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AUTOMOTIVE POWER

Impact of Ultra-Low On-Resistance SiC MOSFETs On Electric Vehicle Drive-Train

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Market News

PEE looks at the latest Market News and company developments

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Industry News

COVER STORY

Impact of Ultra-Low On-Resistance SiC MOSFETs On Electric Vehicle Drive-Train

Continued advances in diameter expansion, volume, quality, and cost of SiC bulk wafers has reached a point where high-volume 150 mm fabrication facilities can utilize SiC wafers as pictured in Figure 1. At Wolfspeed, nearly 18 metric tons of 150 mm SiC wafers were shipped in calendar year 2016 [1] to support markets such as LED, RF, and power, with continued growth forecast for 2017 and beyond. 200 mm diameter SiC wafers have also recently been demonstrated in R&D, as continued wafer diameter expansion development continues. The quality of the SiC wafers has also improved consistently over the years. Now market / technology forces are moving in concert to create an opportunity for SiC MOSFETs to be an enabling technology in the Battery power Electric Vehicle (BEV). The pull of the developing traction-drive requirements for BEV drive-train, which can utilize SiC to cut inverter losses by ~78 % in the EPA drive-cycle, can offer BEV designers increased range or reduced battery costs for the same range. More details on page 18.

Cover image supplied by Wolfspeed/USA

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An Effective Approach to Controlling of Multiple Voltage Rails

The process of powering-up the various voltage rails that accompany system-on-chips (SoCs), field-programmable gate arrays (FPGAs) and embedded modules in the correct order can be quite convoluted. Engineers therefore need to specify a suitable solution. As will be detailed in the following article, there are a multitude of ways in which modern sequencing technology can help to simplify the task. **Mirko Bernacchi, Technical Support Specialist, Mouser Electronics, Milano, Italy**

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How Components Influence Reliability of DC/DC Converter Designs

The pressure to run DC/DC converters at higher operating temperatures to support dense clusters of computing power is growing. It means that converter designers can no longer rely on the limited device specifications that component manufacturers offer at 25°C if they want to produce products that will work reliably over long lifetimes at high operating temperatures. **Ann-Marie Bayliss, Product Marketing Manager, Murata Power Solutions, Fleet, UK**

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High-Power Resistors for Demanding Industrial Applications

Converters/inverters are core systems in industrial power electronics. Their continued development is driven by reduction of installation space and improved power/current quality to reduce harmonics and parasitic currents in order to protect connected drives and generators. Other factors of concern are improved efficiency by reducing parasitic inductances, and the general need to improve the cost structure by minimizing material and assembly cost, thus also increasing the lifetime. **Ch. Lindner, EBG Elektronische Bauelemente; T. Zimmerman, EBG Resistors; D. Custic, DAU; and R. Ratzi, Miba Energy Holding, Austria**

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Accurate Mains Frequency Monitor with Calibration

An AC power mains utility frequency is typically either 50 Hz or 60 Hz. The frequency variation is normally restricted to about +/- 1% in most countries. Variation occurs usually because of varying load on the grid; a higher load causes the frequency to drop and vice versa. The importance of monitoring power frequency is especially important when a local minigrid is set up – such as with solar-powered or wind-powered installations. The inverter in such cases must shoulder the responsibility of monitoring the output power quality. The Silego GreenPAK SLG46620 and a few external components can be used to design a frequency deviation monitor that signals an alert if the frequency deviates by a specified margin. **Ramkumar Ramaswamy, Silego Technology, Santa Clara, USA**

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Products

Product update

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Website Product Locator

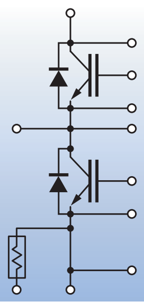
High Power next Core (HPnC)

using high performance MgSiC baseplate

FEATURES

- **High reliability**
  - MgSiC base plate
  - High thermal cycling capability
  - High power cycling capability
  - Ultra sonic welded terminals
  - CTI>600
  - Tj operation target 175 °C
- **Latest chip technology (X-series and SiC-SBD)**
  - Available with Fuji X-series IGBT and FWD
  - Also available with Fuji SiC FWD

	MgSiC	AlSiC
Coefficient of Thermal Expansion	7.5 ppm / K	7.5 ppm / K
Thermal Conductivity	**230 W / mK**	**150 W / mK**
Specific Heat Capacity	0.77 (J / gK)	0.75 (J / gK)

Line-up Plan				
Technology		Rated Voltage	Chip IGBT / FWD
	Silicon	1700 V	1000 A
	(IGBT/Si-Diode)	3300 V	450 A
	Hybrid	1700 V	1000 A
	(IGBT/SiC-SBD)	3300 V	450 A

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Ready for Automotive Drive Train Applications

Both SiC- and GaN- based power devices have distinct benefits for specific applications: SiC is regarded as a stronger candidate for power electronic applications above 1.2 kV, while GaN is suited for high-frequency applications, and is regarded as highly competitive in applications below 1200V. In particular, device voltage rating between 650 V and 1.2k V is a competitive space that can be supported by either SiC or GaN technologies. Compared to Silicon, SiC-based power devices can operate at higher temperatures with higher thermal conductivity, higher breakdown voltage at lower on-stage resistance, faster switching speed, lower conduction and switching on-state loss, and exceptional radiation hardness. Compared with Silicon devices, GaN-based power devices enable applications with higher electron mobility and lower losses at higher frequencies. This combination can facilitate the development of smaller devices with increased power density.

While SiC and GaN devices have demonstrated higher efficiency than Silicon-based devices, reliability concerns still limit the market penetration. Gaining a better understanding of degradation/failure mechanisms under harsh conditions is key to designing more robust components. It is essential to consider three issues related to establishing the reliability of these technologies - generation of high-quality reliability data from advanced testing methods; standardized reliability assessment; and effective communication about reliability best practices to end users.

Continued advances in diameter expansion, volume, quality, and cost of SiC bulk wafers has reached a point where high-volume 150 mm fabrication facilities can utilize SiC wafers. At Wolfspeed, nearly 18 metric tons of 150 mm SiC wafers were shipped in calendar year 2016. Also 200 mm diameter SiC wafers have recently been demonstrated in R&D, as continued wafer diameter expansion development continues. The quality of the SiC wafers has also improved consistently over the years, with median micropipe defect density falling to 0.2 /cm^2 in 2016, enabling large area SiC MOSFETs to be fabricated with high-yield, and meeting automotive AEC-Q-101 qualification.

According to a recently published study 'Evaluation of potentials for SiC-MOSFETs in automotive inverter applications' by Fraunhofer IISB SiC MOSFETs offer potentials in automotive applications due to their significantly reduced losses, junction temperatures above 200°C, and their fast switching capability in comparison to Silicon-based IGBTs and MOSFETs. Especially for high-frequency applications such as electric turbochargers or traction drives with their need for higher switching frequencies, significant benefits on system level can be achieved due to reduced dynamic losses. Higher switching frequencies lead to higher losses in the semiconductors. Especially high-speed traction drives or auxiliary components, like electric turbochargers, or machines with limited winding-inductance may require higher switching frequencies. Otherwise the non-sinusoidal phase current with its high ripple component leads to additional losses in the electric machine or acoustic noise and torque ripple. The results of the study underline our editorials in the past and our cover story – SiC MOSFETs enable the realization of compact and highly efficient inverter systems also for automotive applications. For similar performance data and boundary conditions, the required chip area with SiC MOSFETs is significantly reduced in comparison to IGBT-based inverters. Due to the reduced chip losses, efficiency gains up to five percent can be achieved for a variety of driving scenarios. The best performance gains are obtained for slower urban drive-cycles with a high number of accelerations and therefore high peak-currents. It was also shown that the required cooling effort on the inverter system level can be reduced using SiC-MOSFETs which potentially allows to optimize the vehicle cooling system. Due to the reduced switching losses, the SiC MOSFET performance gains increase with higher switching frequencies also for transient operation.

For a full use of the 1200 V SiC MOSFT potential, a higher DC-link voltage in the range of 800 V would be the optimum, the IISB study pointed ou. This reduces the required currents for a given output power. Reduced losses and chip areas within the inverter are the result. It has to be considered that this would require significant changes of the vehicle high-voltage system and all the involved components like the traction battery. Existing limitations for current electric machines for automotive applications have also to be questioned and analyzed. It would help to further reduce the switching losses and the required chip areas of the SiC MOSFET inverters if higher voltage gradients than 5 to 15 kV/µs would be acceptable for the motor (and also for the vehicle EMC-management). For this targeted high switching speeds also low inductive commutation cells are essential.

The pull of the developing traction-drive requirements for drive-train, which can utilize SiC to cut inverter losses by ~78 % in the EPA drive-cycle, can offer increased range or reduced battery costs for the same range. Today the development activity is focused on efforts to improve SiC performance and reliability, such as recently demonstrated by 650 V, 7 mΩ MOSFETs used for dual-side sintered, 1.7 mΩ power modules for automotive drive-train inverters, that has already shown very good power cycling data to go with the impressive low on-state performance, as shown in our cover story.

Enjoy reading

Achim Scharf
PEE Editor

E-Mobility Reshapes Lithium-Ion Battery Supply Chain

Lithium ion (Li-ion) batteries have become the technology of choice for many applications. The rechargeable Li-ion battery cell market will be worth $60 billion by 2022, thanks to a 20 % CAGR from 2016–2022, according to market researcher Yole Développement.

Consumer electronics, the traditional Li-ion battery market segment, has been overtaken by electric mobility, which includes electric and hybrid electric vehicles (EV/HEV), electric buses, trucks, and bikes. In 2022, e-mobility will represent more than 70 % of the total rechargeable Li-ion battery cell market's value. According to Yole Développement's analysis, the global demand for battery cells in GWh will rise by more than 400 % between 2016 and 2022. To satisfy such huge demand for Li-ion batteries, large manufacturing facilities have to be built in coming years. This provides an opportunity for new players, which can take part in a growing market more easily, and will also result in accelerated implementation of innovations in materials, equipment and processes. The Li-ion industry might therefore experience accelerated technology consolidation and supply chain reshaping, as happened in the photovoltaic industry.

There are numerous business opportunities within the Li-ion supply chain, from raw material mining to material preparation, cell component production, cell manufacturing, integration of battery cells into battery packs and final battery systems. Rapidly growing demand for e-mobility applications will mean that access to and prices of raw materials will be the focus of leading battery players. The most critical materials are cobalt, lithium and graphite.

The refocusing from consumer applications to e-mobility needs different battery characteristics. One example is the cathode material. $LiCoO_2$ (LCO) is mainly used in consumer electronics and was the dominant cell cathode material in the past. Today, the largest cathode material segment is $LiNiMnCoO_2$ (NMC), which better matches the needs of the huge EV/HEV market, but also of most other applications. Therefore, material suppliers and cell makers today focus on NMC technology. The players with the necessary know-how could rapidly increase their revenues by positioning themselves in this market early. Similar trends can be expected for separators, where the trend is toward ceramic separators providing better thermal stability, anodes and electrolytes.

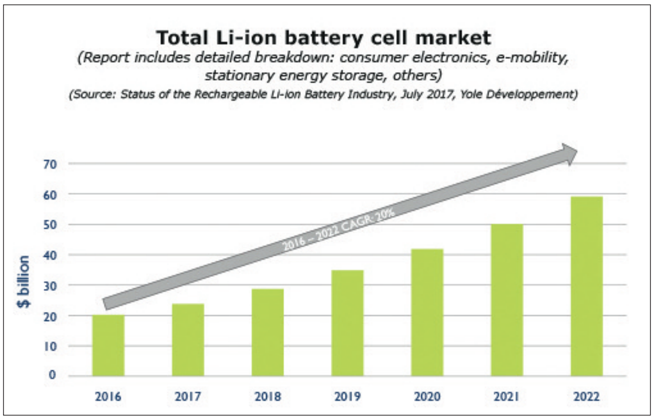
Further innovations are needed both in battery cell and pack manufacturing. Material costs and equipment depreciation represent a large part of battery cell cost. New materials, equipment and processes are being introduced to the battery industry from chemical, microelectronics, power electronics and other industries, providing opportunities for the technology leaders well-established in those industries. Several players such as Manz, F&D Delvotec and Schunk Sonosystems have already developed specific tools for battery manufacturing. Other players involved in wire bonding, ultrasonic welding, laser processing and other technologies will follow, by providing equipment and processes for high-speed, highly-automated battery cell and pack manufacturing.

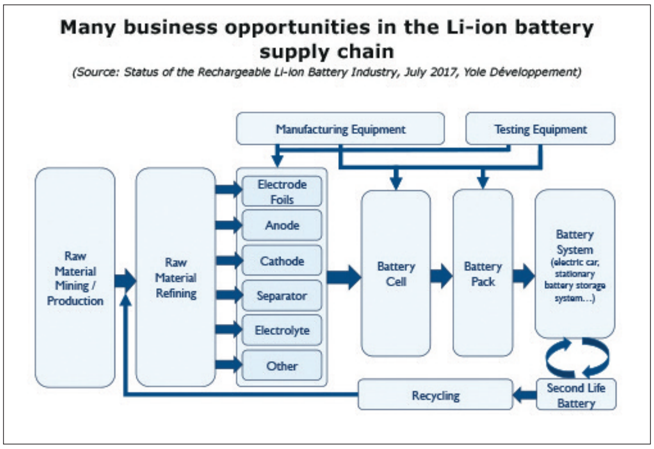
"As the dominant market segment, e-mobility will drive battery technology development and reshape the Li-ion battery supply chain. EV/HEVs are the main focus of both new entrants and established players, but there is growing interest in other applications, like electric bikes, buses and forklifts", analyst Milan Rosina explained.

Many small players and newcomers are trying to minimize the competition they face by focusing on battery market segments that are non-mainstream or have very specific battery characteristic needs. As new Li-ion battery markets mature, the supply chain will become increasingly vertically and horizontally integrated. High cell material costs and the increasing pressure on the cell prices motivate some cell manufacturers to seek higher margins through vertical integration towards cell material manufacturing. Other companies are integrating vertically towards battery pack applications to offer complete product solutions.

Horizontal integration secures cell manufacturers sales in different markets, making their business less susceptible to growing competition. EV/HEV players like BYD, Tesla, Daimler, BMW and Nissan have already entered the stationary battery storage market. BYD and Daimler are also focusing on other e-mobility applications such as e-buses and trucks. "As the stationary battery storage business matures we expect further vertical integration", Milan Rosina pointed out.

www.yole.fr





Ricardo Forms Global E-Automotive Group

As the world's automotive industry strives to accelerate the development of new products based upon hybrid and electrified propulsion systems, Ricardo is creating a new global focus for its automotive business.

The automotive industry is arguably facing a situation of more profound technological change than at almost any point in its history. The regulatory imperatives to reduce carbon dioxide emissions, increase fuel economy, reduce noxious exhaust emissions and improve air quality – especially in the world's urban centers – are providing a significant impetus for product innovation. In parallel with this, the rapid emergence of autonomous vehicle technology and of new models of shared transportation are spurring completely new entrants to the market. Ricardo is growing its IP and project portfolio in areas such as the development of electric vehicle battery systems and autonomous technologies such as heavy-duty truck platooning. The new Ricardo Global Automotive Group will provide a highly customer focused global structure that will enable it to optimally serve the demands of customers for clean powertrain technologies and all aspects of vehicle engineering, including autonomous driving applications. The organization draws together the operations of the company's automotive teams based at its technical centers across Europe, China and North America, which now includes a rapidly growing presence in California.

https://ricardo.com/

Over $1 Billion in VC Funding for Smart Grid Applications

Mercom Capital Group released its report on funding and mergers and acquisitions (M&A) activity for the Battery Storage, Smart Grid, and Energy Efficiency sectors for the second quarter and first half of 2017. In the first half (1H) of 2017, $1.03 billion was raised by Battery Storage, Smart Grid, and Efficiency companies compared to $807 million in 1H 2016.

Venture capital (VC) funding (including private equity and corporate venture capital) for Battery Storage companies jumped in Q2 2017 to $422 million in 10 deals compared to $58 million in eight deals in Q1 2017 due to a very large funding deal. Year-over-year (YoY) funding was higher compared to $125 million raised in Q2 2016 from 10 deals. In the first half (1H) of 2017, $480 million was raised in 18 deals compared to the $179 raised in 20 deals in 1H 2016. The top VC funded Battery Storage companies in Q2 2017 were: Microvast Power, which raised $400 million from CITIC Securities, CDH Investment, National Venture Capital, and others; Vionx Energy received

$12.75; and Moixa Technology raised $3.2 million in funding from the Greater Manchester Combined Authority, Tokyo Electric Power Company (TEPCO), and First Imagine! Ventures.

Eleven investors participated in Battery Storage funding in Q2 2017 with Lithium-based Battery companies raising the most. There were seven debt and public market financing deals in Battery Storage in Q2 2017 totaling $107 million compared to $22 million in two deals in Q1 2017. In 1H 2017, there was $129 million raised in nine deals compared to three deals bringing in $69 million in 1H 2016. There was one Battery Storage project fund in 1H 2017 for $152 million compared to three deals raising $195 million in 1H 2016. Battery Storage project funding in 1H 2017 totaled $5 million in two deals compared to no deals in 1H 2016.

VC funding for Smart Grid companies in Q2 2017 came to $139 million in eight deals compared to $164 million in 14 deals in Q1 2017. In a YoY comparison, $222 million was raised from 15 deals in Q2 2016. $304 million was raised in 22 deals in 1H 2017 compared to $331 million raised in 29 deals in 1H 2016. The top VC funded Smart Grid companies included: Actility, which secured $75 million from Creadev, Bosch, Inmarsat, Idinvest, Bpifrance, Ginko Ventures, KPN, Orange Digital Ventures, Swisscom, and Foxconn; ChargePoint raised $43 million from Siemens; FreeWire Technologies received $7.6 million; and Enervalis secured $4.8 million from LRM, Nuhma, and ABB.

VC funding into Energy Efficiency technology companies fell significantly to $29 million in six deals in Q2 2017 compared to the $213 million in 14 deals in Q1 2017 and $86 million in nine deals in Q2 2016. $242 million was raised in 20 deals in 1H 2017 compared to $297 million raised in 23 deals in 1H 2016.

www.mercomcapital.com

Rail Network for the Renewable Age

By 2018, Holland's rail network will run entirely on renewable energy. The country's existing wind farms already supply almost half of the network's traction power. Investment in new farms will ratchet this up to the full 1.4 TWh of electricity needed to transport Dutch commuters each year.

World leaders took action at the end of 2015 with the United Nations climate conference of parties (COP) reaching a landmark agreement to limit the rise of global temperatures to less than two degrees Celsius. Nearly 200 countries committed to upholding this agreement, which will naturally mean a concerted, international push to move away from fossil fuels and to use renewable energy instead. This evolution, while great news for the environment, has the potential to create power quality problems for rail providers that can negatively affect the reliability, safety and performance of trains and railways. This is particularly the case as technology and railways begin to operate at higher speeds, both of which are reliant on reliable energy and power.

As electrical control systems get more complex, they become responsible for higher currents and frequencies. This can lead to power quality issues such as voltage fluctuations and overheating, as well as inefficiencies that lead to higher energy costs. This is driving demand for current transformers that can provide precise measurement even at these increased levels of operation and regardless of current type. To this end, REO UK has launched a new range of current transformers designed to ensure high power efficiency and quality by offering highly accurate linear current sensing and electricity metering. These transformers come in a selection of power ranges to suit industry sectors including automation, railway engineering and renewable energy. REO's range of current transformers is able to accurately measure currents up to 3000 A and frequencies up to 150 kHz while providing superior linearity and over-current protection. Each series of transformers is designed to deliver reliable power quality catering to a specific industrial sector; for example, the series IE is ideal for use under high currents in the rail sector. Steve Hughes, managing director of REO UK, refers to a recent report from infrastructure consultancy WSP outlining how Network Rail could utilize solar energy to help the UK meet these environmental goals. "The firm suggests that if Network Rail could invite investors to fund trackside solar arrays it could cut carbon emissions by 895,000 tonnes a year, as well as reducing costs by £150m between 2019 and 2024. By taking small measures, such as finding the right transformer, rail providers will be able to lead the charge in reducing our reliance on fossil fuels and transport us into a more environmentally friendly future."

REO manufactures resistive and inductive wound components for use with static frequency converter drives in lift and HVAC applications. The company is becoming increasingly involved in renewable energy technology. REO has manufacturing operations in Germany, the US, China and India.

www.reo.co.uk

New Managers at SEMIKRON

SEMIKRON strengthens its top management team. Christian Eiber, who will be responsible for the automotive business segment, will be joining SEMIKRON as of August 2017, while Karl-Heinz Gaubatz will take over as Chief Technology Officer in December.

Christian Eiber previously held a long-term management position at Nemak, where he was in charge of the development of the business segment Aluminium Castings, among others for electric vehicles. Karl-Heinz Gaubatz has extensive international management experience in the business segment Electrics / Electronics at the BMW Group as well as with global automotive supplier Dräxlmaier.

www.semikron.com

New SEMIKRON managers Christian Eiber (left) and Karl-Heinz Gaubatz

Three-Phase High PWM Frequency GaN Inverter

Texas Instruments introduced a three-phase, GaN-based inverter reference design that helps engineers build 200-V, 2-kW AC servo motor drives and next-generation industrial robotics with fast current-loop control, higher efficiency, more accurate speed, and torque control.

The TIDA-00915 design is a three-phase inverter for driving 200-V AC servo motors with 2 kW peak. It features 600 V and a 12-A LMG3410 gallium nitride (GaN) power module with an integrated FET and gate driver. GaN FETs can switch much faster than Silicon FETs, and integrating the driver in the same package reduces parasitic inductances and optimizes switching performance to reduce power loss, thus allowing the designer to downsize the heat sink. The space savings are beneficial for compact servo drives and motor integrated drives. Operating the inverter at a high switching frequency of 100 kHz reduces the current ripple, which improves torque ripple when used with low-inductance motors.

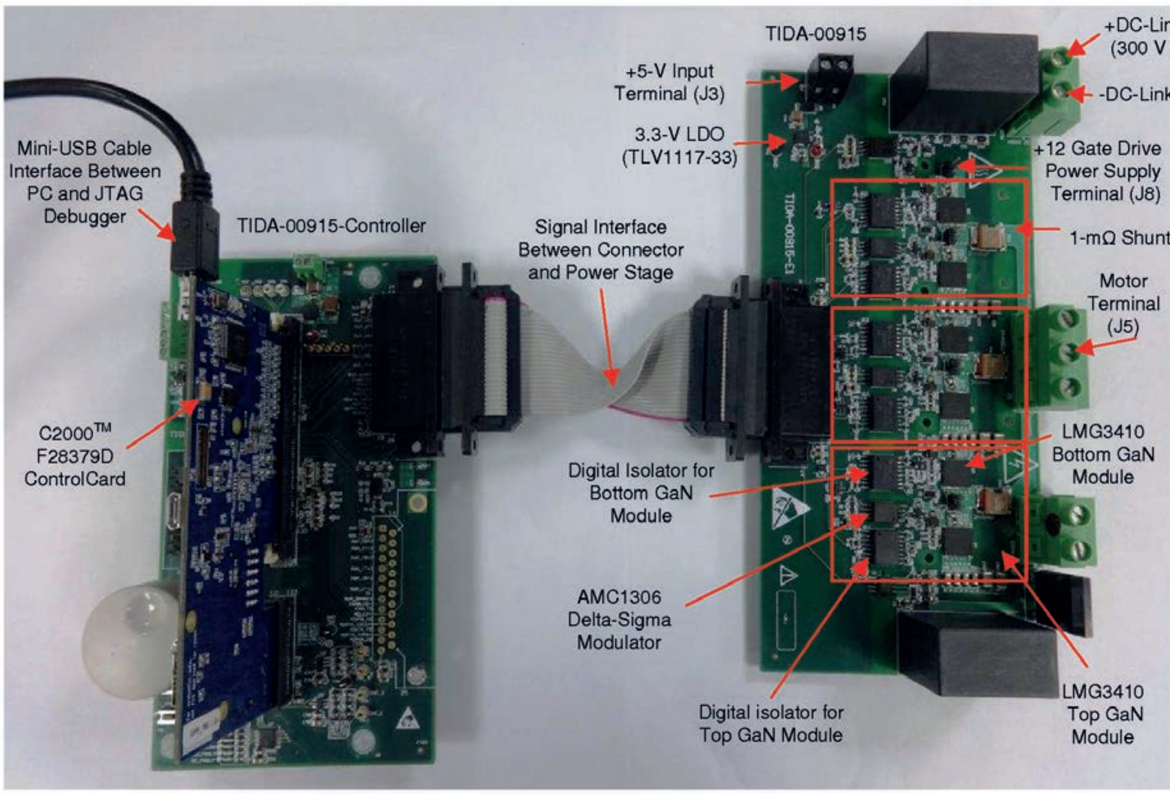
High-voltage brushless motors with low inductance and high speed are used in precision applications like servo drives, CNC machines, and industrial robotics. There is a need for driving low-inductance motors using a three-phase inverter at a high switching frequency to reduce the torque ripple in the motor and minimize the losses in the motor.

The phase current ripple is inversely proportional to the switching frequency of the pulse width modulation (PWM). The phase current ripple contributes to motor losses, which reduce the efficiency of the motor and increase the temperature of the motor. These losses are especially present in motor-integrated power electronics and multi-axis drives used in service robots, where any additional motor losses limit the maximum power of the device over the rated operating temperature range.

For precision servo drives, which require high position accuracy, a torque ripple can have a negative impact on static position accuracy. The motor phase-current ripple must be reduced to reduce the torque ripple for a given motor, which can be achieved by increasing the inverter PWM switching frequency. However, inverters based on IGBTs cannot increase the switching frequency above 40 kHz due to large switching losses. The switching losses necessitates to use a large heat sink with an IGBT. A larger heat sink increases the system cost, weight, and space. The solution to this problem is to use GaN FETs, which can operate with much lower power dissipation.

GaN transistors can switch much faster than Silicon MOSFETs, which allows the potential to achieve lower switching losses. However, at high slew rates, certain package types can limit GaN FET switching performance. Integrating the GaN FET and driver in the same package reduces parasitic inductances and optimizes switching performance. The faster switching is achieved with little or no turn-on or turn-off ringing, which reduces the electromagnetic interferences.

The low-power dissipation benefits servo and embedded drives. In servo drives, the low-power dissipation results in a small form factor. In embedded

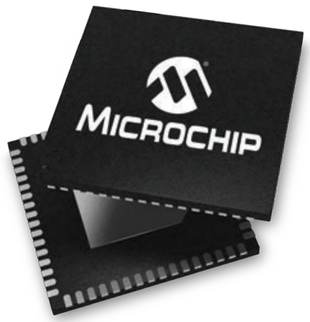


TIDA-00915 PCB and TIDA-00915 controller top side

PIC18F "K40" MCUs feature Intelligent ADC with Filtering and Signal Analysis Capabilities

8-bit PIC® MCUs are ideal for Touch and Signal Conditioning

The Core Independent Peripherals (CIPs) in Microchip's PIC18F "K40" family of 8-bit PIC® MCUs support filtering and signal analysis for advanced touch and signal-conditioning applications.



Among the intelligent analog CIPs is an Analog-to-Digital Converter with Computation (ADC2) for averaging, filtering, oversampling and automatic threshold comparison. The MCUs also integrate safety-critical CIPs and hardware PWMs with multiple communication interfaces and generous on-chip Flash and EEPROM. These features, combined with 5V operation, enable the PIC18F "K40" family to increase design flexibility whilst also reducing system cost.

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drives, the drive electronics is enclosed inside the motor hub, and the inverter uses the motor frame as the heat sink. Here the inverter has to operate at high ambient temperatures with little cooling. The low-power dissipation allows the embedded drive inverter to deliver more power for the same operating temperature.

The TIDA-00915 is a three-phase inverter for driving 200-V AC servo motors with 2 kWPEAK. The inverter is able to operate at a high switching frequency of 100 kHz, which reduces the current ripple and improves torque ripple when used with low-inductance motors. The TIDA-00915 has the three-phase inverter with the required isolation, DC-link voltage sensing, and in-line current sensing. The board supports interface to a C2000TM F28379D control card through an adaptor card (TIDA-00915-Controller).

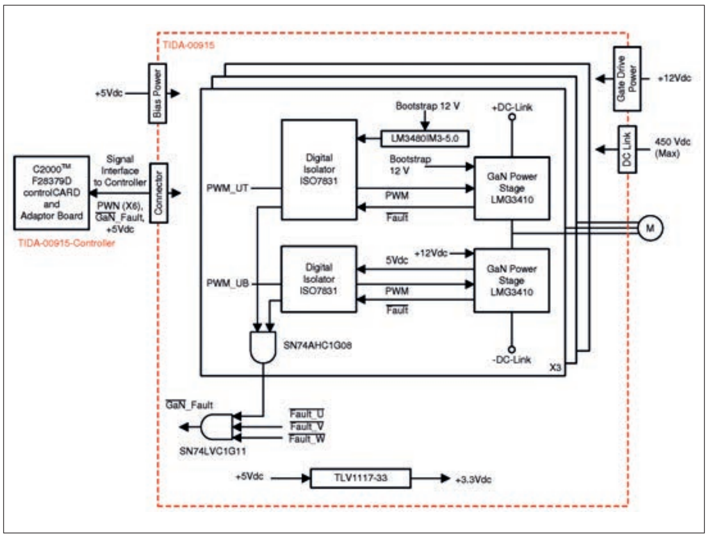
System design

The system block diagram of the three-phase GaN inverter with the TIDA-00915 reference design is indicated in the red dotted box. The three-phase inverter employs six GaN power modules

LMG3410, which have a 600-V and 12-A rating. There are three isolated line current sensing using shunt-based isolated delta-sigma modulators (AMC1306), one on each motor terminal. The inverter accepts voltages from 200- to 450-V DC at the DC-link input. The nominal DC input voltage is 300-V DC. The GaN module has built-in undervoltage lockout (UVLO) on the gate drive input, over-current protection, and over-temperature protection.

Reinforced isolation is provided between the low-voltage MCU side and the high-voltage GaN inverter using ISO7831 digital isolators. The digital isolators are needed for the six PWMs of the inverter and connect the FAULT signals to the low-voltage side. The FAULT signal from each power module is grouped using AND gates (SN74AHC1G08, SN74LVC1G11).

The low-voltage side is powered from an external 5-V input. A TLV1117-33 LDO is used to generate a 3.3-V rail from this 5-V input for powering the MCU side of the digital isolator. An external 12-V gate drive power supply is used, which has to be isolated from the 5-V input given on the low-voltage side. The 12-V gate drive power supply biases the three low-voltage GaN modules. A three-bootstrap 12-V rail is derived from the gate drive power supply for the three high-side GaN modules. The GaN module generates 5-V and –12-V rails, which are used internally. This 5-V rail is also used to bias the three bottom digital isolators. The high-voltage side of the top digital isolator is powered from the LM3480 5-V LDO.



TIDA-00915 block diagram

The inverter power stage interfaces to the C2000 control card. The adaptor board interfaces the TIDA-00915 through a ribbon cable. The C2000 control card and implements a simple space vector modulated PWM to generate a rotating voltage vector where the voltage vectors frequency and magnitude can be controlled. The firmware is based on the controlSUITE library.

GaN power stage

The LMG3410 Single-Channel GaN Power Stage contains a 70-mΩ, 600-V GaN power transistor and specialized driver in an 8-mm by 8-mm QFN package. The Direct Drive architecture is used to create a normally-off device while providing the native switching performance of the GaN power transistor. When the LMG3410 is unpowered, the integrated low-voltage Silicon MOSFET turns the GaN device off at its source. In normal operation, the low-voltage Silicon MOSFET is held on continuously while the GaN device is gated directly from an internally generated negative voltage supply.

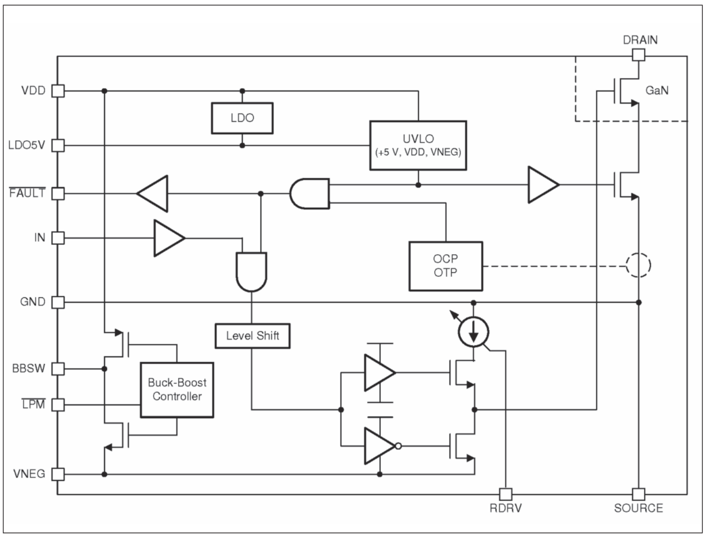
The LMG3410 can support maximum peak current of ±12 A, which corresponds to an RMS current of 8.4 A. The continuous current is determined by the thermal design. The board should be able to deliver 4.5 ARMS (IRMS) continuously at full speed, which is at 200 VAC (VRMS) and at the unity power factor. The rated output power is calculated as $P_{OUT} = \sqrt{3} \times 200\ V \times 4.5\ A \times 1 = 1558\ W$.

The power stage consist of three identical half bridges; each GaN module generates 5 V from an internal LDO, which is used internally and also to power the high-voltage side of digital isolator for the bottom GaN module. The high-voltage side of the top digital isolator is biased by the 5-V LDO connected to the 15-V bootstrap power supplies. The GaN module also generates a negative 12-V power supply rail for the gate drive using an internal switching regulator.

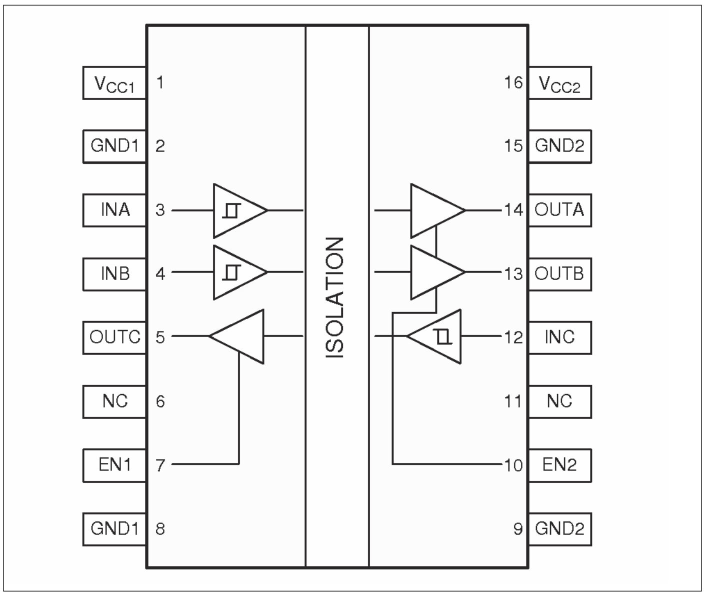
The integrated driver provides additional protection and convenience features. Fast over-current, over-temperature, and UVLO protections help create a fail-safe system; the device's status is indicated by the FAULT output. An internal 5-V low-dropout regulator (LDO) can provide up to 5 mA to supply external signal isolators. Finally, externally-adjustable slew rate and a low-inductance QFN package minimize switching loss, drain ringing, and electrical noise generation.

Three-channel digital isolator

The three-channel digital isolator ISO7831x has isolation certifications according to VDE, CSA, TUV, and CQC. The device also incorporates advanced circuit techniques to maximize the CMTI performance of ±100-kV/µs minimum. The isolator provides high EMI and low emissions at low power consumption, while isolating CMOS or LVCMOS digital I/Os. Each isolation channel has a logic input and output buffer separated by silicon dioxide (SiO_2) insulation barrier. The ISO7831x device has two forward and



Functional GaN power stage block diagram



Functional block diagram of ISO7831

one reverse-direction channels. If the input power or signal is lost, the default output is high for the ISO7831 device and low for the ISO7831F device.

Delta-sigma modulator

The AMC1306 is a precision, ΔΣ modulator with the output separated from the input circuitry by a capacitive double isolation barrier that is highly resistant to magnetic interference. This barrier is certified to the DIN V VDE V 0884-10 and cUL1577 standards. Used in conjunction with isolated power supplies, the device prevents noise currents on a high common-mode voltage line from entering the local system ground and interfering with or damaging low-voltage circuitry.

The input of the AMC1306 is optimized for direct connection to shunt resistors or other low-voltage level signal sources. The low input voltage range of the ±50-mV device allows significant reduction of the power dissipation through the shunt while supporting excellent AC and DC performance.

The output bit stream of the AMC1306 is Manchester coded (AMC1306Ex) or un-coded (AMC1306Mx), depending on the derivate. By using an appropriate digital filter (that is, as integrated on the TMS320F2807x or TMS320F2837x families) to decimate the bit stream, the device can achieve 16 bits of resolution with a dynamic range of 81 dB (13.2 ENOB) at a data rate of 78 kSPS. On the high-side, the modulator is supplied by a 3.3- or 5-V power supply (AVDD). The isolated digital interface operates from a 3.0-V, 3.3-V, or 5-V power supply (DVDD). The AMC1306 provides a very high CMTI performance of 100 kV/?s, required in high-switching environments like GaN inverter to suppress data corruption.

Tests

Tests verified the safe operation of the inverter with the chosen heat sink and fan cooling with the PCB in an open environment. However, characteristics depend on the amount of cooling available, hence results can vary in the end product depending on if more or less cooling available. A small thermal solution is possible for a 2-kW inverter and is made possible by the low-power loss of the GaN module-based inverter.

www.ti.com/tool/TIDA-00915

Power Electronics for Cordless Power Tools

Ease-of-use, portability and enhanced safety are driving the growth of cordless power tools by bothprofessional and 'do-it-yourself' communities. Manufacturers of these tools are under pressure to continually lower the weight and size of these tools. They are also looking to extend operational life from a single battery charge and ensure reliable operation in a variety of use cases over many years. Advanced lithium-ion batteries can play a role in meeting these requirements, but are only one part of the story. Correct selection of power semiconductors is also a vital in designing a successful product.

According to research firm Future Market Insights, the power tools market was worth $27.6 billion in 2015 and will reach $46.47 billion by 2025. North America, Western Europe and Asia-Pacific account for over 70 % of these figures. The significant resurgence in the housing market and rapidly expanding infrastructure in developing countries is driving greater demand among professional users. For many reasons, not least convenience, portability and safety, there is a strong shift from mains-powered corded power tools to cordless equivalents. Improvements in battery technology have enabled a large part of this growth. Older Ni-Cd technology is rapidly being replaced by Li-Ion, enhancing weight, operational life and efficiency of modern cordless power tools.

Motor options

The motor is pivotal to every cordless power tool, converting the electrical energy from the battery into movement that performs the task that the tool is dedicated to. By definition, all cordless power tools use some form of DC motor. These motors allow speed to be controlled over a wide range and offer a high starting torque - key attributes for cordless power tools. However, there are multiple options available, each with different advantages and performance parameters.

Brushed motors are the oldest form of DC motor and have been around for a long time. Simple brushed motors comprise an armature (rotor), commutator, brushes, spindle and permanent magnets. Current travels through the brushes, which are electrically and physically in contact with the commutator. The essential magnetic field is created by the current passing through the armature.

The permanent magnets that surround the armature interact with the armature-generated fields, thereby causing the armature to rotate around the spindle. If greater current is applied, stronger magnetic fields are created in the armature, increasing the magnetic interaction forces, thereby increasing rotational speed.

Another option is Brushless DC (BLDC) motors. As the name suggests, BLDC motors have no brushes, removing a wear-out mechanism as well as any frictional energy losses. Permanent magnets are located on the brushless rotor with the armature's electromagnetic coils in fixed positions surrounding it.

In a brushed motor, the commutator reverses the current flow through the armature coils, flipping the magnetic fields so that the rotor continues to spin. In a brushless motor, an electronic control switches the phase of current through the armature windings at precise timings to accomplish the rotational response. In general BLDC motors cost more than brushed motors and are more complex to control. On the positive side they offer a longer, low-maintenance lifetime, and they are typically more powerful than a similarly sized brushed motor.

Key building blocks

While different manufacturers each have their own approach to designing cordless power tools, the fundamentals of the power train between the power source and the motor are very similar.

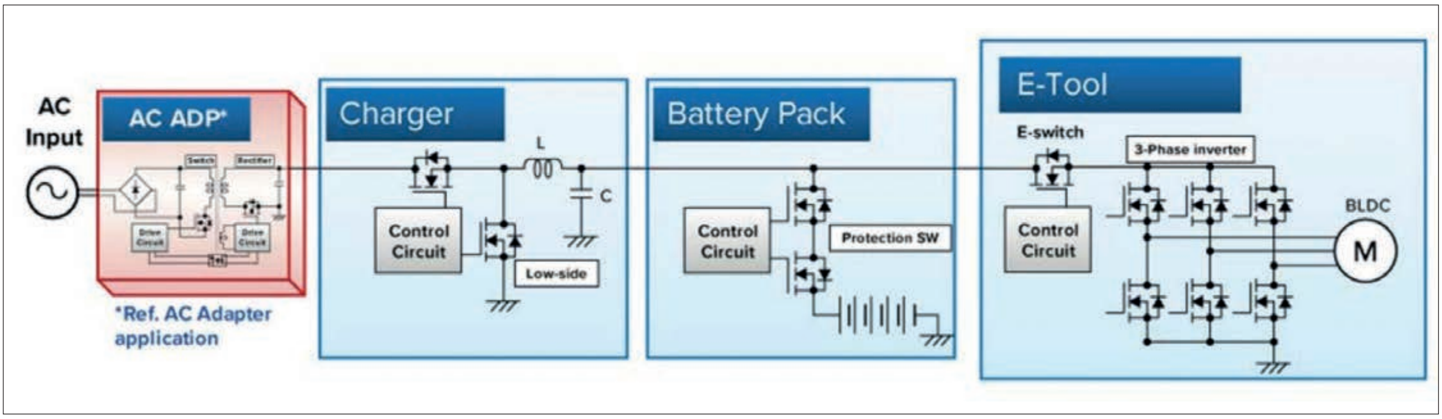
All cordless devices, including power tools, need to be recharged at some point. In almost all cases this is from AC mains power, although other options such as solar recharging are possible. In most cordless power tools, the battery pack can be detached from the tool to allow long-term continuous working. Each exhausted battery is plugged into a charger that is often separate from the tool itself.

The charging station will normally take its power from the mains; the front-end is an AC adapter that rectifies and conditions the AC mains. The power then flows to a charger circuit that charges the battery. Because the type and size of battery to be charged is known so the charger can be highly optimized.

Battery packs themselves are becoming increasingly sophisticated and now hold significant amounts of energy. Alongside multiple compact cells they incorporate control and protection circuitry, ensuring safe and consistent delivery of power to the tool. The tool contains the motor drive circuitry, which comprises a control circuit and discrete semiconductors that form a 3-phase inverter. This inverter creates the interleaved power signals for correctly driving the BLDC motor.

Challenges facing designers

With cordless power tools, designers face a



Most cordless power tools have a similar fundamental layout

◎ excellent fit, ○ good fit, △ fair fit

Characteristics		Q_g (Q_{sw})	$R_{DS(ON)}$	Q_{rr} (Q_{oss}/E_{oss})	Voltage Lineup
Influence		Switching speed	Conduction loss	Recovery charge	
U-MOS for Low voltage (20V-250V)	U-MOS IX-H	◎	◎	◎	30V-60V
	U-MOS VIII-H	◎	○	○	30V-250V
	U-MOS VII-H	△	△	○	20V-30V

he U-MOS range offers various combinations of performance parameters

number of challenges; many of these interact and, in some cases, compete with each other. One challenge, for example, is ergonomics as this defines the form factor of the tool. As the tools are often used for long periods user comfort and convenience is fundamental key to the success of a product in the market. The shape is important, as this is the tactile interface with the user; it also defines the available room for the motor and other electronics. Features such as the ability to use a tool either right- or left-handed can sometimes constrain the space available for the technology or define where certain switches have to be placed on the device.

Weight is another key criterion and this drives design decisions about the motor technology (BLDC is lighter), battery and housing. Users now expecting important information such as battery life indication, or inbuilt LED lights, which make working in dark, cramped spaces easier. All of these require additional circuitry and consume battery power.

The battery itself is one of the biggest and most obvious trade-offs. With users wanting lighter, more convenient tools and also extended operational lifetimes, designers are faced with finding the 'sweet spot' that balances these two competing requirements. One solution is to offer a range of battery sizes and capacities for the tool. The real answer lies in selecting the battery technology with the most energy per unit weight, and ensuring that all aspects of the design are as efficient as possible so as not to waste energy.

Despite their value to the user, tools often have a tough life. Even in normal use, the nature of the work means that they will endure both mechanical and electrical stresses and peaks. Particularly tight nuts or a jamming drill will demand peaks of current to deliver the requisite torque. Yet, control and protection circuitry must ensure that the battery does not deliver so much instantaneous power that the electronics or motor are damaged.

Tools will inevitably be used in harsh environments; dust, dirt and damp are just some of the hazards they will face. Temperature is another. Not only may the tool be required to operate in a high ambient temperature but it is, itself, a source of heat. Improving efficiency allows the tool to run cooler and, therefore, work at higher ambient temperatures.

Addressing the efficiency challenges

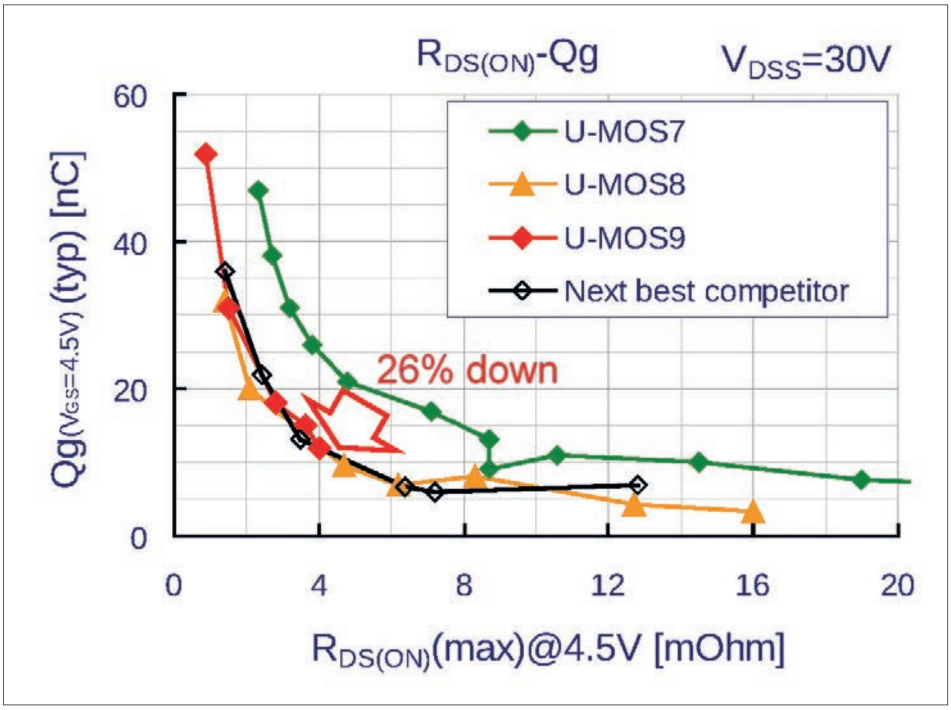
Obtaining the most usable energy from the battery and then processing that energy as efficiently as possible are two critical challenges for the tool designer. Batteries have advanced significantly in recent years and will continue to do so. In general, voltages are increasing with the older 12 V and 14.4 V solutions being replaced with batteries in the 18 V to 21 V category. More recently, a growth in 36 V options can be observed. These give the ability to deliver more power rapidly and are popular in larger items such as garden tools and professional-grade hand tools.

The basic battery technology has moved from NiCd through NiMH to Li-Ion. While NiCd was inconvenient as it had to be discharged fully before charging (the so-called 'memory effect') it is a robust technology and many batteries remain in use. NiCd was superceded by NiMH - this could be charged at any point in the discharge cycle and also offered higher ampere-hour capacities.

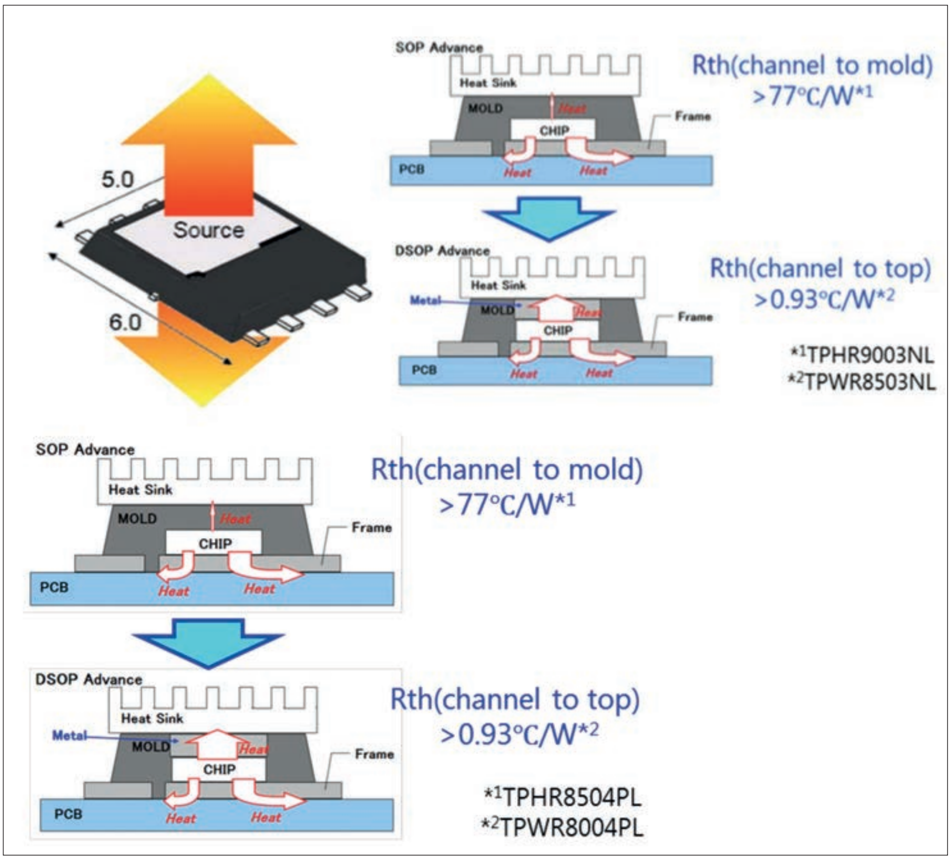
Almost all tools on sale today have Li-Ion based batteries. This technology also has no memory effect and can be topped up as needed. The big advantage of Li-Ion is that it typically weighs 40 % less than the equivalent NiMH battery.

Designers are challenged to ensure that cordless power tools operate at the highest possibly efficiency to make best use of the available battery power. This impacts all aspects of the electronic design, but the key switching elements - the MOSFETs - have the biggest impact.

Each of the key building blocks rely on MOSFET



Successive U-MOS generations have shown continued improvement in Q_g vs $R_{DS(ON)}$



DSOP advance delivers huge gains in thermal conductivity

technology for converting and processing the energy. Firstly converting the mains power to charge the battery and then delivering that stored energy in the most efficient way possible to the motor through the MOSFET-based inverter circuit.

For success in demanding power applications - especially in compact battery powered equipment – modern power MOSFETs need to offer low loss levels in a small convenient package.

One of the more recent technologies specifically aimed at meeting the challenging needs of cordless power tool design is the trench LV MOSFETs from Toshiba. The Company's U-MOS VIII MOSFET technology, for example, offers a 30 – 250 V class MOSFET series that boasts a broad product line up with a wide voltage range. U-MOS IX technology supports 30 -60 V class MOSFETs with some of the lowest on- resistance values. Within the U-MOS IX series, the 3 mm x 3 mm 40 V package has on-resistance values as low as 2.3 mΩ, while the 5 mm x 6 mm 40 V package drops values to 0.85 mΩ.

In developing this technology, Toshiba has focused on three main parameters that affect the losses in power switching applications; Gate charge (Q_g), On-Resistance ($R_{DS(ON)}$) and Recovery charge (Q_{rr} – sometimes Q_{oss}/E_{oss}). The gate charge and recovery charge are discharged during every switching cycle and therefore have the greatest impact in the fastest switching devices. The on-resistance is sometimes known as the conduction loss because the resistance generates waste heat while the MOSFET is conducting current.

As can be seen from the table, the U-MOS range offers various different performance levels and combinations of these critical parameters, allowing designers to select the most appropriate for their particular application.

Each of these advances has been a hieved through specific, targeted developments. The relationship between Qg and $R_{DS(ON)}$ is important as there is a trade-off between the two parameters, meaning that an improvement in static losses can negatively impact dynamic losses and vice-versa.

Each successive U-MOS generation has improved the trade-off of these key parameters. The latest U-MOS IX (U-MOS 9) shows a 26 % improvement in $R_{DS(ON)}$ vs Q_0 when compared to the earlier U-MOS VII (U-MOS 7). The latest U-MOS IX-H achieves reduced recovery loss through tuning of the Qoss parameter, which directly affects the all-important recovery charge. Recovery charge effects not only loss, but also EMI, and sometimes leads to current monitoring error. The range will be further broadened with the future introduction of 100 V and 80 V devices.

In enclosed applications, a wide range of available package types is important in order to be able to fit the devices in the available space. Additional cooling features allow heat to be quickly and easily channelled away to the case of the tool and, ultimately, the environment. Toshiba's LV-MOSFET range offers a wide range of packaging. This includes industry-standard package types such as 3 mm x 3 mm TSON Advance and 5 mm x 6 mm SOP Advance, which feature underside cooling, and DSOP-advance that offers additional topside cooling. A further benefit of the wide range of industry-standard packages is the ability to upgrade existing Silicon on the same footprint, thereby allowing the latest developments to be deployed in legacy product without the risk of a PCB redesign.

While SOP Advance is considered to be a high-performance package, DSOP advance offers dramatic performance enhancements as the silicon die ('chip') has direct thermal connection to the PCB and heat-sink. This allows it to achieve a significant increase in thermal conductivity. Devices in this package are suited to cordless power tools where space and convection cooling is often limited.

The DSOP package is competing with conventional and relatively expensive metal can packages. These require solder joint control by x-ray, whilst a DSOP package a portion of the PIN is exposed.

Also, compared to other vendors offering plastic mold solutions with dual sided cooling, the Toshiba DSOP has the advantage of a wider top side connector. This ultimately leads to significantly improved R_{th} to the topside. Therefore it is a simple step for customers to upgrade from the existing concept of 5 mm x 6 mm standard items with advanced DSOP solutions.

Within a typical cordless power tool, such as a screwdriver / drill, each of the main building blocks will benefit from the high performance MOSFET technology. Within the charger, MOSFETs act as the high- and low-side switching elements. In the battery pack, MOSFETs provide protection, with the ability to disconnect the battery rapidly in fault conditions. In the tool itself, MOSFETs are used for the E-switch as well as forming the six-element, 3-phase inverter that provides the motor drive.

www.dmags.co.uk/xblast/link/dfa/

Impact of Ultra-Low On-Resistance SiC MOSFETs On Electric Vehicle Drive-Train

Three market / technology forces are moving in concert to create an opportunity for SiC MOSFETs to be an enabling technology in the Battery powered Electric Vehicle (BEV). The pull of the developing traction-drive requirements for BEV drive-train, which can utilize SiC to cut inverter losses by ~78 % in the EPA drive-cycle, can offer BEV designers increased range or reduced battery costs for the same range.

Jeff Casady, Business Development & Program Manager, Wolfspeed; Monty B. Hayes, Manager Advanced Hardware, Electronic Controls, Delphi

Cree/Wolfspeed has had SiC wafers commercially released since 1991, diodes since 2001, and MOSFETs since 2011. The SiC power device market continues to mature and grow each year, now well above $200 million per year and increasing in 2017.

SiC development over time

First, continued advances in diameter expansion, volume, quality, and cost of SiC bulk wafers has reached a point where high-volume 150 mm fabrication facilities can utilize SiC wafers as pictured in Figure 1. At Wolfspeed, nearly 18 metric tons of 150 mm SiC wafers were shipped in calendar year 2016 [1] to support markets such as LED, RF, and power, with continued growth forecast for 2017 and beyond. 200 mm diameter SiC wafers have also recently been demonstrated in R&D, as continued wafer diameter expansion development continues. The quality of the SiC wafers has also improved consistently over the years, with median micropipe defect density falling to 0.2 /cm^2 in 2016, enabling large area SiC MOSFETs to be fabricated with high-yield, and meeting automotive AEC-Q-101 qualification.

Second, SiC MOSFETs, first released in 2011, have continued to improve in terms of on-resistance per unit area. For example, the first generation SiC MOSFETs (CMF product series at Wolfspeed [2]) released in 2011 had 25°C specific R_{DSON} of ~8 mΩ·cm^2, rising to 11mΩ·cm^2 at 150°C. The second generation (C2M), released in 2013, dropped on-resistance per unit area substantially, and 1200 V third-generation (C3M [3]) SiC MOSFETs have now been commercially released beginning in 2017 with yet another drastic reduction, especially at operating temperature.

For example, as shown in Figure 2, C3M 1200V SiC MOSFETs (C3M0075120K) have specific RDSON of only 4.4 mΩ·cm^2 at 150°C, which is 60 % lower than the original CMF transistor. The device design aspects are described elsewhere [4]; all three generations are planar DMOS structures, with the third generation utilizing a more compact cell pitch, and optimized doping in the drift region to lower the resistance of the MOSFET over the temperature range. The peak electric fields in the SiC MOSFET are the same or lower than previous generations, so reliability and ruggedness are not compromised.

SiC for automotive applications

Third, the world-wide proliferation of BEVs to accommodate fuel efficiency and CO2 emission standards is driving the need for a different semiconductor technology in the drive-train inverter. Bus voltages vary between 400V-900V typically, depending upon the power of the drive-train inverter, and whether the battery voltage is boosted or not. Since the drive-train inverter is driving a motor, inverter frequencies are typically limited to 20 kHz, with higher-frequencies only benefitting to operate above the audible noise frequency range. Subsequently, most inverter efficiency losses are conduction losses, especially at the light-load conditions typical in BEV

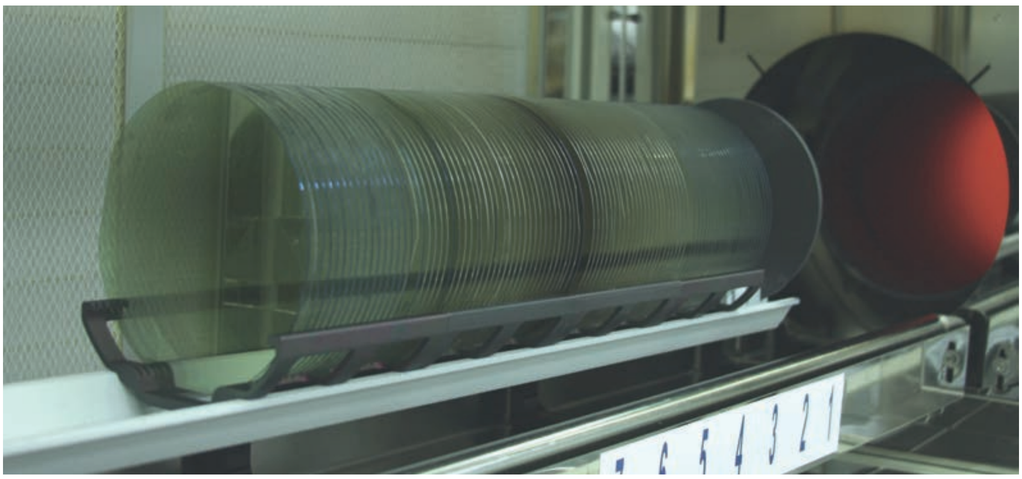


Figure 1: 150 mm diameter SiC substrates are now in common use for global fabrication of SiC power devices. Nearly 18 metric tons of 150mm diameter SiC wafers were produced by Wolfspeed in 2016 [1]

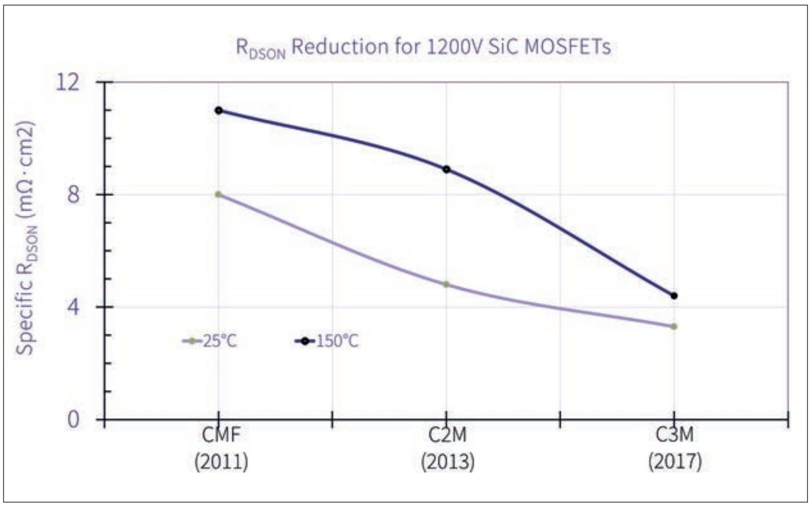


Figure 2: 1200 V SiC MOSFETs introduced since 2011 have drastically lowered on-resistance per unit area, with the third generation SiC MOSFET (C3M product series) enabling a 60 % drop in the 150°C specific RDSON values compared to the originally introduced SiC MOSFET. These latest generation SiC MOSFETs have closer cell pitch and a more optimized doping profile, while maintaining the same or better reliability and ruggedness as the previous generations

operation.

The semiconductor of choice thus far, the silicon IGBT, has an inherent knee-voltage at light-load (due to its bipolar nature) which cannot be easily reduced, even in paralleling copious amounts of Si IGBTs together. However, SiC has 10X higher electric field strength (~3 MV/cm) than Si, so the unipolar SiC MOSFET structure is well-suited for power switch transistors of 650 V, 900 V, and 1200 V, which enables several key-features such as

- SiC MOSFETs have no on-state knee-voltage as found in Si IGBTs.
- SiC MOSFETs can easily be operated in parallel to reduce on-state losses to ≤ 1-2 mΩ.
- SiC MOSFETs can utilize third quadrant conduction, unlike Si IGBTs, by using the SiC body diode during the dead-time (which is quite short with SiC operation), and then opening the SiC MOSFET channel the third quadrant providing the same low on-state losses in reverse conduction as found in forward conduction. The combination of body diode use in dead time and synchronous channel rectification eliminates the need for an external anti-parallel SiC diode, saving space and cost with minimal efficiency impact at frequencies up to 50 kHz.
- SiC MOSFETs can eliminate ~78 % of the inverter losses in a typical BEV EPA drive-cycle [5].

Recent results

Wolfspeed, among other suppliers, has been developing low-RDSON SiC MOSFETs for power modules in BEV drive-train applications. The basic SiC MOSFET technology can be scaled from 650-900-1200 V by simply adjusting the drift region epitaxy (blocking layer) and edge termination. The basic MOSFET layout remains the same for all devices in this voltage range, leading to ease of assembly into power modules.

In Figure 3, an example of a traditional top-side wire-bonded approach for module construction is illustrated using the 3rd-generation SiC power MOSFET chips. This module can accommodate either 650 V, 900 V, or 1200 V interchangeably with very small differences in chip layout. For 900 V, a low resistance 10 mΩ SiC MOSFET (CPM3-0900-0010A) is commercially available [6], and has been used to construct 900 V versions of this power module [5,7] which have been characterized for static and dynamic losses. Using the measured data from a 900 V, 2.5 mΩ SiC half-bridge power module (four MOSFETs per switch position), Ford compared the performance to their 700 V Si IGBT based inverter in a 90 kW motor drive, and found an average 78 % reduction in inverter losses over a standard EPA drive-cycle [5].

More recently, much attention has been focused on the use of sintered SiC power modules [8-10], which offer potential advantages by eliminating wire bonds on the chip assembly. One primary targeted benefit is increased Intermittent Operating Life (IOL) as wire bond fatigue or die attach is often a cause of IOL failure. Better (dual-sided) cooling, better heat spreading, and increased short-circuit rating are other potential benefits being explored. A recent example from Delphi [10] was demonstrated using five double-side sintered, 650V, 7 mΩ SiC MOSFETs in parallel in a 1.7 mΩ single switch configured module as shown in Figure 4. The sintering was performed on Wolfspeed 650 V, 7 mΩ SiC MOSFETs with both top and bottom chip metallurgy of Ni:Au.

The resulting module performance was impressive, with a low 1.7 mΩ RDSON measured up to 750 A in the module at 25°C, increasing modestly to 2.3 mΩ at 175°C, as shown in Figure 5 (top). Power cycling was performed as well on this first module prototype, with DC setup currents of 520 A for each phase (shoot-through current), and a ΔT_J of 100 K from 50°C to 150°C target settings. Using a 25 s period

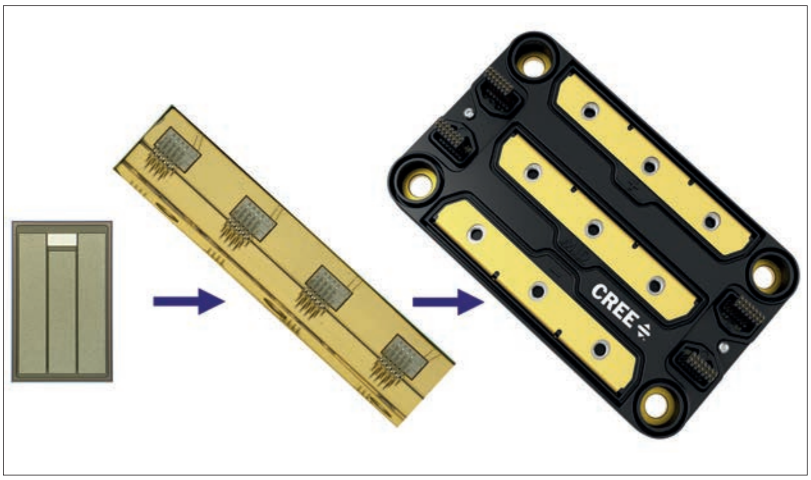


Figure 3: Wolfspeed's SiC MOSFETs (left) can be scaled from 650 V/7 mΩ to 900 V/10 mΩ to 1200 V/13 mΩ with simple modifications to blocking region and edge termination. The SiC MOSFETs can be easily paralleled to create a very low on-state resistance power module. In this example image (center and right), four of the 3rd generation 900 V/10 mΩ SiC MOSFETs (CPM3-0900-0010A) are placed in parallel to make up one switch of a half-bridge low-profile 62 mm power module (right). The resulting half-bridge SiC power module is rated at 900 V, 2.5 mΩ, 400 A. The module can allow up to twice as many chips to be assembled, which would cut the on-state resistance further to 1.25 mΩ

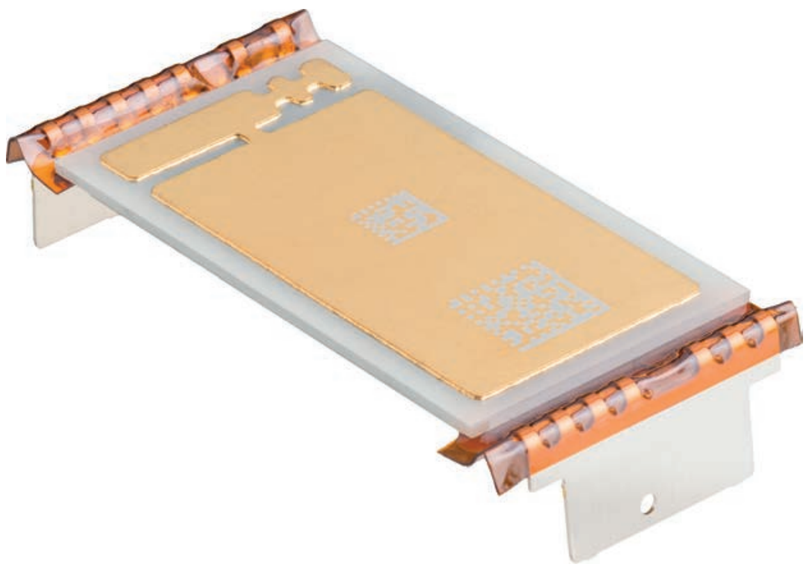


Figure 4: **The 650 V, 1.7 mΩ, 750 A Delphi SiC module contains five 650 V, dual-side sintered,, 7 mΩ SiC MOSFETs in a single switch configuration**

(all three phases running), with 10 s off-time, the on-state drop was measured after 36,000 cycles for six modules. None of the modules exceeded 5 % increase over the 36,000 cycles as shown in Figure 5 (bottom).

In parallel to the 650 V and 900 V development, similar work is progressing with 1200 V SiC MOSFETs. With a chip area of 32 mm^2, room-temperature R_{DSON} is 13 mΩ, and 175°C R_{DSON} is 23 mΩ.

Conclusions

The combination of larger diameter (150-200 mm) SiC wafers with increased materials quality, coupled with advances in SiC MOSFET design (lowering 1200 V rated specific R_{DSON} at 150°C by 60 % from 2011-17), have enabled ultra-low (<15 mΩ) resistance SiC MOSFETs to be commercialized. A 900 V, 10 mΩ SiC MOSFET was released commercially in January 2017.

The pull of the developing traction-drive requirements for BEV drive-train, which can utilize SiC to cut inverter losses by ~78 % in the EPA drive-cycle, can offer BEV designers increased range or reduced battery costs for the same range. Today the development activity is focused on efforts to improve SiC performance and reliability, such as recently demonstrated by 650 V, 7 mΩ MOSFETs used for dual-side sintered, 1.7 mΩ power modules for automotive drive-train inverters, that has already shown very good power cycling data to go with the impressive low on-state performance.

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[7] J. Casady, et al., "Ultra-low (1.25mΩ) On-Resistance 900V SiC 62mm Half-Bridge Power Modules Using New 10mΩ SiC MOSFETs," PCIM Europe, Nuremberg, Germany, May 10-12, 2016.

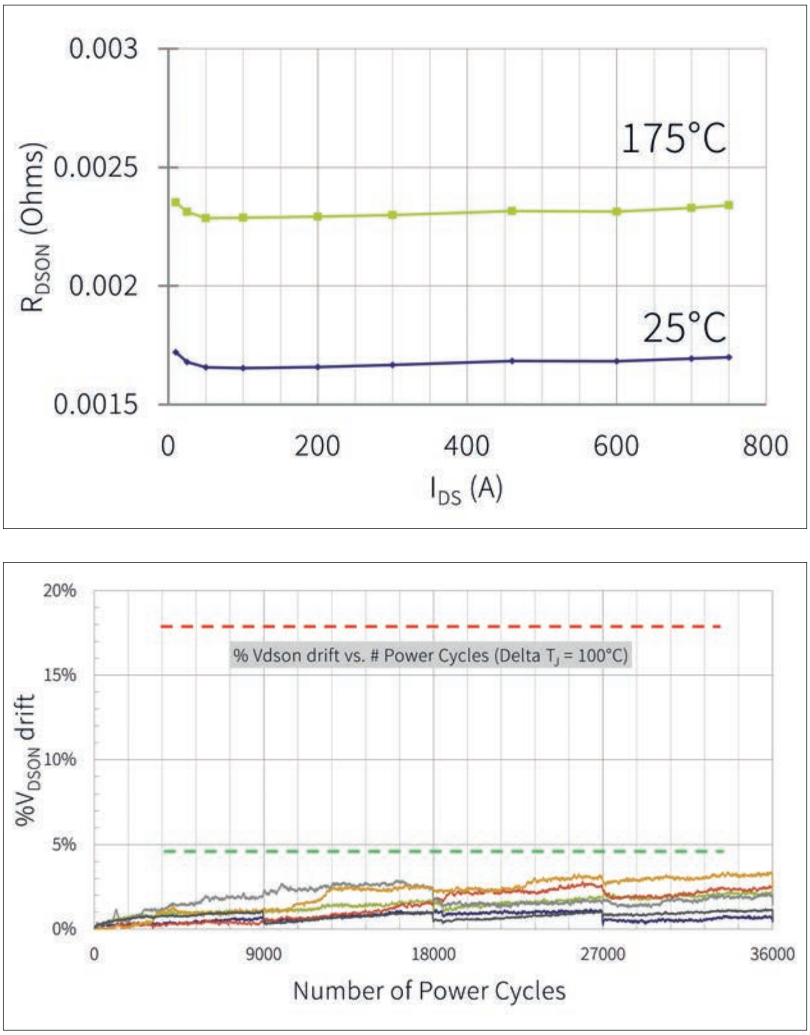


Figure 5: **The 650V, 1.7 mΩ, 750A Delphi SiC module shown in Figure 4 is tested up to 750A for RDSON values of ~2.3 mΩ at 175°C (top); six of the same SiC modules subjected to 36,000 power cycles with ?TJ of 100 K from 50°C to 150°C passed successfully with <5 % change in on-state voltage drop**

An Effective Approach to Controlling of Multiple Voltage Rails

The process of powering-up the various voltage rails that accompany system-on-chips (SoCs), field-programmable gate arrays (FPGAs) and embedded modules in the correct order can be quite convoluted. Engineers therefore need to specify a suitable solution. As will be detailed in the following article, there are a multitude of ways in which modern sequencing technology can help to simplify the task.

Mirko Bernacchi, Technical Support Specialist, Mouser Electronics, Milano, Italy

The contemporary processor-based designs upon which the embedded systems sector now relies all mandate that power is supplied at different voltages. As well as having different values, these voltage rails must be initiated in a specific sequence - the processor core, the related peripherals, the I/O buses (such as LVDS, I^2C, SPI, etc.) and the memory resources all being attended to in turn. Through sequencing, the risk of large inrush currents that could potentially damage sensitive elements of the subsystem during the start-up process can be circumvented.

The trend towards increasing degrees of integration has meant that a greater proportion of an embedded system's functionality will generally be packed onto a single SoC device, in order to save board space and reduce bill-of materials (BoM) costs. Such SoCs need multiple power rails, each at the appropriate voltage level, to be applied to the associated pins. Those that are not SoC-oriented will often utilize programmable logic, with large FPGAs leaving engineers with similar (if not greater) power rail complexity to contend with. In some cases it may be necessary for this to be extended to other elements situated on the board - discrete devices (MOSFETs, IGBTs, etc.), sensors (CMOS imaging devices, magnetometers, etc.) or actuators (motor drivers, LED drivers, etc.) potentially requiring dedicated voltage lines.

More and more rails

Even a relatively simple embedded system implementation can have a considerable number of rails involved (over 10 not being uncommon today). Engineering effort will need to be allocated to ensure that the correct sequencing is adhered to - the output supplied by a given power regulator having reached a sufficient level before regulators that are related to other voltage lines are activated. As it is more straightforward to measure timing in a precise manner than it is to measure voltage, often a time based approach is more effective - working on the principle that the value that is expected on a voltage rail will be attained in a predetermined period.

Though the time between the different rails being powered-up is normally very short (just a few milliseconds), it can potentially be much longer than this (several seconds in fact). For example, if some sort of electro-mechanical component within the system, such as a heater, needs to reach its optimum temperature prior to subsequent elements in the system being activated, or if the central processing unit has to complete a calibration procedure, then time will be taken up - and this needs to be recognized by the design engineer.

Where the discrete power converters that are incorporated into the system each respectively possesses enable pins and power-good outputs, engineers can use each power-good signal to ensure that the next converter in the sequence will only start when the preceding rail has attained an adequate value for that signal to continue to be asserted. If one or more of the converters does not have an enable input, engineers can achieve sequencing by using the turn-on signal to control the gate of a MOSFET placed in series with the output.

Under circumstances where there isn't any access to a power-good signal, engineers may need additional circuitry to provide the necessary assistance. Through this the output voltage of one power converter can be sampled to generate an enable signal for another power converter. An alternative to voltage sampling is utilising timing circuitry. In either of these scenarios, however, a fairly large number of components is required - resulting in heavy BoM costs, substantial PCB real estate being used up and additional engineering resource needing to be allocated. Also are there issues associated with discretes providing a reverse sequence when the system is being powered down.

Rather than taking a discrete approach, engineers may find it more effective to look an integrated power-sequencing or PMIC-based alternative.

Integrated solutions

Offering straightforward implementation, Texas Instruments' LM3880 (see Figure 1) can be specified for power sequencing purposes (with the device's power-down procedure matching the same sequence and same time intervals as used in power-up, but in reverse). Thanks to its three open-drain output flags (which upon initiation of power-up are all held low), it has the capacity to generate enable signals to serve up to three individual voltage rails, with the option to cascade two sequencer ICs together in order to have six sequenced rails available. The PMIC incorporates its own precision enable input. This is connected to an internal comparator with a 1.25V reference. Through it engineers can arrange for the power-up sequence to begin once a logic signal is received, or when another voltage rail reaches a certain predetermined level. A delay can be included by attaching a capacitor to the enable input.

When the enable becomes valid, the first output flag is asserted after a preset delay (which is programmed into the EPROM during the OEM production process). An identical time period is then

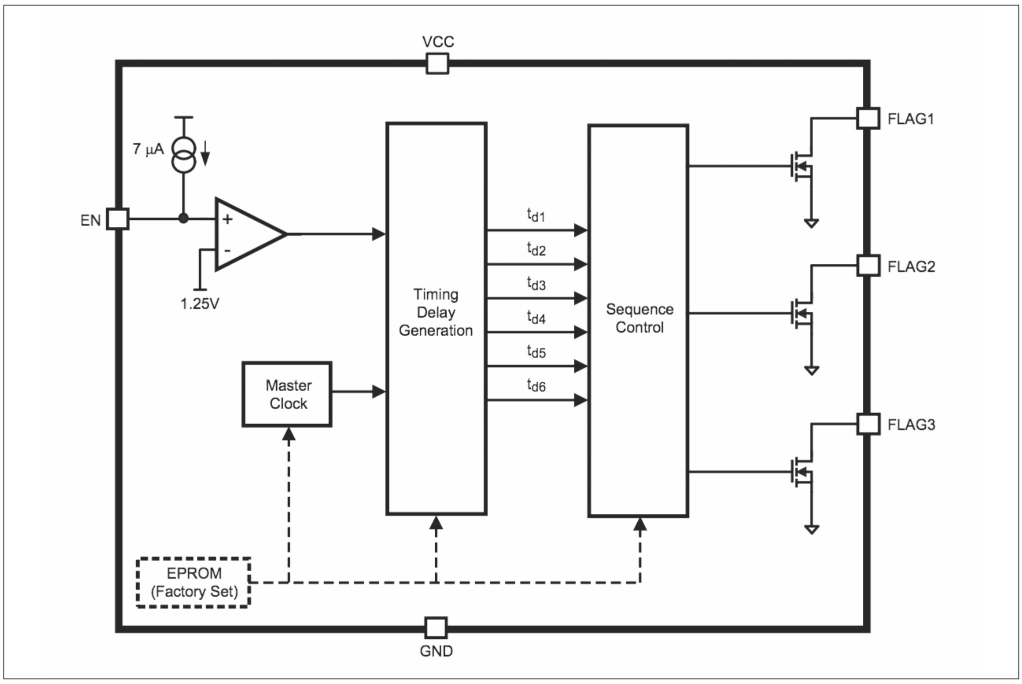


Figure 1: Functional block diagram for the LM3880 from Texas Instruments

allowed to elapse before the second flag is set, and this is repeated once again before the third flag is set. Six different pre-set timing designations that span from 2 ms through to 120 ms can be chosen from.

Maxim's MAX16029 supervisor device also has capacitor-adjustable time delay. It can be used to sequence up to four voltages rails via one single PMIC. The company also has sequencer devices in its portfolio that enable to set timing via PMBus interfaces. This means that a number of them can be daisy-chained together in order to address larger quantities of voltage rails.

By procuring sequencing technology in which multiple power source elements have been incorporated, engineers can benefit from marked reductions in board utilisation and overall system complexity. The TPS65916 PMIC from Texas Instruments' has five configurable step-down converters integrated. These take care of powering the processor core, plus the various memory reserves and I/Os that are featured in a broad array of different microprocessor devices. By supporting adaptive voltage scaling, these converters are able to deliver power efficient operation that won't impinge on the system's power budget. The PMIC also contains five low voltage drop-out controllers to address low current or low noise domains. The power-up and power-down sequences can be configured by the engineer to suit their application via the one-time programmable memory.

Circumstances may dictate more complicated sequencing will be required, with a greater breadth of voltage rails to take into consideration. In such cases the turn-on and turn-off sequencing must be managed with a higher degree of sophistication. Specifying a simple sequencer or a general-purpose PMIC may not be enough. What is needed instead is the full user-programmability of microcontroller unit (MCU).

The popular PIC16F1XXX family from Microchip (as shown in Figure 2) presents a power sequencing solution capable of dealing with a large number of voltage rails. Its user-programmable embedded firmware can be used to define the required timing. The device also offers ample provision for setting power-good criteria, as well as ramp-up and ramp-down periods. The 10-bit analogue-to-digital converter digitizes each rail 16 times and then calculates an average value (so that performance can be accurately evaluated). The MCU's diagnostic capabilities mean that if a supply fails the situation is rapidly flagged.

Conclusions

Ensuring that the appropriate sequence is used when powering-up/powering-down electronic circuitry is critical. Long term operational integrity can thus be maintained and system reliability is not in any way compromised. Solutions for this range all the way from basic sequencers right through to more feature-rich PMICs and fully programmable MCU devices. With a wealth of different options now on the market, it is simply a matter of assessing which sequencing method is best suited to the principal design objectives (whether that is maximizing performance, keeping the BoM down, dealing with space constraints, curbing system power consumption, etc.), then sourcing the necessary devices.

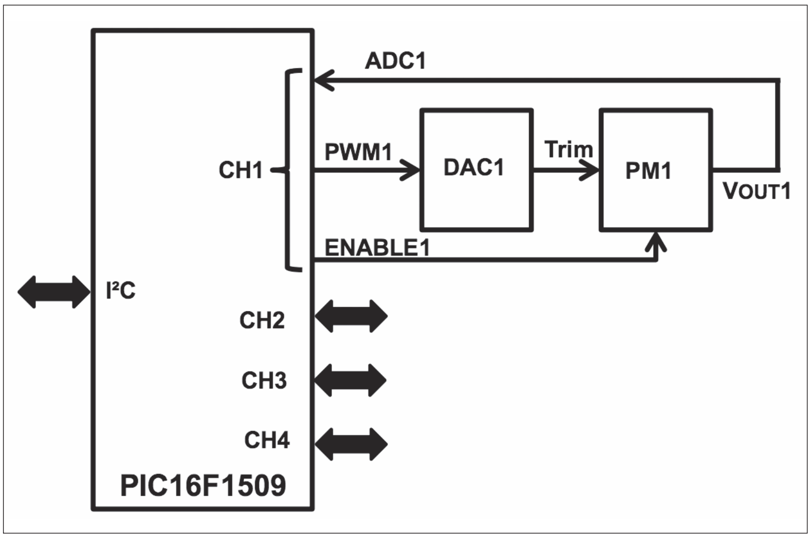


Figure 2: Microchip's PIC16F1XXX family can support flexible power sequencing of numerous voltage rails

How Components Influence Reliability of DC/DC Converter Designs

The pressure to run DC/DC converters at higher operating temperatures to support dense clusters of computing power is growing. It means that converter designers can no longer rely on the limited device specifications that component manufacturers offer at 25°C if they want to produce products that will work reliably over long lifetimes at high operating temperatures. **Ann-Marie Bayliss, Product Marketing Manager, Murata Power Solutions, Fleet, UK**

One of the biggest issues in building large data centers, high-performance mobile networks and other systems that rely on concentrating a lot of computing power in one place is managing the heat they dissipate. Small systems such as cellular base stations manage waste heat using complex heat-sinks and fans. Large data centers face the dual cost of buying energy as electricity to power their systems, and then buying more energy to dispose of the resultant waste heat of computation. The cooling strategies applied to data centers can be so complex to manage that Google recently applied machine-learning algorithms to one of its data center cooling systems and managed to improve its efficiency by 40 %.

The 'hot electronics' issue is only going to get more challenging. As the operating voltages of integrated circuits have dropped from the traditional 5 V to 1.8 V and below in the core of today's fastest chips, to accommodate smaller devices and faster switching, their current consumption has increased. This has led to greater heating in the ICs themselves, as well as greater resistive heating in supporting systems such as the DC/DC converters that power most of this computation.

Large systems are increasingly distributing power on 24 V or 48 V DC buses, relying on local DC/DC converters to deliver the required supply voltages wherever they are needed. As operating voltages fall, though, these converters must accommodate increasingly large step-down ratios – at the cost of reduced conversion efficiency and hence greater thermal load.

In smaller systems, variable-speed fans can be an extremely effective way to cool the on-board electronics. Unfortunately, fans create noise, have bearings that can wear out, and need filters that have to be changed. System designers would prefer their systems not to need this kind of maintenance burden and face this potential reliability issue.

In both cases, being able to run a system at a higher operating temperature can mean direct cost saving in terms of reduced cooling needs – that's why companies that run large server estates specify the use of industrial-grade processors that can run at higher temperatures without reducing their reliability. To run such processors hotter, you also need to run the supporting infrastructure, such as the DC/DC converters, hotter – which is both an opportunity and a challenge.

Temperature affects component characteristics

How can equipment designers be confident about specifying a DC/DC converter for use at higher temperatures? One consideration is how the converter's components will be affected by higher operating temperatures. There's a rule of thumb says that for each 10°C decrease in operating temperature from a component's maximum rating, the failure rate during its useful life halves. This guidance stems from the Arrhenius equation, which quantifies chemical reaction times at varying temperatures in both the diffusion and migration processes that happen in electronic components. The equation provides a solid basis for predicting mean-time-to-failure due to temperature rises.

Designers have to expect lower performance from many types of components when they are operated above 75°C. The best designers understand the mechanisms that affect each type of component and so choose parts that will work well in the target operating environment. For example, there's a clear correlation between the lifetime of electrolytic capacitors and their operating temperature, electrical stress, and the rate of electrolyte diffusion. This can be expressed in this equation, which predicts a component's lifetime:

$L = L_r \times (T_{max} - T)/5 \times (V_{max}/V)2.5$, where

- L is the predicted lifetime in hours
- Lr is the manufacturer's rated endurance at maximum temperature Tmax, in hours
- T is the operating temperature expected of the capacitor
- V_{max} is the capacitor's maximum operating voltage
- V is the circuit's operating voltage

If a designer operates a 25 V DC rated part at 70 % of its maximum voltage rating, a normal commercial-grade component that is rated for 2,000 hours at 85°C should have a lifetime of around 50,000 hours at 50°C. If the designer substitutes a part rated at 105°C, the operating lifetime could be extended to almost 80,000 hours.

The model demonstrates the effect of component choice on service lifetime. In practice, many designers avoid using aluminium electrolytic capacitors, whose wear-out mechanisms have been shown to be one of the main reasons why power

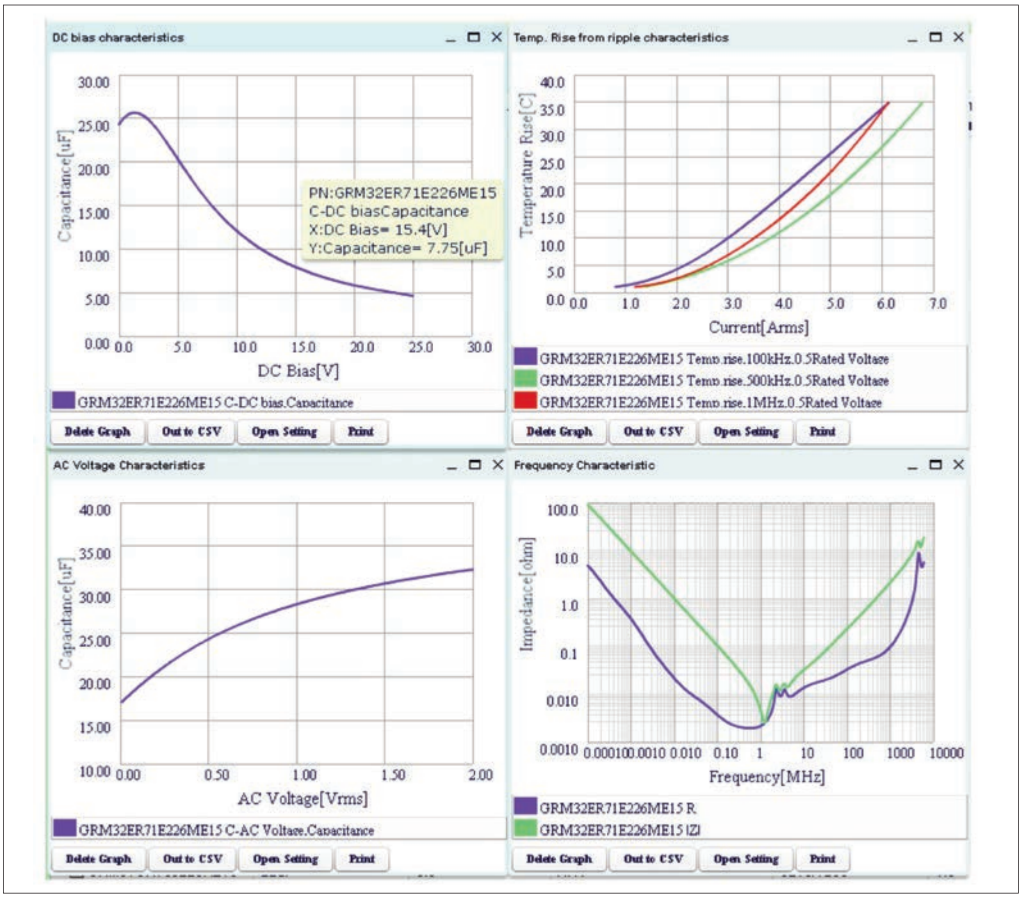


Figure 1: The SimSurfing simulator shows the behavior of ceramic capacitors and inductors under varying conditions. This plot shows the characteristics of a 22 µF / 25 V capacitor

supplies fail.

The main reason ceramic capacitors fail is because they are mishandled, but they can also be affected by excess temperature and voltage stresses. These effects depend upon the dielectric material and become more significant as capacitance values approach the technology's limits. The parts lose effective capacitance rather than fail. For instance, the X7R material often used as a dielectric has a basic capacitance tolerance of ±15 % from -55 to +125°C. In contrast, the capacitance of the Y5V dielectric material can fall by more than 80 % at +85°C. A ceramic capacitor's effective value will also decrease significantly under DC bias, due to an intrinsic characteristic of the BaTiO3 ceramic material of which it is made.

Similar considerations apply to power inductors, whose performance depends upon their core material. Different materials exhibit different amounts of loss at different temperatures, depending on circuit conditions. However, power inductors rarely fail unless they have been grossly overloaded.

Exploring component behavior online

Murata offers a browser-based simulation tool called SimSurfing, which engineers can use to explore the effects of AC and DC bias levels, frequency and temperature on a wide range of capacitors and inductors. It can produce unexpected results. For example, the DC bias pane of Figure 1 shows that a 22 µF, 25 V DC X7R part has an effective capacitance of just 7.75 µF when subjected to 15 V DC bias. The Temp Rise pane in the figure shows that capacitors that handle ripple currents can also be subject to internal temperature rises.

Engineers are used to taking into account the temperature-dependent characteristics of semiconductors in their designs, calculating junction temperatures using thermal-resistance models to ensue they stay below 150–175°C. However, the characteristics of Schottky diodes can create an issue in DC/DC converter design, because they become increasingly 'leaky' as their temperature rises. This can produce high dissipation when they are reverse biased, eventually causing component failure. Similarly, the feedback circuits in DC/DC converters often use opto-isolators, the current-transfer ratios of which can vary as they age and are exposed to high temperatures. The changing characteristics of these opto-isolators can cause instability and, eventually, premature converter failure.

If designers choose MOSFETs rather than diodes in synchronous-rectifier configurations, this can combat the issues with Schottky rectifiers – and improve efficiency. For designs where it is hard to avoid using a Schottky rectifier, such as for the freewheeling diode across the synchronous switch of a buck converter, it is possible to find Schottky diodes and opto-isolators that will withstand junction temperatures of 150°C. Using these means choosing the other components and the circuit design with care, to avoid hot-spots and so enable circuits to operate reliably at high temperatures. As is usual in any design, other systemic issues need to be considered, such as maximum operating temperatures of 130°C for typical circuit boards.

Choosing appropriate components

Designers can no longer rely on the limited device specifications that component manufacturers offer at 25°C if they want to produce products that will work reliably over long lifetimes at high operating temperatures. To produce such converters, designers need to develop a deeper understanding of each component's characteristics, and then center their designs on an efficiency sweet spot within the intended operating temperature range. Designers must also find out where the temperature of components should be measured, and ensure that they make such measurements within a representative operating environment, with an air temperature and flow that reflects the target application. It's only by taking these steps that DC/DC converter designers can hope to produce robust designs that will serve the increasingly challenging needs of systems that use dense clusters of computing, reliably and for the long term.

High-Power Resistors for Demanding Industrial Applications

Converters/inverters are core systems in industrial power electronics. Their continued development is driven by reduction of installation space and improved power/current quality to reduce harmonics and parasitic currents in order to protect connected drives and generators. Other factors of concern are improved efficiency by reducing parasitic inductances, and the general need to improve the cost structure by minimizing material and assembly cost, thus also increasing the lifetime. **Ch. Lindner, EBG Elektronische Bauelemente; T. Zimmerman, EBG Resistors; D. Custic, DAU; and R. Ratzi, Miba Energy Holding, Austria**

High power resistors in converters can take over protection as well as safety functionalities like pre- and discharging of DC-links, di/dt filtering, current limiting, as snubber and chopper resistors, and braking resistors. Now with the possibility to integrate a high-voltage fuse inside the UXP/ULX resistor housing, it is possible to leverage the protective

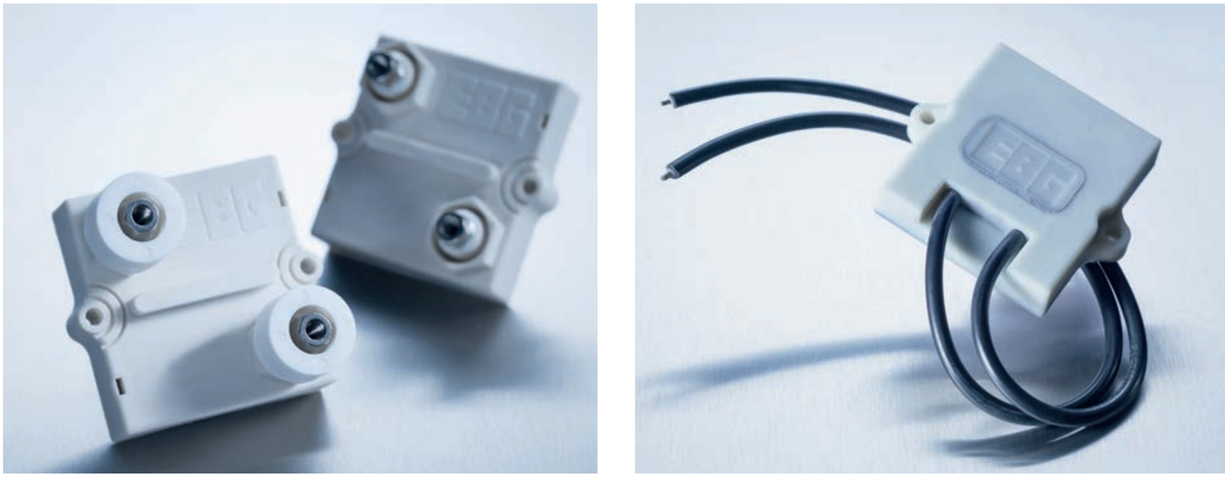


Figure 1: UXP2000 (left) and ULX2000 resistor type for inverter applications

Figure 2: Resistor heat-sink unit for industrial filter application (left), and resistor with preapplied PCM (phase change material)

functionality of the resistor element as well.

High-performance resistor family

The new UXP/ULX 2000 (Figure 1) resistor family is the solution to reduce installation space as well as installation cost, and to contribute to improved TCO of converters and the connected electric motors.

The resistors offers a wide range of unique properties. The outside dimensions are identical with the proven UXP600/UXP800 resistor series, therefore multiplying the applicable power and reducing the installation space by a factor to up to 3.3 versus the standard UXP resistor series. Based on resistor substrate technology, incorporating high thermal conducting ceramics the prerequisite for high performance is given. The resistors withstand typically currents of up to 80 A at a dielectric strength of >20 kV DC combined with a partial discharge capability of up to 8 kV @ 5 pC at resistances down to 0.15 Ω. Similar to the standard UXP series the mechanical features of the UXP/ULX family comprise the baseplate which automatically aligns itself with the heat-sink surface. A wide range of electrical connection options with different electrical contact heights, different insulation lengths, and the option to connect via cables (ULX 2000) is available, too.

An efficient thermal interface to the heat-sink is mandatory to utilize the performance and improvements given by the UXP/ULX200 resistor technology. Proper usage and application of thermal interface material is also a mandatory requirement such as using a high-performance thermal grease. EBG can also offer a TIM based phase change material which is already applied onto the resistors baseplate as per special request, making the UXP/ULX2000 resistors suitable for automated assembly. In addition EBG also offers fully assembled resistor – heat-sink units as well (see Figure 2). The thermal engineering of these assemblies is performed by DAU, a sister company of EBG, and can be optimized for the individual application. Thermal experts at DAU can provide the proper thermal engineering (including CFD simulation) and testing.

Fit for demanding applications

Such heat-sink units are suited for demanding modern industry applications ranging from deep drawing presses in steel working to powering advanced electric propulsion systems in large ships. It is not only the sizing and power level of the UXP2000, also the robustness and performance levels are outstanding, too. An empirical load testing of up to 3000 W did not show any degradation. This makes the EBG UXP/ULX 2000 resistors also the preferred choice for applications where other technologies such as cooled wire wound resistors are normally used.

Because of its small size the UXP/ULX 2000 is easily scalable to be combined to high power resistor units as shown as an example in Figures 2/3. If necessary the integrated heat-sink can be engineered to hold resistors on both sides, making the whole unit still more powerful and further minimizing the footprint.

Accurate Mains Frequency Monitor with Calibration

An AC power mains utility frequency is typically either 50 Hz or 60 Hz. The frequency variation is normally restricted to about +/- 1% in most countries. Variation occurs usually because of varying load on the grid; a higher load causes the frequency to drop and vice versa. The importance of monitoring power frequency is especially important when a local minigrid is set up – such as with solar-powered or wind-powered installations. The inverter in such cases must shoulder the responsibility of monitoring the output power quality. The Silego GreenPAK SLG46620 and a few external components can be used to design a frequency deviation monitor that signals an alert if the frequency deviates by a specified margin.

Ramkumar Ramaswamy, Silego Technology, Santa Clara, USA

In industrial setups that use equipment such as induction motors, it is important to maintain the proper frequency because the speed of an induction motor is a function of the frequency. More elaborate and sensitive setups may use AC drives to maintain the motor speed, but in many situations the motor may be directly connected to the power source without a drive, in which case variations in power frequency directly impact the motor speed.

Broad design strategy

The design is based on measuring the period of the waveform. Many designs use a zero-crossing detector as the basis for period measurement. The mains input is stepped down and half-wave rectified with a few components shown in Figure 1. The rectified pulses are fed to the GreenPAK chip (see sidebar) and used to trigger an analog comparator (ACMP) reading at Pin 12. The ACMP's IN-terminal is held at 50 mV, and when it toggles, it enables a counter which counts pulses from an internal oscillator until the end of the half-cycle. The ACMP's low-bandwidth mode is enabled to prevent spurious responses due to noise. To determine whether the deviation of the mains input frequency is acceptable, two DCMPs are used to compare the output of the counter at the end of the half-cycle with two registers which store the upper and lower bounds of interest. DCMPs are available in the GreenPAK 4 series, such as the SLG46620.

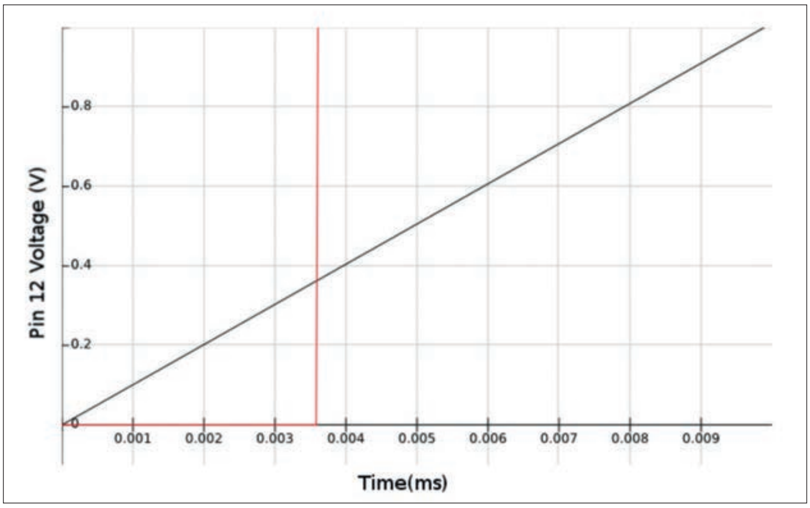


Figure 2: The first few microseconds of a 230 V/50 Hz mains waveform

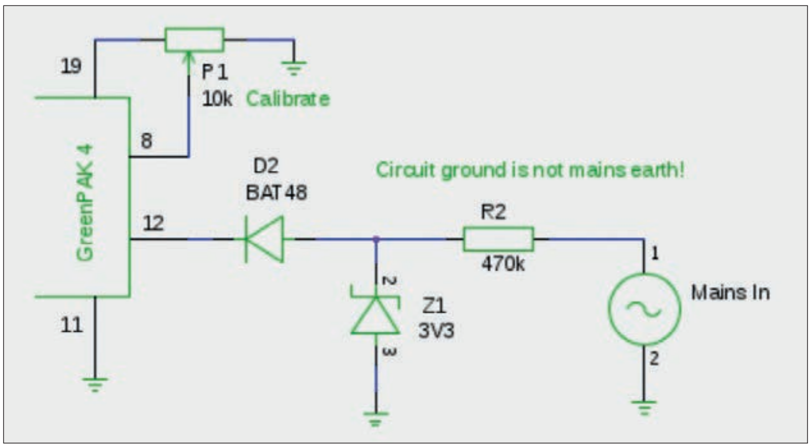


Figure 1: Suggested input schematic

The graph in Figure 2 shows the first few microseconds of the half-wave cycle for a 230 V, 50 Hz waveform (black curve). The error introduced by the use of a half-wave rectifier in the above fashion is quite small. Given the presence of the protective Schottky diode BAT48 at the input, we need a voltage of at most 350 mV to trigger the ACMP. The time taken for the mains voltage to reach a level of 350 mV is about 3.6μs; double that to account for the ramp-down as well, and we have a 0.07 % error which can be neglected in most mains frequency monitoring applications. The output of the ACMP is shown by the red line in Figure 2.

Realization with the GreenPAK designer

Figures 3 and 4 show the GreenPAK

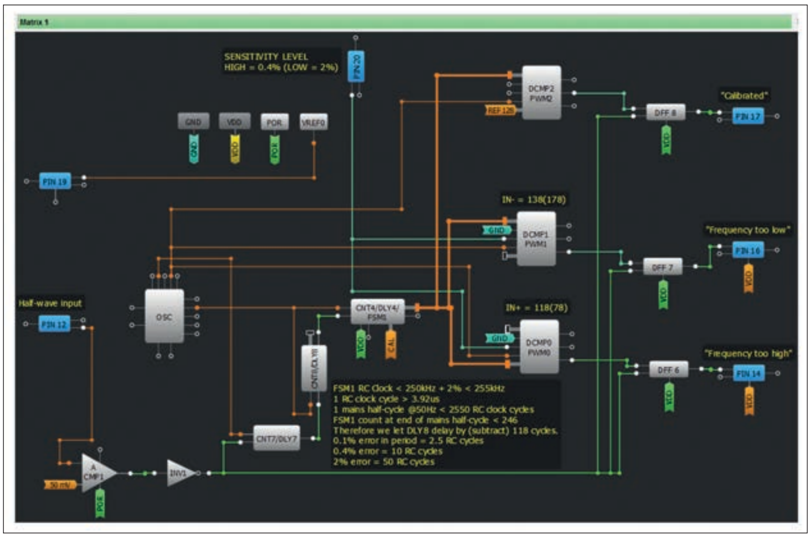


Figure 3: **GreenPAK Design - Matrix 1**

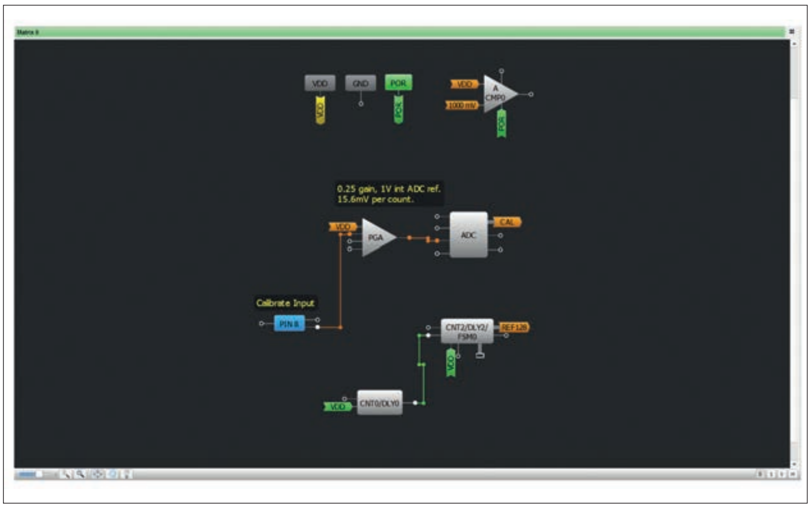


Figure 4: **GreenPAK Design - Matrix 0**

design. The broad idea is to drive the SET input of FSM1 low when the mains half-cycle starts, and bring it back high when the half-cycle ends. When the half-cycle ends, the rising edge produced by INV1 feeds into DFF6/7/8, locking the DCMPs' states into pins 14, 16 and 17 respectively, after which the rising edge (delayed slightly by DLY7), SETs FSM1.

To make the above strategy work in practice, we need to work around a couple of things. Firstly, we note that the GreenPAK 4's DCMP works with 8-bit data, which offers us a resolution of only 1 part in 256. What if we are interested in better accuracy than this? Secondly, the internal oscillator is not as accurate as a crystal oscillator so if we need to keep the external parts count really low we need a method of calibrating the frequency monitor. We will describe how both these are achieved.

Oscillator and counter design

We choose OSC's 2 MHz RC oscillator. The OSC output divisor and the FSM1 clock input divisor are set to 2 and 4 respectively so that the counter frequency is now 2000/8 = 250 kHz (period = 4 μs). Let us see what happens with a nominal mains frequency of 50 Hz, with the half cycle being 10 ms. Suppose FSM1 is configured to count UP with counter data = 0. Then at the end of the 10 ms half-cycle, the Q output of FSM1 will be 10 ms/4 μs = 2500 modulo 256 = 196. Let us call this the "STOP value" for further discussion.

However we now need to take cognisance of the error in the oscillator frequency. From the device's datasheet we see that if the SLG46620 operates at a supply voltage of 3.3 V, the frequency tolerance of the 2 MHz RC oscillator at 25°C is -1.74 % / +1.55 %. Instead of adding an external crystal oscillator, we show how we can institute a calibration procedure to compensate for this variation in an actual implementation.

As a first step towards achieving this, we design things with an assumed OSC frequency that is at the upper end of the range (or a little beyond, to account for minor temperature variations). In other words, we design things in such a way that if the OSC frequency error was +2 %, then the STOP value would be 128, which is the midpoint of the possible range 0-255 of the STOP value. Knowing that the OSC error is actually less than 2 %, what this implies is that the actual STOP value will be (slightly) less than 128. The next step is to have a trimmer external to the GreenPAK which may be tweaked to "push" the actual STOP value to 128 when the input frequency is known to be exactly 50 Hz. This would give us a practical calibration procedure that can be used in the field.

Let us now work out the numbers and calculate the STOP value:

- Assumed OSC RC frequency = 2040 kHz/8 = 255 kHz
- One RC clock cycle = 3.92μs
- STOP value after 10ms = 246
- Delay introduced by DLY8 = 118 cycles
- New STOP value = 246-118=128 which is desired.

Field calibration

When the actual OSC frequency is less than 2040 kHz, the STOP value will be somewhat less than 128. How do we now "push" the STOP value using an external trimmer? Enter the ADC (Figure 4). The ADC takes an analog voltage from Pin 8 and generates a digital value labelled CAL, that is used by FSM1 as its counter data. When the input voltage at Pin 8 is zero, the CAL value is zero. As we increase the voltage, the CAL value increases. Since FSM1 starts counting at the CAL value rather than at zero when it receives a SET signal, the STOP value also increases. We now have the following procedure for field calibration when the input signal is known to be at 50.00 Hz: the Pin 8 voltage is increased slowly from zero till the STOP value touches 128. At that point, DCMP2, whose IN- pin is fed with the constant reference value of 128 generated by FSM0, outputs a signal on its EQ output which lights up an LED on Pin 17 indicating that the unit is calibrated.

The calibraton input voltage for Pin 8 may be conveniently generated by using the V_{REF} macrocell to output a reference voltage of 1 V on Pin 19 and using a trimmer as shown in Figure 1.

Now comes the relatively simple part: deciding what the reference values for DCMP0/1 should be. From the calculations we see that a 0.1 % error in mains frequency amounts to an error of 2.5 in the STOP value. For this application we have chosen selectable sensitivity levels of 0.4 % and 2 %. A 0.4 % error equals 10 RC cycles and 2 % error equals 50 RC cycles. Correspondingly, the lower and upper limits for the DCMPs may be set to 128 +/- 10 or 128 +/- 50 depending on the sensitivity level desired. The sensitivity level is selectable using a LOW/HIGH input on Pin 20 which feed the MTRX SEL inputs of the two DCMPs which select from Register 0-3 into which the corresponding bounds are programmed.

Implementation notes and results

For the most part, the design can be tested with emulation. The emulation signal generator has a resolution of about 1 % so it is possible to test the basic correctness of the design with a sensitivity not greater than 1 %. It is difficult to test a breadboarded unit with mains input because of the stray hum pickup at the ACMP inputs that cause spurious readings. The author has tested this design under emulation where the calibration input to Pin 8 was via emulation, and the waveform input at Pin 12 was from a Tektronix SG502 square wave generator set to 50 Hz. Time periods were verified using a Tektronix DC503A counter reading the time period at a resolution of 0.001 ms. The unit under emulation attained calibrated at a Pin8 voltage of about 440 mV, corresponding to a CAL value of about 28, after which the design worked correctly at both low and high sensitivities.

Conclusion

In this application a simple but useful design for a mains frequency monitor has been described. The design can be used for simple alert or data collection purposes, or can be made a part of a more elaborate feedback loop or changeover/shutdown circuitry in, say, an inverter design. In a real implementation, care must be taken to lay out the circuit and provide adequate shielding so that there is no noise or hum at the ACMP input that could cause spurious triggering and affect the reliability of the unit. A demonstration can be seen at Electronica 2016, Nov. 8-11 in Munich, hall A6 booth 428.

Programming Mixed-Signal Functions

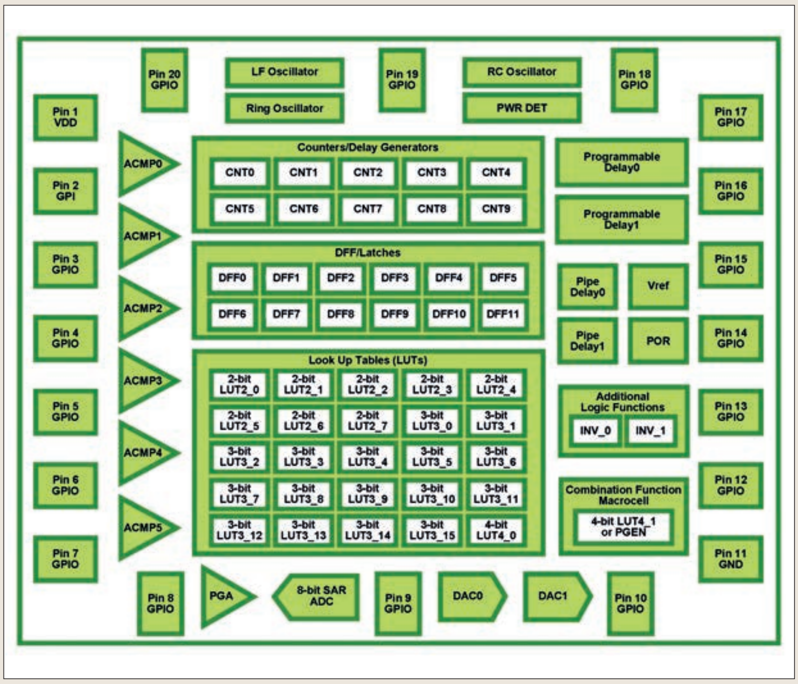
The SLG46620 provides a small, low power component for commonly used mixed-signal functions. The user creates their circuit design by programming the one time Non-Volatile Memory (NVM) to configure the interconnect logic, the I/O Pins and the macro cells. This versatile device allows a wide variety of mixed-signal functions to be designed within a very small, low power single integrated circuit.

The SLG46620 has two Connection Matrices, which are used to create the internal routing for internal digital signals inside the device, once it is programmed. The registers are programmed from the one-time NVM cells during Test Mode Operation. All of the connection points for each logic cell have a specific digital bit code assigned to it that is either set to active “High” or inactive “Low” based on the design that is created. Once the 2048 register bits are programmed, a fully custom circuit will be created.

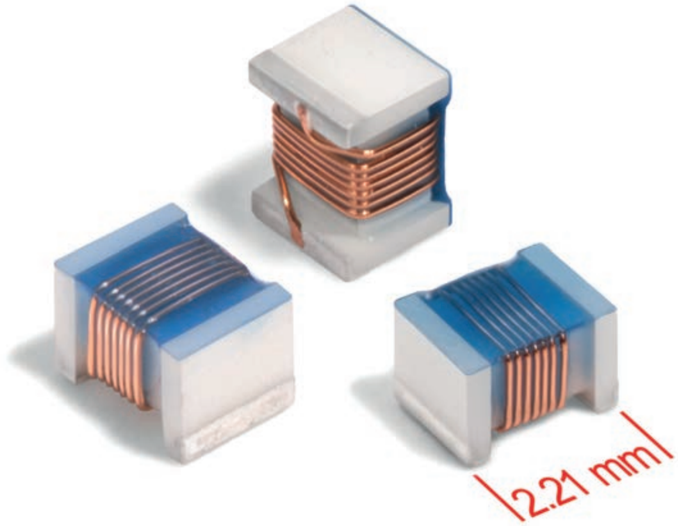
Each Connection Matrix within the device has 64 inputs and 95 outputs. Each of the 64 inputs to each Connection Matrix is hard-wired to the digital output of a particular source macro-cell, including I/O pins, LUTs, ADC, analog comparators, other digital macro-cells and VDD and VSS. The input to a digital macro-cell uses a 6-bit register to select one of these 64 input lines. All

macro-cells associated with a particular matrix has both its inputs and outputs connected to that matrix. To make connections to macro-cells associated with the other matrix, the user can select the Matrix Cross Connection lines. Each matrix has 10 dedicated output connections for connecting to the other matrix, known as the “Cross Connection “outputs. When using these cross connections, any macro-cell can be connected to any other macro-cell in the device by first going through the other matrix. As there is fixed number of the Matrix Cross Connections, it is important when making connections of the outputs of macro-cells to the inputs of other macro-cells that this is done within the same matrix whenever possible. This will leave the Matrix Cross Connection lines free for digital connections to resources associated with the other matrix.

When a design is ready for in-circuit testing, the GreenPAK development tools can be used to program the NVM and create samples for small quantity builds. Once the NVM is programmed, the device will retain this configuration for the duration of its lifetime. Once the design is finalized, the design file can be forwarded to Silego to integrate into the production process.



Block diagram of the SLG46620



High-Current Ceramic Chip Inductors

Coilcraft's new 0805HP Series ceramic wirewound chip inductors offer highest Q factors in an 0805 size at frequencies up to 3 GHz. It is available with 23 inductance values ranging from 2.6 to 820 nH, with 2 % tolerance available for most values. The inductors feature a wirewound construction for highest possible self resonance – up to 9.5 GHz, and offer significantly lower DCR (as low as 15 mΩ) than the previous generation products, making it appropriate for high current applications. The inductors feature RoHS compliant, silver-palladium-platinum-glass frit terminations and offer a maximum reflow temperature of 260°C. COTS Plus tin-silver-copper and tin-lead terminations are also available.

www.coilcraft.com

Small Brake Chopper Resistor

Vincotech, a supplier of power modules, announced a new type of compact brake resistors engineered to absorb higher energy pulses. The Q992-A module for motion control brake chopper applications features thick-film-on-ceramic technology with 4 kV isolation to the heat sink, an ultra-low profile and a fast-on terminal. Resistance value is 400 Ω / 200 W (tolerance 20 %) and 2 kW peak power. The Q992-A is simply mounted to a heat sink using pre-applied thermal interface material, and measures 42.2 mm x 27.86 mm x 6.09 mm.

www.vincotech.com/products.html

OptiMOS Linear FET Series

Infineon Technologies launches the OptiMOS™ Linear FET series. This new product family combines the state-of-the-art on-state resistance of a trench MOSFET with the wide Safe Operating Area of a planar MOSFET. This solves the trade-off between on-resistance and linear mode capability. The OptiMOS Linear FET can operate in the saturation region of an enhanced mode MOSFET. It is suited for hot-swap, e-fuse, and protection applications commonly found in telecom and battery management systems (BMS). Both, the rugged linear mode operation and the higher pulse current contribute to low conduction losses, faster start-up, and shorter down time. The OptiMOS Linear FET prevents damage at the load if there is a short circuit, by limiting high in-rush currents. The OptiMOS Linear FET is available now in the voltage classes 100 V, 150 V, and 200 V. They can be supplied in either a D²PAK or D²PAK 7pin package. These industry standard packages offer a compatible footprint for drop-in replacement.

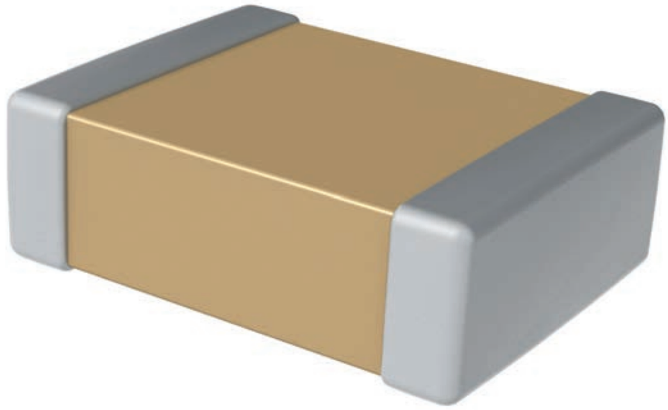
www.infineon.com/optimos-linearfet

Single-Chip Buck-Boost Charge Controllers

Texas Instruments offer a pair of single-chip buck-boost battery charge controllers for one- to four-cell (1S to 4S) designs. The device's USB Power Delivery compatibility offers an input voltage range from 3.5 V to 24 V, which designers can use in multiple ports including USB 2.0, USB 3.0 and the newest standard, and USB Type-C. The bq25703A and bq25700A synchronous charge controllers support charging through USB Type-C and other USB ports in end equipment ranging from notebooks and tablets to power banks, drones and smart home applications. Supporting both I?C and SMBus interfaces, the bq25703Aand bq25700A feature a new advanced battery algorithm enabling full power output by adding intelligence to battery charging through maximum power point tracking technology. The unique algorithm, referred to as input current optimization (ICO), automatically detects the full capacity of input power to optimize current, while maintaining consistent system and charging current to ensure the utilization of maximum input power.

www.ti.com/bq25700A-pr-eu

High-Voltage Multilayer Ceramic Capacitors



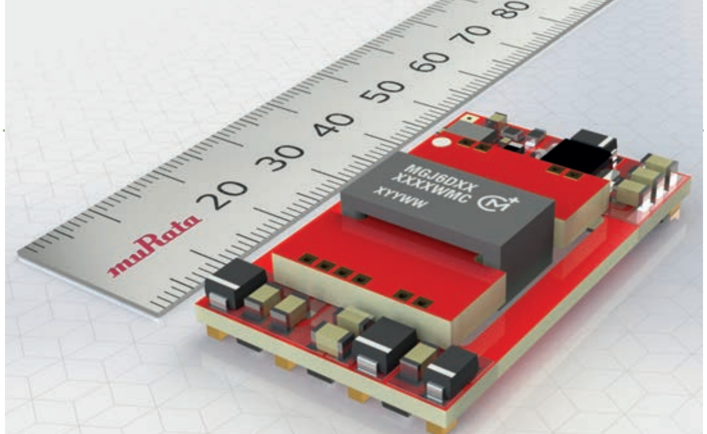
KEMET expands its surface mount high-voltage X7R 0603 Multilayer Ceramic Capacitor portfolio with the addition of the EIA 0603 case size (1608 metric) with C0G temperature characteristics. These devices offer miniaturization while maintaining operating voltages up to 1,000 V DC. KEMET additionally announced extended capacitance ranges in EIA 0805–1812 case sizes. Capacitance availability is now on average three times greater in devices with voltage ratings of 500, 630 and 1,000 V DC. By utilizing patented base metal electrode (BME) technology, the C0G High Voltage series provides superior stability with no capacitance change versus DC voltage and negligible capacitance change over temperature. Available in both commercial and automotive grades in standard and flexible termination systems, this series is Pb-Free, RoHS and REACH compliant.

www.kemet.com/high-volt-mlcc

Quad DMOS Full-Bridge PWM Motor Driver IC

Allegro MicroSystems Europe introduces a new quad DMOS full-bridge driver IC capable of driving up to two stepper motors or four DC motors. Each full-bridge output is rated up to 1.6 A and 40 V. Allegro's A5990 includes fixed off-time PWM current regulators, along with 2- bit nonlinear DACs that allow stepper motors to be controlled in full, half, and quarter steps, and DC motors in forward, reverse, and coast modes. High resolution microstepping control is possible via independent current control reference voltage inputs for each full bridge. The A5990 PWM current regulator features externally adjustable off-time to adapt the current control to supply voltage and motor parameters - each bridge pair can be adjusted independently. The device also features an adaptive percent fast decay (APFD) option which automatically and continuously adjusts the fast decay portion of the off-time to provide increased step accuracy, lower current ripple, and reduced power dissipation. Alternatively it can be set to use the patented mixed decay mode with fixed percent fast decay of 30.1 %. Internal synchronous rectification control circuitry is provided to improve power dissipation during PWM operation. To minimize power consumption when not in use, the device can be put into a low current Sleep Mode. Protection features include thermal shutdown with hysteresis, under-voltage lockout (UVLO), over-current (OCP) and crossover-current protection. Special power-up sequencing is not required. The A5990 is supplied in an EV package, a 6 mm ? 6 mm, 40-pin QFN package with a nominal overall package height of 0.90 mm. The package is lead free, with 100 % matt-tin leadframe plating.

www.allegromicro.com

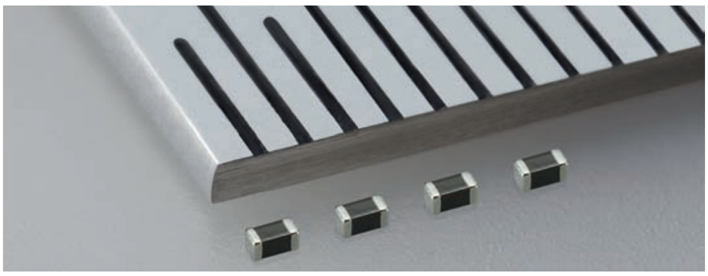


Industrial DC/DC Converters Feature High Isolation

Murata offers a series of high isolation DC/DC converters developed by Murata Power Solutions. The MGJ6 wide, low-profile series converters feature a 14 mm creepage and clearance distance for use in reinforced-rated isolated-gate drive-power applications in higher efficiency 690 V AC industrial electrical distribution systems. This high isolation DC/DC converter series is designed for powering high- and low-side gate-drive circuits for IGBTs and Silicon and SiC MOSFETs in bridge circuits used in motor control applications and industrial power installations. Rated at 6 W, the dual output converters provide a wide 2:1 input voltage range with nominal values of 5, 12 and 24 V, and with output voltages of 15/-10 V, 20/-5 V and 15/-5 V. Suitable for power applications that require a DC link voltage up to 3 kV DC, asymmetric outputs provide an optimum drive level to maintain a high system efficiency with low EMI levels. With their frequency synchronisation-capability and very low coupling capacitance, typically 13 pF, EMC compliance is easier. The converters' compact design reduces board space and development time, whilst their characterized dV/dt immunity of 80 kV/µs gives users confidence in a long service life, and similarly the use of planar magnetics increases product reliability and repeatability of performance. Operating temperature ranges from -40 to 105°C, with derating above 90°C. Typical applications include motor drives/motion control, solar inverters, UPS, alternative energy (wind-power generators), high-power AC/DC conversion, traction, EV/HEV and welding. The series is pending IEC 61800-5-1 approval based on a high working voltage of 690 Vrms maximum between primary and secondary, and similarly is also pending UL approval to UL 60950 for reinforced insulation to a working voltage of 690 V RMS.

www.murata.com

Decoupling Multilayer Ceramic Capacitor



TAIYO YUDEN released the the AMK052 BJ105MR, a 05025-size (0.5 x 0.25 x 0.25 mm) multilayer ceramic capacitor with a capacitance of 1 µF. This product is used in decoupling applications for power supply lines to ICs in devices requiring increased thinness and multi-functionality such as smartphones, or small, thin devices such as wearable devices. The capacitance enhancement technique enables the smallest class 05025-size capacitor to achieve a capacitance of 1 µF at a size that is 42 % smaller than its conventional product, the AMK063ABJ105MP (0.6 x 0.3 x 0.3 mm). Mass production of this product began in June 2017 with 10 million units per month.

www.taiyo-yuden.com

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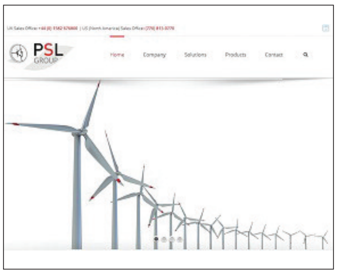

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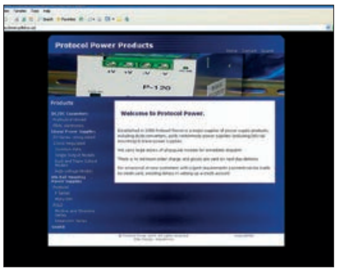

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