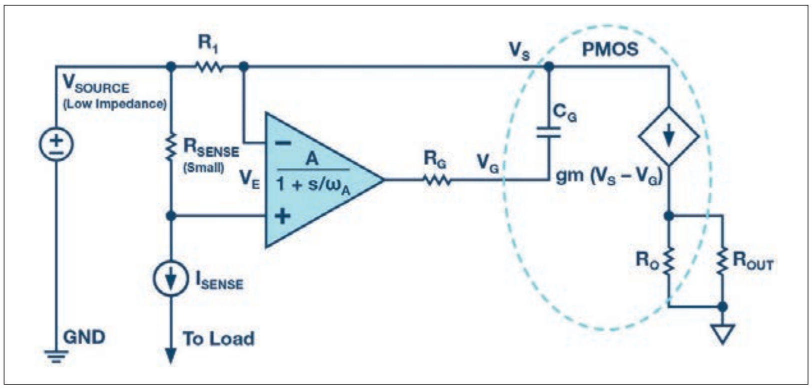


Figure 4: High-side sense circuit as a block diagram

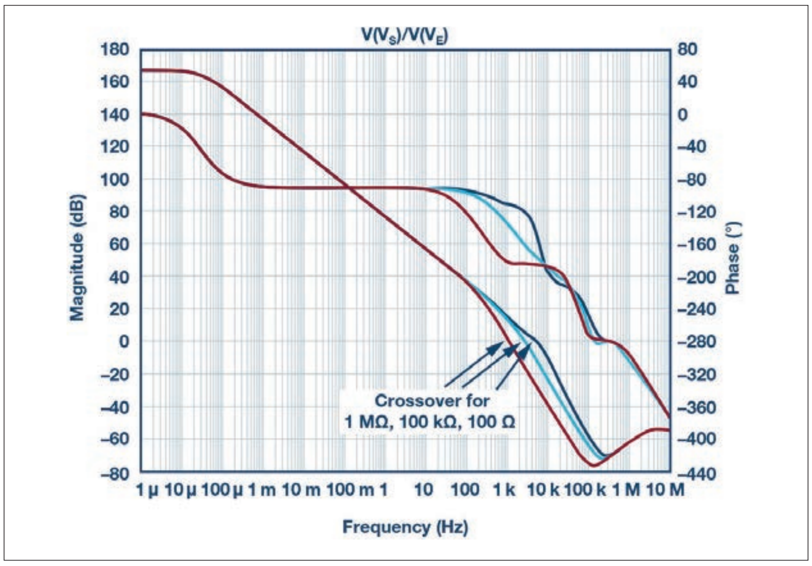


Figure 5: Frequency response from the error voltage to the source voltage, non-zero sense current

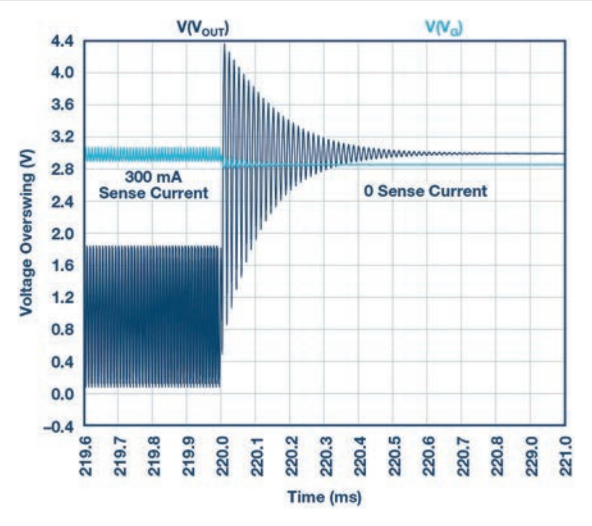


Figure 6: **A time domain plot with ringing**

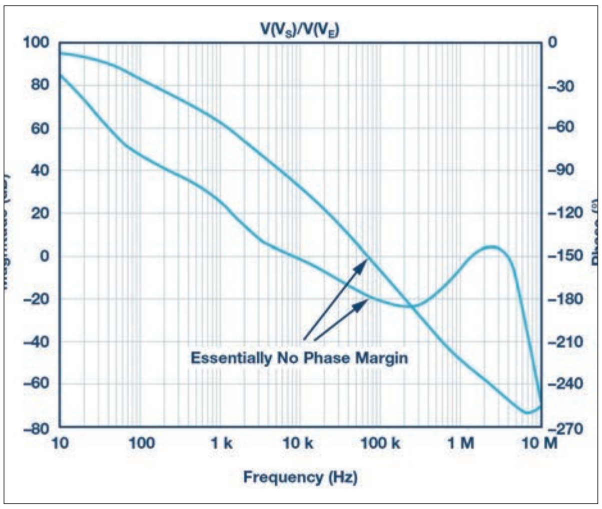


Figure 7: **A normal Bode plot with added current, V_E to V_S, with terrible phase margin**

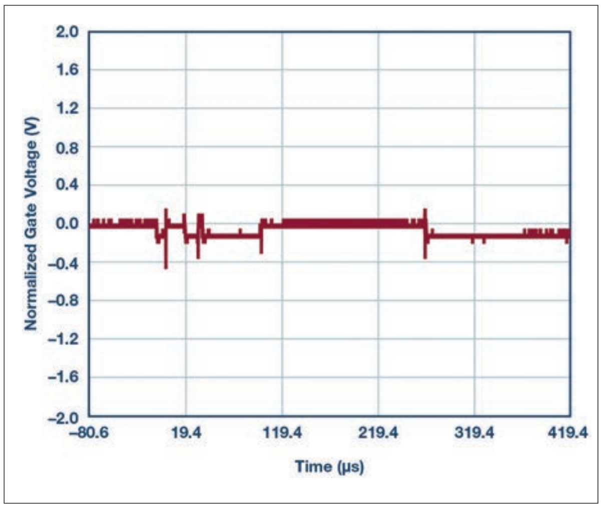


Figure 8: **RGATE = 100 Ω, current from low to high transient**

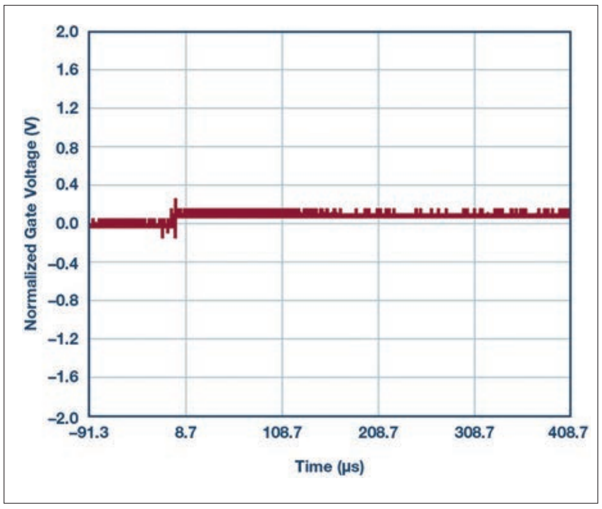


Figure 9: **RGATE = 100 Ω, current from high to low transient**

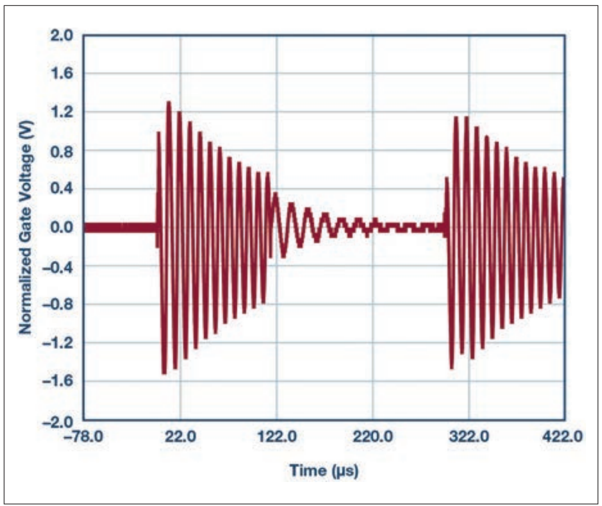


Figure 10: **RGATE = 100 kΩ, current from low to high transient**

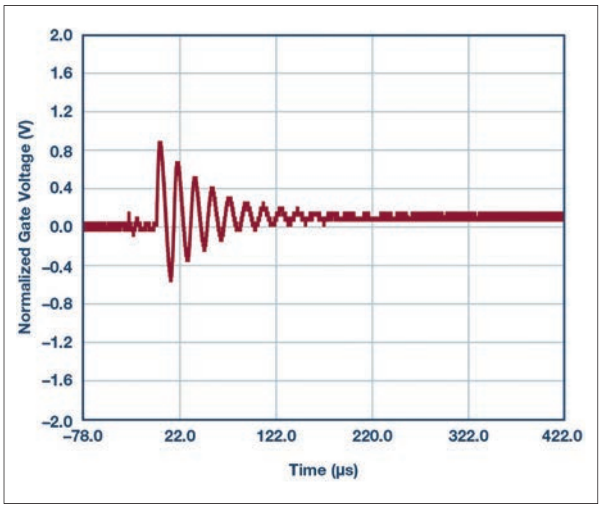


Figure 11: **RGATE = 100 kΩ, current from high to low transient**

pole is at 6.4 MHz; with 100 kΩ, the pole is at 6.4 kHz; and with 1 MΩ, the pole is at 640 Hz. The LTC2063 gain bandwidth product (GBP) is 20 kHz. When the LTC2063 takes gain, the closed-loop crossover frequency can easily slide below any effect of the R_{GATE} – C_{GATE} pole.

Realizing that the op amp dynamics need to continue up into the range of the RGATE – CGATE pole, a higher gain bandwidth product has been chosen. The LTC6255 5 V op amp will directly fit into the circuit with a higher 6.5 MHz GBP. Thus, a simulation with 100 kΩ gate resistance and with 300 mA sense current

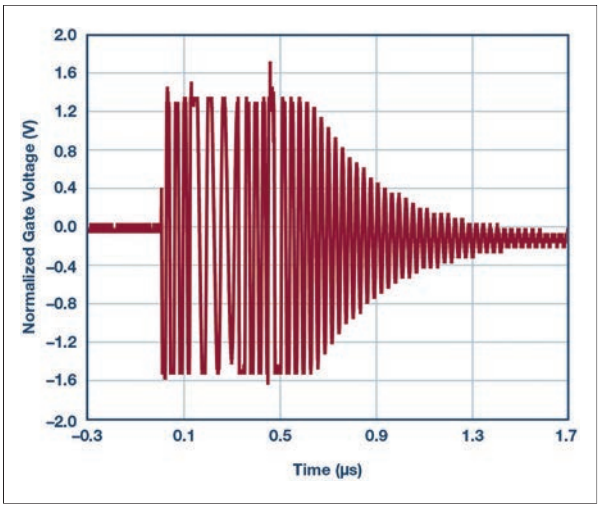


Figure 12: RGATE = 1 MΩ, current from low to high transient

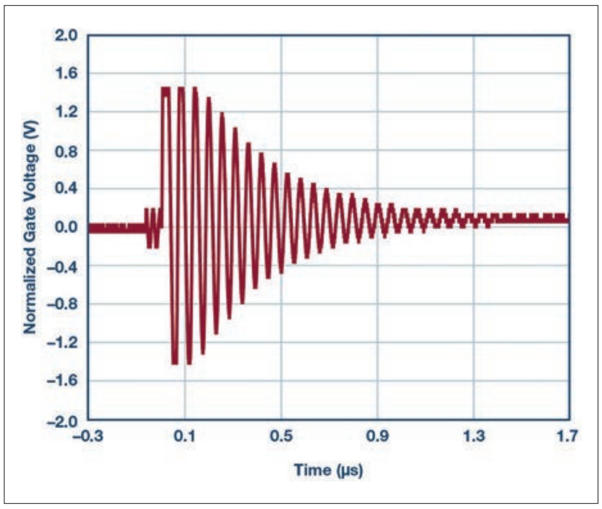


Figure 13: RGATE = 1 MΩ, current from high to low transient

have been tried. Neubean then proceeds to add R_{GATE} in simulation. With enough R_{GATE}, an extra pole can destabilize a circuit.

Figure 6 and Figure 7 show simulation results with high R_{GATE} values. At a constant 300 mA sense current, this simulation shows instability.

Lab results

Wanting to see if the circuit might act badly while sensing a non-zero current, Neubean tries the LTC6255 with a step changing load current and uses three different R_{GATE} values. I_{SENSE} transitions from a base of 60 mA to a higher value of 220 mA enabled by a momentary switch that brings in more parallel load resistance. There is no zero I_{SENSE} measurement, because it is already shown that the MOSFET gain is too low in that case.

Indeed, Figure 8 finally shows truly compromised stability with 100 kΩ and 1 MΩ resistors. Because the output voltage is heavily filtered, the gate voltage becomes the detector for ringing. Ringing denotes poor or negative phase margin, and ringing frequency indicates crossover frequency.

A moment to brainstorm

Neubean realizes that he has seen many high-side integrated current sense circuits and, unfortunately, there is no chance for an engineer to decide on gate resistance, because everything is inside the part. Examples that came to his mind were AD8212, LTC6101, LTC6102, and LTC6104 high voltage, high-side current sense devices. In fact, the AD8212 uses a PNP transistor rather than a PMOS FET. Thus it doesn't really matter, because modern devices already solve this problem?

The professional responds: "Let's say you want a combination of extremely low supply current and zero-drift input offset, such as in a remotely located battery-powered instrument. You might want an LTC2063 or LTC2066 as the primary amplifier. Or, perhaps, you need to measure a low level current level perhaps through a 470 Ω shunt as accurately and noiselessly as possible; in that case you might want to use the ADA4528, which has rail-to-rail input capability. In these cases you will need to deal with the MOSFET drive circuitry."

Clearly, then, it is possible to destabilize the high-side current sense circuit by using too large of a gate resistor. RGATE can in fact destabilize the circuit, but the initial inability to find this behavior drew from a wrongly formulated problem. There needed to be gain, which in this circuit required there to be non-zero signal being measured. When a pole erodes the phase margin at a crossover, ringing happens. But a 1 MΩ of added gate resistance is absurd—even 100 kΩ is crazy. It is always good to try to limit the output current of an op amp in case it tries to swing a gate capacitance from one rail to another rail. "So what value of resistance do I use?" Gureux notes confidently, "100 Ω."

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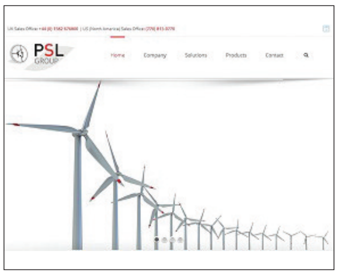

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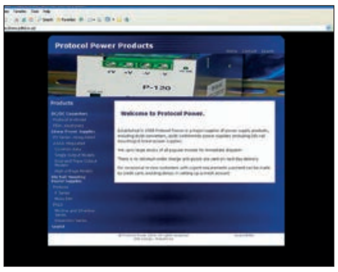

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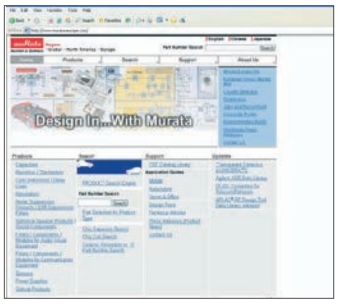

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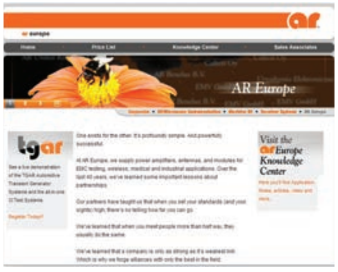

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