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Bodo´s Power Systems®

Electronics in Motion and Conversion

September 2016

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Freedom and Peace,

Most of us live in freedom, and my country has been at peace since I was born. We have only this one world and our duty is to keep it in good shape for future generations. The wars that are raging across the globe must be ended to give the suffering people a perspective of a life in freedom. Those whose only solution is to build fences do not have the skills to be a leader. Is our society gotten so silly as to vote for the noisiest and most crazy politician? Politicians who use their position to threaten freedom and to arrest journalists do not have peace in their mind, and unfortunately, there seems to be an increasing number of them! We must have free journalism to publicize misbehavior. Watergate is an example from the past and we could count more. Civil rights must always be respected.

Terrorism is what we need to fight. We can all help promote economic development in countries with low living standards. Education is the first step in bringing people together to generate understanding and peaceful behavior.

With our work as engineers we have the strength and the power to develop better technology to keep our world in good shape for generations. Many people still believe that nuclear energy is a solution, but that is too simplified an opinion. To get a permit to build a house you need to prove that your dirty water has a connection to go somewhere for treatment. For a nuclear plant, optimists just hope that the future has a solution for nuclear waste. That has been the way the subject has been treated. In the meantime, nuclear waste is being stored somewhere around in the country, in barrels that are corroding and

falling apart. Politicians and nuclear business managers have but a few years in their term, while the waste remains for thousands of years. Some fanciful people have suggested rockets to send this stuff off into the universe. A simple calculation has shown that we will never have enough rockets to send all nuclear waste into space. If just as far as earth-orbit, it could easily return. We already have accumulated too much nuclear waste, and we simply need to stop making more immediately. The best alternative to nuclear is to reduce our overall energy consumption, and to invest in renewable sources.

September is the right time to return refreshed from the summer holidays, and to visit technical conferences all over the world. ECCE will take place in September in the USA and as EPE/ECCE in Germany. I am looking forward to EPE/ECCE in Karlsruhe to see the progress since PCIM. Engineers together, exchanging ideas in conferences, generate progress.

Bodo's Power Systems reaches readers across the globe. If you are using any kind of tablet or smart phone, you will now find all of our content on the new web-site www.eepower.com. If you speak the language, or just want to have a look, don't miss our Chinese version: www.bodospowerschina.com

My Green Power Tip for September:
Pick your own gooseberries from the bush. You can eat them while you pick! There they are as fresh as can be. It'll be an energy efficient experience not to cook them into jam!

Best Regards

Events

EPE ECCE 2016,
Karlsruhe, Germany, September 5-9
http://www.epe2016.com/

ECCE 2016,
Milwaukee, WI USA, September 18-22
http://2016.ecceconferences.org/

LED PROFESSIONAL,
Bregenz,Austria, Sep. 20-22
www.led-professional-symposium.com/

WindEnergy Hamburg,
September 27-30
www.windenergyhamburg.com/

CWIEME Chicago,
MI USA; October 4-6
www.coilwindingexpo.com/chicago

INTELEC 2016,
Austin TX, October 23-27
http://www.intelec.org/

SEMICON Europa 2016,
Grenoble, France, October 25-27
http://www.semiconeuropa.org/

Power Electronics 2016
Moscow, Russia, October 25-27
http://expoelectronica.primexpo.ru/en/

United Silicon Carbide Inc. and ECOMAL Conclude Cooperation

USCi - a leading manufacturer for SiC devices, headquartered in Monmouth Junction, New Jersey - announces the establishing of cooperation with ECOMAL GmbH.
"With over 25 years of experience in distribution, ECOMAL has a strong network within the European power electronics community with a focus on Germany", says Christopher Rocneanu, Director of Sales Europe. "USCi is focused to work with Design In oriented distributors like ECOMAL which are not only selling one product but who are selling the whole system and offer an excellent technical and logistical support to the customer. ECOMAL's technical design center team can make the difference supporting customers in their applications to lower system cost and increase efficiency"
Thomas Steidl, Technical Director Ecomal: "With its leading edge SiC Technology USCi is another perfect partner for us to serve current customer and extend our customer base to new applications. "

The cooperation will cover USCi portfolio of SiC Diodes, JFETs and Cascodes and will be valid for Europe.

www.unitedsic.com

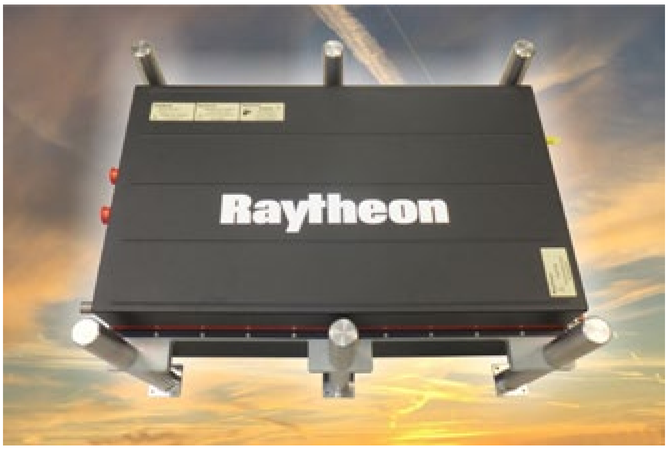
Sales, Marketing, and Technical Support Partner for Europe

To support its accelerating growth throughout Europe, Efficient Power Conversion Corporation (EPC) is proud to announce the appointment of Ismosys as its sales, marketing, and technical support representative. Ismosys, founded in 1994, provides support to design houses, designers and engineers across Europe. This is achieved through 10 regional offices covering the entire EMEA and a significant centralized resource, fostering sales, driving marketing and enabling technical support. "Ismosys has extensive reach and experience throughout Europe in making leading edge electronics available to designers and engineers. Their technical knowledge, along with their ability to provide local support, will provide the personal touch for taking our products to markets throughout Europe," commented Nick Caltaldo, EPC vice president of sales and marketing.
Nigel Watts, Managing Director of Ismosys, noted that, "Our new partnership with EPC is an exciting addition to our portfolio and will allow us to bring leading edge power solutions to Europe. Gallium nitride technologies are an exciting innovation and will enable the design houses we are partnered with and the wider European design community to embrace GaN and produce really exciting, high performance designs."

www.epc-co.com

More Electric Aircraft Journey with Bi-Directional Primary Power Converter

At Farnborough International Airshow, United Kingdom in July Raytheon UK's Integrated Power Solutions (IPS) business unit in Glenrothes, Scotland, has demonstrated a scalable Technology Readiness Level (TRL) 5 primary power converter; supporting the aerospace industry's Electrical Power Systems demands and the More Electric Aircraft (MEA) challenge.



Raytheon UK's demonstrator AC-DC and DC-AC power converter validates many of the technologies needed to meet the More Electric Aircraft challenge.

Scalable to 90kW, this bi-directional non-isolated power supply is capable of converting 3-phase 115V AC generator supplied power into 540V DC (to meet the aircraft's varying electrical load requirements) and also converting DC into 3-phase AC for engine start duty; i.e. the generator becomes a motor. In addition, the converter utilises Silicon Carbide (SiC) power semiconductors, high frequency switching and liquid cooling to minimize size and weight.
"The More Electric Aircraft initiative means less reliance on pneumatic and hydraulic systems and making more use of electricity as a 'common energy carrier'," comments Dr. Grant MacLean, Technical Lead for Power & Control within Raytheon's IPS business unit. "Doing so requires a far more versatile and intelligent power architecture while moving away from the traditional approach of largely one-way power distribution. The More Electric Aircraft also requires more efficient and higher density conversion technology if weight savings are to be realised."
The development of the demonstration converter incorporates technology developed during a series of Aerospace Technology Institute (ATI) / Innovate UK funded projects including the Rolls-Royce led 'Siloet2' project and the Airbus led Integrated Power & Propulsion Architectures (IPPA) project, which is providing aerospace engineers with data to optimise tomorrow's aircraft electrical systems for greater efficiency, minimized emissions and reduced operating costs.
Also, IPPA has brought together UK suppliers for many of the major elements in an aircraft's electrical system, including engines, generators, power distribution and electrical loads (such as motors and actuators).
"Raytheon's role within IPPA has been to help develop a clear understanding of how the More Electric Aircraft's power architecture can be modelled and subsequently optimised" concludes Dr. MacLean. "We're now bringing our power design expertise, which ranges from semiconductor fabrication through to system-wide power architecture modelling, to develop fitforpurpose, reliable and high-density power converters and other products to support the More Electric Aircraft."

www.raytheon.com

Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicle

In France, thanks to its high-tech industries and its research laboratories, the Toulouse area is known to be the largest research hub in the field of aeronautics, space and embedded systems. It was therefore quite logical that the next ESARS-ITEC conference would be held in Toulouse November 2nd to 4th. Experts from industry and academia will present their latest developments in the fields of aeronautics, space, electrical or hybrid vehicles and railway systems. The conference program includes numerous oral sessions, poster sessions as well as industrial workshops. Technical visits are proposed on the last day.

http://www.esars-itec.org

Supplier of the Year 2015 Award

ROHM Semiconductor has been recognized by Continental in the category Broadliner Electronics with the „Supplier of the Year 2015" Award. The highly renowned supplier prize, granted since 2008, rewards outstanding achievements in the production and delivery of products and services. In total, Continental awarded 13 companies, among them two electronic providers, out of 800 strategic suppliers. To determine the winners, the Group executes a comprehensive systematic review based on strictly defined criteria in terms of quality, technology, logistics, costs and purchase conditions.

ROHM received the award during the Supplier Day 2016 in Dresden by Dr. Elmar Degenhart, Executive Chairman of the Board, Continental AG, and Günter Fella, Head of Purchasing at Continental Automotive. „We are delighted to get this award validating our corporate mission and focus on top quality. The prize is both, acknowledgement and motivation to provide high-quality, robust and advanced products as well as best services, in order to support our customers by all means in achieving their business goals," said Christian André, President ROHM Semiconductor GmbH.

www.rohm.com/eu

Modeling and Simulation of Power Electronic Systems, Workshops about PLECS.

Plexim is going to conduct workshops entitled «Advanced Modeling and Simulation of Power Electronic Systems» in Germany. The workshops are free of charge, except Karlsruhe.

05.09. in Karlsruhe
13.09. in Stuttgart
17.10. in Aachen
18.10. in Aachen (main focus Processor-in-the-Loop simulation)

The workshops are designed for engineers to improve and deepen their understanding of

modeling and simulation of power electronic systems. Using presentations, demonstrations, discussions and hands-on exercises, the subject is learned and applied on specific problems.

Importat concepts of the PLECS Blockset and Standalone will be covered, including numerical algorithms, thermal and magnetical modeling and analysis tools.
The workshops contain hands-on exercises. A computer with PLECS Standalone installed will be needed. The PLECS license can be obtained from the Plexim website in advance.

www.plexim.com/events

WindEnergy Hamburg 27 to 30 September 2016

WindEnergy Hamburg, the world's leading expo for wind energy, will be held for the second time from 27 to 30 September 2016. Following the successful premiere in 2014, the Hamburg Fair site will again be the meeting point for decision makers in the energy business from all parts of the world. WindEnergy Hamburg covers the whole value chain of both the onshore and offshore wind industry, and is expanding this year, with an additional exhibition hall. Some 1,200 exhibitors are expected at WindEnergy Hamburg in September, presenting their innovations on some 65,000 square metres, in a total of nine exhibition halls. This global expo will be opened by its patron Sigmar Gabriel, Germany's Minister of Economics. This year, for the first time, the WindEurope Conference will be held in parallel to WindEnergy Hamburg.

http://www.windenergyhamburg.com/

Automotive, Renewables and Power Conversion Strong

Infineon Q3 FY 2016: Revenue €1,632 million; Segment Result €254 million; Segment Result Margin 15.6 percent
Outlook for Q4 FY 2016: quarter-on-quarter revenue increase of 3 percent (plus or minus 2 percentage points), Segment Result Margin 17 percent at mid-point of revenue guidance
Gross margin 36.6 percent, adjusted gross margin 38.1 percent
Earnings per share €0.16 (basic and diluted), adjusted earnings per share (diluted) €0.19

Neubiberg, Germany, August 2, 2016 – Infineon Technologies AG today reported results for the third quarter of its 2016 fiscal year (period ended June 30, 2016).

"Revenue, earnings and margin all increased in line with expectations in the third quarter. Demand was particularly strong for our automotive electronics, renewables and power supply solutions. Despite the current contraction of the semiconductor market and contrary to many of our competitors, Infineon has grown once again compared to the prior year's corresponding quarter, reflecting its focus on sub-markets with structural growth. We therefore continue to forecast a long-term compound annual growth rate of 8 percent," stated Dr. Reinhard Ploss, CEO of Infineon. "We are enabling cleaner and safer cars, greener energy and even faster mobile communication. The planned acquisition of Wolfspeed will secure us a decisive technological advantage in the long term and help us grow our system understanding. We are thereby focusing on promising growth areas such as electromobility and the Internet of Things."

www.infineon.com

CWIEME Chicago now a Three Day Event

After three years of steady growth, North America's leading electrical manufacturing tradeshow is moving from two days to three – allowing more time for visitors and exhibitors to connect, as well as participate in the esteemed seminar program.

This October CWIEME Chicago will return to the Donald E. Stevens Convention Center in Rosemont, Illinois, for not just two but three days of buying, selling, networking and knowledge sharing within the electric motor, generator and transformer manufacturing communities. The move is in response to both visitor and exhibitor demand, backed by a steady increase in participation figures over the last few years. In 2015, the show saw a 10 percent rise in total attendance with a 24 percent increase in OEM representation. This growth shows no sign of slowing in 2016.
"The level of interaction was astounding last year between both the exhibitors and customers," said Hank Pennington, president of Essex Brownell, supplier of wire, cable, insulation and other components to the motor repair, OEM and electronics markets. "We've seen CWIEME Chicago grow over the years and are very excited about the momentum this year. We plan to get a bigger booth to keep this momentum going!"

www.coilwindingexpo.com/chicago

Call for Papers PCIM Europe 2017

Experts from industry and academia are kindly invited to present their latest developments and expectations for future trends at the PCIM Europe 2017 Conference (previously unpublished submissions only). Conference language is English.
Authors are expected to secure registration fee (cut-price) of EUR 330,00 + 19% VAT, travel and accommodation funding through their sponsoring organizations before submitting abstracts. Only original material should be submitted.

Those who wish to offer a technical paper should send their abstract/synopsis by using the online submission form. This has to be filled out exactly to the required information.
All submitted abstracts will be reviewed by the Advisory Board to ensure a high-quality conference. Notification about acceptance will be in January 2017. Submitted papers may be selected for oral or poster/dialogue presentation.
In case of acceptance your final paper will be published in the official conference proceedings. Detailed information and guidelines for preparing and presenting the final paper will be provided with the author's information in January 2017.
Moreover, outstanding presentations will receive one of the PCIM Europe Awards
Submit your abstract by 18th of October 2016.

https://www.mesago.de/en/PCIM/

TRIAC-Dimmable LED Driver ICs Cut BOM Count by 40%

Bleeder-less, highly efficient, robust IC family serves bulbs, tubes and fixtures up to 22 W

By Roland Ackermann, Bodo's Power Systems

Power Integrations, a leading innovator in semiconductor technologies for high-voltage power conversion and leader in high-efficiency, high-reliability LED driver ICs, announced its LYTSwitch-7 single-stage, non-isolated, TRIAC-dimmable, buck topology LED driver IC family end of July. These LED driver ICs provide a highly robust solution while requiring a BOM count that is approximately 40% less than for conventional circuits.

Capable of delivering up to 22 watts without a heatsink in a very small SO-8 footprint, these high-efficiency devices are suitable for bulbs, tubes and fixtures. LYTSwitch-7 designs do not require bleeders; employing simple, passive damping for TRIAC management and an off-the-shelf, single-winding inductor, reducing component count to just 20, as compared to approximately 35 parts for typical dimmable LED driver boards. The internal 725 V MOSFET delivers better withstand performance during line surges, while the bleeder-less design has high TRIAC compatibility but does not produce wasted heat, resulting in a more efficient and reliable driver.

LYTSwitch-7 ICs deliver a phase-cut (TRIAC) dimming solution with a wide dimming range and monotonic dimming response in the 10:1 range. It is characterized by its advanced thermal performance – the lamp provides light output in abnormal ambient conditions with the wide hysteresis following shutdown. The LED drivers enable efficiency of greater than 86% - around 2% higher than conventional dimmable products – with high PF, accurate regulation and comprehensive protection. They suit low- or high-line input as well as wide-range universal-input designs for U.S. commercial lighting applications, which operate from 90 VAC to 305 VAC with TRIAC dimming enabled in low-line installations.

LYTSwitch-7 is a constant-current device – power delivery is dependent on load voltage. The family consists of two parts: LYT7503D and LYT7504D, both housed in a SO-8 "D" package, MSL-1 rated. It features a very low EMI with a quiet (source potential) heatsinking, boundary-mode and low-side architecture (with a high-side architecture coming soon), a wide input range with excellent line regulation, and an accurate OVP reduces stress on O/P capacitor. As it is self-biased, low-cost off-the-shelf magnetics can be used. The low VF current measurement increases efficiency. Comprehensive protection includes over-temperature fold-back, end-stop thermal shutdown, O/P over current short circuit, line OVP, output OVP and open/short IC pins.

A sophisticated proprietary algorithm provides a high power factor (PF) with accurate regulation and best protection:

- Accurate CC across line, load and production
- Simple geometric control maintains CC
- Line-noise rejection in current-limit mode
- High MOSFET utilization factor - best use of integrated MOSFET
- Small buck power inductor: single winding allows the use of off-the-shelf parts
- Small EMI inductor (low EMI): boundary mode, quiet source pin cooling, low-side.

Like all Power Integrations LED drivers, LYTSwitch-7 ICs have a host of protection features including thermal foldback with end-stop shutdown, which protects the IC, driver and fixture at abnormally-high ambient temperatures by automatically reducing the current flow and dimming the lamp. Developers find that thermal foldback is the key to reducing costs associated with over-design of both electrical and mechanical components to meet reliability goals since the IC automatically limits unusual temperature excursions without extinguishing the lamp. Devices are also protected from open- and short-circuit conditions, input and output OV, overcurrent and SOA. LYTSwitch-7 ICs meet international standards including: DOE Level 6 (external power supply), CEC Titles 20 and 24, ENERGY STAR® Lamps Program Requirements Version 2.0, NEMA SSL-7A and EN61000-3-2 (C&D).

Key applications include low-cost A19 lamps, small-form-factor lamps such as candle-style and GU10 bulbs, commercial & industrial applications, ceiling lamps and downlight fixtures. LYTSwitch-7 IC samples are available now. Devices are priced at $0.33 in 10,000-piece quantities. Two reference designs (DER-539 and DER-540) are available for download now from the Power Integrations website at https://www.power.com/lytswitch-7.

Summary

The newly introduced LED drivers LYTSwitch-7 ICs combine the following features:

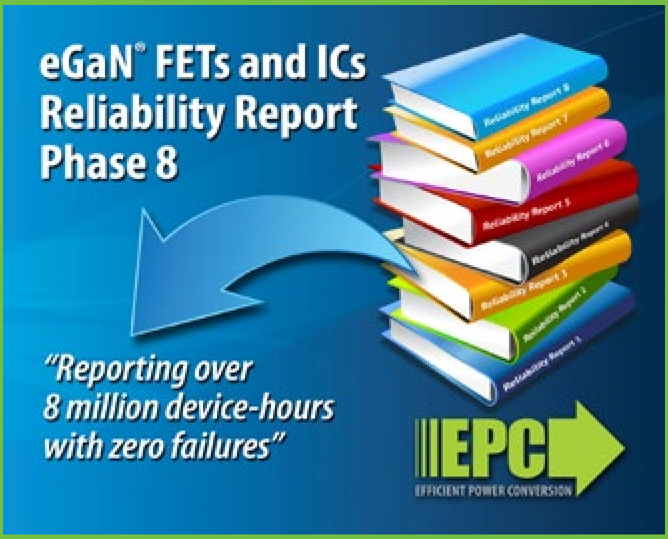
- Excellent performance
- Better than 0.9 power factor
- 86% efficiency at 230 VAC
- Deep and monotonic dimming response
- Supporting universal input with 120 VAC dimming for U.S. market
- Regulation better than ±3% across a wide range of line and load
- Simplified BOM
- Lowest total component count (20 components)
- Dimmable without a bleeder
- Single-sided PCB
- Off-the-shelf magnetics
- Up to 22 W with a thermally efficient SO-8 package
- Highly flexible and reliable
- High-side/low-side buck conversion
- Surge resistant with line OV protection
- Integrated accurate input and output OVP, SC, OC, over-current, pin short/open
- Thermal foldback with end stop shutdown
- TRIAC dimmable up to 22 W
- Compatible with standard TRIAC dimmers
- Linear and monotonic dimming
- 90 VAC to 305 VAC input, dimmable at low line
- Highly cost-effective
- Bleeder-less solution
- Standard off-the-shelf magnetics (no bias winding)
- Only 20 total components, small SO-8 package
- 725 V integrated MOSFET enhances surge reliability
- Integrated protection features
- Line overvoltage - surge protection for LED load
- Overcurrent and short-circuit
- Thermal fold-back with end-stop thermal shutdown.

www.power.com

Documenting GaN Technology Reliability after Millions of Device Hours of Rigorous Stress Testing

EPC Phase Eight Reliability Report documents a combined total of over 8 million GaN device-hours with zero failures. The report examines, in detail, the stress tests that EPC devices are subjected to prior to release as qualified products and analyzes the physics of failure.

EPC announces its Phase Eight Reliability Report showing the results of the rigorous set of JEDEC-based qualification stress tests eGaN FETS and integrated circuits undertake prior to being considered qualified products.



In this report, product-specific detailed stress test results for over millions of actual device hours are provided. In addition to product qualification stress testing, due diligence is necessary in other areas of reliability such as field experience, failures over device operational lifetime, and board level reliability. More specifically, the three sections of tests covered in this Phase Eight Reliability Report are:

I: Field Reliability Experience
- Field Failures Examined
- Assembly Failures
- Applications Failures
- Intrinsic Die Qualification

II: Early Life Failure and Wear-out Capability
- Early Life Failure Rate
- Electromigration

III: Board Level Reliability and Thermo-mechanical Capability
- Intermittent Operating Life
- Temperature Cycling
- Board-Level Reliability

This report, coupled with the excellent field reliability of eGaN FETs and ICs given in the Phase Seven Reliability Report, which documented the accumulation of over 17 billion device operation hours combined with a very low failure rate below 1 FIT (failures per billion hours), demonstrates that the stress-based qualification testing is capable of ensuring reliability in customer applications. The cumulative reliability information compiled shows that eGaN FETs and ICs have solid reliability and are able to operate with very low probability of failures within reasonable lifetimes of end products manufactured today.

According to Dr. Alex Lidow, CEO and co-founder of EPC, "Demonstration of the reliability of new technology is a major undertaking and one that EPC takes very seriously. The tests described in this report, along with the reported results, show that EPC gallium nitride products have the requisite reliability to displace silicon as the technology of choice for semiconductors."

About EPC

EPC is the leader in enhancement mode gallium nitride based power management devices and was the first to introduce enhancement-mode gallium-nitride-on-silicon (eGaN) FETs as power MOSFET replacements in applications such as DC-DC converters, wireless power transfer, envelope tracking, RF transmission, power inverters, remote sensing technology (LiDAR), and class-D audio amplifiers with device performance many times greater than the best silicon power MOSFETs.

www.epc-co.com

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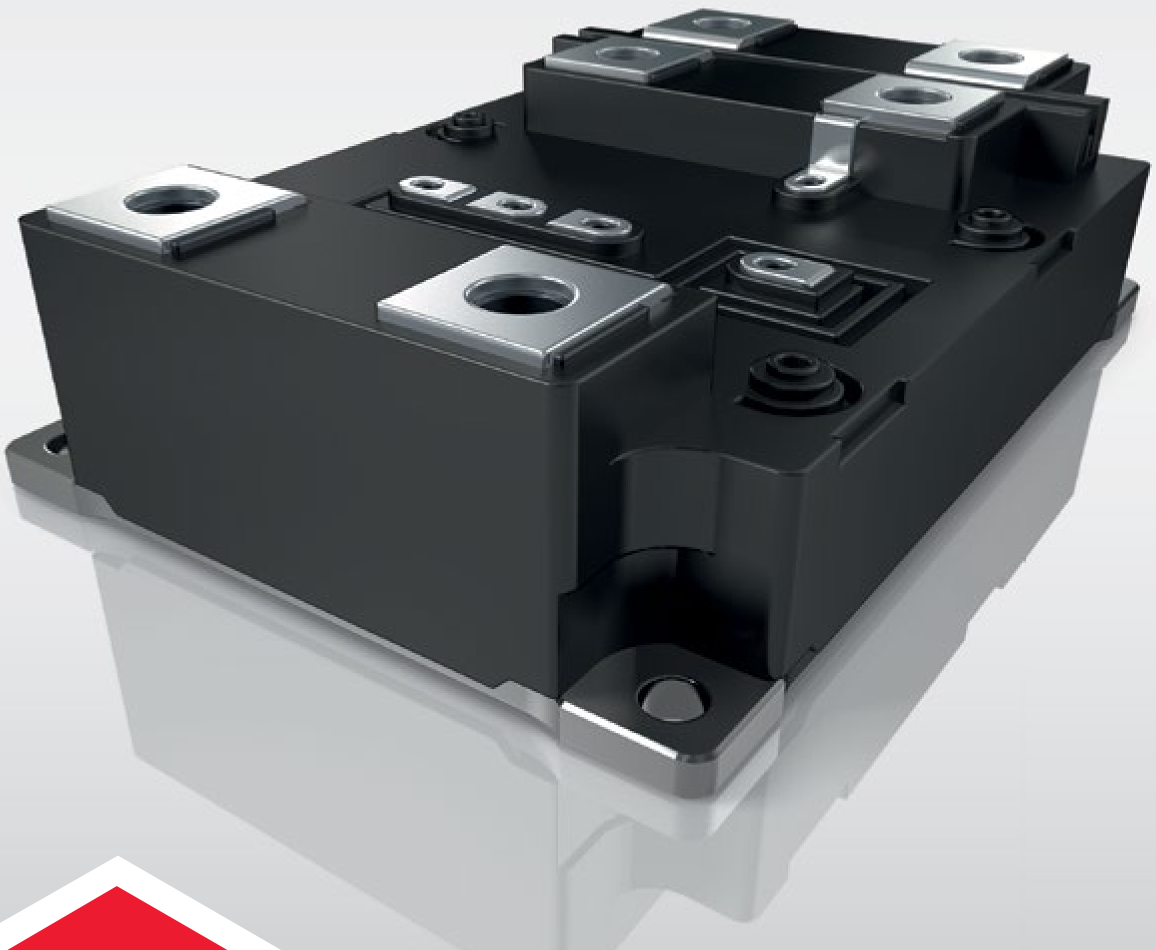

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Keeping Technology Current in the Changing World of Power Electroinics

By Dr. Chris Hewson, CEO, Power Electronic Measurements (PEM) Ltd.

'Why isn't there a simple to use wide-band current probe for power electronics?' was the question that two successful power electronics professors, turned entrepreneurs, asked back in 1991. The two colleagues began to scratch an itch that had been a background irritation for over 30 years.

Rogowski coils seemed a suitable candidate. The technology first described in a paper in 1911 was potentially wide-bandwidth, had limitless current capability independent of the size of the probe and could be built with a thin clip-around coil making it easy to get a measurement in difficult to reach parts of a power converter. Some innovative design, a first patent, a student project, a technical paper and a successful prototype later the two colleagues formed Power Electronic Measurements (PEM) Ltd, wondering if this technology would be of interest to any other engineers in the field of power electronics?

What they didn't foresee is that 25 years later PEM would still be at the forefront of the design and manufacture of wide-band current sensors. As this technology developed the power electronics industry continued to grow beyond all recognition. Power electronics is now embedded in power utility and transmission, renewable power generation, industrial processes such as induction heating and welding, traction applications and electric vehicles. Somewhere in the process of design and development, converter control, product approvals or diagnostics, current measurement is required and each application presents its own distinct set of challenges to the current sensor manufacturer.

Rogowski technology is just one among many methods of current measurement competing for the power electronic engineer's attention. Current transformers (CTs) offer high bandwidth and isolation, combination Hall effect and CT current probes offer wide bandwidth and DC current capability. Shunts range from low cost highly accurate devices to co-axial shunts offering GHz capability and Fluxgate sensors, though bandwidth limited, offer exceptional accuracy. Each has their place in power electronics. However, manufacturers of all these technologies are challenged with keeping their technologies relevant a world where power electronics increasingly infiltrates all areas of engineering and commands vast budgets ushering in rapid change.

One such example of rapid change in power electronics is the challenge posed by the introduction of GaN and SiC switches. For Rogowski probes these new semiconductor technologies help drive new product improvement. Twenty five years ago a 10mm thick, unscreened, semi rigid coil, with a 1MHz bandwidth was state-of- the art. Now, engineers using such a probe to measure a current transient in a SiC device would observe a burst of noise on an oscilloscope rather than an accurate representation of a current waveform. Rogowski probes still offer ease of use, and incredibly low insertion impedance, but to stay relevant significant improvements have had to be made;

- Rejection of common mode interference from close coupled capacitive interference due to voltage transients >> 20V/ns, whilst retaining high frequency capability and accuracy with conductor position in the sensor loop
- Maintaining accurate operation from -40 to +125degC with repeated thermal cycling
- Measurements of rise times of 10 to 50ns with good fidelity and predictable delay for power measurements
- Significant size reduction as semiconductor package sizes shrink

But of course there is still much to do. GaN demands even higher bandwidths and smaller coils and these solutions can't take 25years as the pace of GaN take up accelerates.

However, it is not just a case of smaller and faster. Other measurement problems can occur, often unforeseen by engineers pushing for ever more performance. For example, over the past 15 years in motor drives the installation of VSDs with faster switches operating at higher voltages has had unforeseen consequences for bearings. Harmonics created by these switching phenomena can induce high frequency leakage currents in the machine shaft causing the bearings to heat and lifetime to rapidly degrade. Tracking these leakage currents is not easy. There is interference from strong magnetic power frequency fields and a large machine shaft requires a sensor with a very big aperture that retains the ability to measure spikes of current of a few Amps with sub μs duration. Difficult, but ideal for a carefully designed Rogowski probe. As measurement manufacturers we are always listening to the problems of engineers and advising on how our technology can solve a given measurement problem.

Once that first 'production' Rogowski probe was built and began to sell, we sat discussing our future and briefly considered what technology we should tackle next. Ideas about speed sensors were considered – perhaps commercialising some of the large current test sets that we had developed? But it didn't take long before power electronic engineers began to explain their particular set of challenges, 'could you customise your probes for induction heating, we have a protection application that needs volume but lower cost, we have a new semiconductor device that needs a higher bandwidth', were some of the challenges. Twenty five years later and we're still pursuing smaller, faster more accurate Rogowski probes but continuing to listen to engineers explain their new applications and directions to take this flexible technology……and we still haven't got around to developing those speed sensors.

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www.pemuk.com

Wide Bandgap Now

By Dan Kinzer, COO/CTO, Navitas Semiconductor

Five years ago, in this column, I wrote an editorial entitled, "When Wide Bandgap?"[1] In that piece I predicted, "The key to success in silicon carbide (SiC) is to accelerate the cost and material defectivity learnings, expand substrate and epitaxial capacity, and to transition to 150mm diameter." In addition, "The key to success in gallium nitride (GaN) is improved high volume and lower cost MOCVD processes on silicon in the 150mm to 200mm range, with device and material designs that can withstand the high operating voltage and surface electric field stresses," predicting successfully that this would happen in the next 2-3 years. Cost is still an issue, especially for SiC materials but there are still tremendous opportunities for cost learning through material and system improvements, and economies of scale.

Not everything happened as predicted. While there are still proponents of the BJT, the focus has been to advance the state-of-the-art SiC power MOSFET. Vertical GaN devices have not flourished as wafers are too small, too expensive and the devices are extremely difficult to fabricate. For applications above 1KV, SiC is the way to go.

I concluded, "As system designers learn to use the high frequency capability… system performance, size, and cost advantages will emerge and drive a gradual shift in the industry through the rest of this decade and into the next." The shift has begun, with WBG representing 1-2% of the power market. Now, the time has come for WBG to break strongly into the market and displace Si in multiple applications.[2] In fact with GaN, revolutionary - not evolutionary - changes are now happening that were not predicted.

System designer learning was not the barrier; tools were lacking. Mainstream controllers and magnetic materials continued to be designed for frequencies around 100 kHz. The market asked for efficiency and low cost, and the system designers delivered. When Si switches and drivers were pushed to higher frequency in existing topologies attempting to achieve higher density, the power losses increased unacceptably. Even the early wide bandgap devices were hard to drive, difficult to use, and lacking evidence of reliability.

Power density - the reduction of size - has become a major selling point. Today, 1MHz+ controllers are becoming widely available to support proven, accepted, soft switching topologies. 1MHz+ magnetic materials are available in traditional wire wound and PCB-embedded planar winding configurations. Critically, lateral GaN power devices are now available and operate at those frequencies, at higher efficiency than the low frequency conventional designs. They are reliable, volume production ready, and cost effective. Moreover, GaN power integrated circuits have emerged that are extremely straightforward to drive, because input is no longer high current analog, but low power digital.

AllGaN™ is the industry's first eMode GaN Power IC process, allowing monolithic integration of 650V GaN IC circuits (drive, logic) with GaN FETs.[3] This is an impossible dream for superjunction Silicon MOSFETs, dMode GaN, or SiC with their complex, expensive gate drive and protection systems which restrict switching frequency. With AllGaN, the GaN FET gate is driven safely, precisely and efficiently by the upstream integrated GaN driver. Simple, robust, low-current digital signals, from standard, low cost, low voltage 'no driver' control ICs are fed directly into the GaN Power IC for a simple, low component count design. Waveforms exhibit a true "text book" feeling with very clean rising and falling edges, no ringing, and extremely fast turn-on and turn-off propagation delays. Integration eliminates gate overshoot and undershoot, while zero on-chip inductance ensures no turn-off loss and tight control of deadtime in half-bridge circuits. The internal gate drive voltage can be precisely controlled, and even the turn on speed can be programmable.

How does AllGaN™ performance translate into real-life application benefits? High critical electric field capability means reduced device dimensions, smaller die size, lower capacitances and lower losses. In turn, less cooling is needed and converters use smaller magnetic components, leading to large savings in application size, weight and cost. The eMode HEMT device relies on electron current exclusively, so there is no recovery loss in switching and integrated gate drive enables 1MHz operation easily. In a 150W adapter example, a small step from switching at 65/100kHz to 300kHz with 650V GaN Power ICs in a 'CrCM PFC plus LLC' topology yields a 2x increase in power density compared to best-in-class Si-based systems.[4] For 25W smartphone / tablet chargers, GaN Power ICs in a soft-switching active clamp flyback achieves 70% more power density than benchmark Si designs.

Additional GaN Power IC features, expanded voltage and current capabilities are forecasted. Combined with controller and magnetic advances, lateral GaN will deliver unprecedented and cost-effective performance, driving the rapid and widespread adoption of this fantastic new technology.

www.navitassemi.com

(Endnotes)

1 "Wide Bandgap When?" D. Kinzer, Bodo's Power Systems, Sep 2011. http://www.bodospower.com/restricted/downloads/bp_2011_09.pdf

2 "Adoption of Wide Bandgap Power Devices Increases", A. Bhindra, IEEE Electronics 360, July 2016. http://electronics360.globalspec.com/article/7054/adoption-of-wide-bandgap-power-devices-increases

3 "Breaking Speed Limits with GaN Power ICs", D. Kinzer, plenary APEC 2016, http://www.apec-conf.org/wp-content/uploads/APEC-2016-Plenary-3rd-Speaker-Dan-Kinzer.pdf

4 "Make it Easy, with GaN Power ICs", T. Ribarich, Bodo's Power Systems, May 2016, http://www.bodospower.com/restricted/downloads/bp_2016_05.pdf

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- Offered in an ultra-compact 6.5 mm x 9 mm package, the **high efficiency fully integrated ISL8203M** can be configured as a dual channel 3A or a single channel 6A power module. Supporting parallel operations for 12A+ output currents, the ISL8203M is so flexible that it reduces your design time for virtually all your low power point of load designs.

With complete fault protection for long-term reliability, fast transient response, adjustable soft start and more, we've got your power supply needs covered.

Output current	$33.75mm^2$ QFN22 4.5x7.5mm 1.85mm height	$58.5mm^2$ QFN23 6.5x9mm 1.85mm height
3A	ISL8202M	ISL8203M
5A	ISL8205M	
6A		ISL8203M
12A+		ISL8203M x 2+

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VIP Interview with Steve Sanghi, CEO Microchip

By Henning Wriedt, corresponding editor Bodo´s Power Systems

CEO Steve Sanghi, Microchip Technology, Inc.

Henning Wriedt: Mr. Sanghi, you are the CEO of Microchip Technology for 25 years - Congratulations! In a nutshell, what happened in the MCU market since 1991 regarding specifications and market developments?

Steve Sanghi: Microchip was founded in April 1989 as a spin-off of General Instruments' semiconductor division. Annual revenue in 1989 was ~$65M, and our annual revenue in our most recent fiscal year was ~$2.2 Billion.

A lot has happened in the MCU market since 1991. First, almost the entire market has converted to field programmable MCUs. In 1991, the majority of the market was based on ROM based MCUs that were programmed in the FAB using a mask. Microchip brought the first cost effective field programmability to the market in 1990 and today if you don't have field programmability, you are not a player.

Beyond that, the MCU market has seen multi-dimensional progress in photolithography, compute performance, integration of analog, small package sizes, C+ programming language versus assembly language in 1991, integration of MCU with peripherals (like USB, Ethernet, display drivers, IR, Wireless protocols, power management etc) and multi-chip modules.

From a market standpoint, there has been a tremendous growth in the MCU market in automotive, industrial, PCs and tablets, mobile phones, communication, medical and consumer end markets.

With a predominant focus on the MCU market, but also including analog, Microchip has achieved 102 consecutive quarters of profitability, something that no other semiconductor company has been able to achieve. For long time, our vision has been that you can take any end product, and either it has a MCU or should have one to add connectivity, security or intelligence to the device.

Figure 2: Microchip Headquarter in Chandler, Arizona

Henning Wriedt: Microchip bought 12 companies during the last 14 years. Is this M&A strategy the best strategy to stay current with customers, technologies and markets?

Steve Sanghi: As the semiconductor industry consolidates, Microchip continues to execute a highly successful consolidation strategy with a string of acquisitions that have helped to double our revenue growth rate compared to our organic revenue growth rate over the last few years.

The Atmel acquisition is the latest chapter of our growth strategy and will add further operational and customer scale to Microchip. Both companies have a strong tradition of innovation, stretching across microcontroller, analog, touch, connectivity and memory solutions. Joining forces and combining our product portfolios will offer our customers a richer set of solution options to enable innovative and competitive products for the markets they serve.

Our corporate guiding values include "Customers are our focus," and "Employees are our greatest strength." Each time we complete an acquisition, it allows us to better serve our customer base with a more complete portfolio and we add tremendously talented employees and their innovations.

Henning Wriedt: What are your strategic plans regarding wireless technologies?

Steve Sanghi: Wireless-connectivity continues to proliferate, and our efforts here are focused on providing unique and complete solutions that provide true ease of use, as well as rapid implementation that covers all of the major standards.

Microchip has a broad portfolio of wireless solutions including Bluetooth and WiFi along with new standards such as LoRa. Microchip's RN2483 LoRa module was the world's first module to pass the LoRa Alliance's LoRaWAN Certification Program. We were also the first to deliver LoRa evaluation kits with everything needed for a developer to create a LoRaWAN network right at their desk.

Henning Wriedt: How is the market acceptance of MPLAB Xpress, your cloud-based development platform?

Steve Sanghi: Today, all Microchip 8-, 16- and 32-bit PIC microcontrollers and dsPIC digital signal controllers are supported by a singular integrated development environment—the free MPLAB X IDE. MPLAB Xpress, the cloud-based development platform for 8-bit MCUs, brings the most popular features of MPLAB X IDE to Internet-connected PCs, laptops or tablets, has been extremely well received, especially by customers who are new to Microchip.

To date, MPLAB Xpress has been immensely successful, with over 17,000 unique users and 34,000 software projects begun since February 2016. In addition, we have seen strong demand for the

IDE's recently launched companion hardware, the MPLAB Xpress Evaluation Board. With plans to expand support for our 16-bit MCUs in July of this year, we expect continued success of our cloud-based development.

MPLAB Xpress is the easiest way to get started with PIC microcontrollers with zero downloads, sign-in or setup needed to start designing. It is free and users can access a library of Microchip-validated code examples and interface to MPLAB Code Configurator (MCC) for GUI-based MCU peripheral setup and automatic code generation. Additionally, the MPLAB Xpress Community enables developers to share their code, design ideas and knowledge.

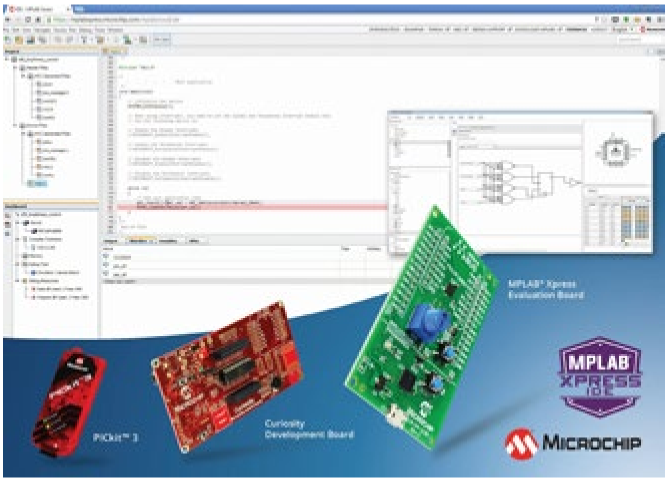

Figure 3: Screenshot of MPLAB Xpress

Henning Wriedt: Is IoT still hype or real business for Microchip?

Steve Sanghi: It is definitely real business for Microchip and our customers are creating new and exciting products daily. However, Microchip customers have been making connected devices for years. Smart, connected devices are growing and it's been given a clever name, IoT, but the activities have been going on for many years.

That said, we are not significantly dependent on any specific market, customer or application. Our existing customers are looking to enable IoT functionality in their products. The existing devices from Microchip, such as 8, 16 and 32-bit PIC microcontrollers, analog, mixed-signal, memory and embedded Wi-Fi and Bluetooth modules are already well situated to enable IoT functionality.

In addition, there are emerging products and applications that can take advantage of Microchip's flexible development environment, broad connectivity solutions and product longevity. We are also engaged with IoT ecosystem partners such as cloud providers to help our customers get to market. One of the challenges I see around IoT is security and privacy.

This is also at the forefront of consumers' minds. Companies creating products in the IoT market need to make certain that they can reassure their customers of data robustness, security and privacy, as well as the secure functionality of the device. We are creating and introducing products for this very purpose.

The recent acquisition of Atmel will continue to strengthen our portfolio by adding 32-bit microprocessors and additional security devices such as the ECC508A that integrates ECDH (Elliptic Curve Diffie–Hellman) security protocol—an ultra-secure method to provide key agreement for encryption/decryption, along with ECDSA (Elliptic Curve Digital Signature Algorithm) sign-verify authentication suitable for many applications outside IoT as well.

Figure 4: The MCP87000 family of high-speed MOSFETs maximizes the power conversion efficiency in switched mode power supplies.

Henning Wriedt: What is the status of your MOST technology?

Steve Sanghi: Microchip is dedicated to MOST networking, and the team working on this technology continues to drive it into the future with the added expertise that Microchip brings to the table. MOST continues to expand to all car sizes and manufacturers across the globe.

We recently announced MOST technology is now in the global compact car platform for GM that includes the Chevy Cruze, Chevy Volt, Opel Astra, Buick Excelle and Buick Verano.

MOST networking technology is in compact, mid-size, full-size, performance, cross-over and SUV, truck and luxury platforms and is the de-facto networking system standard for 30 global car maker brands and over 204 vehicle models. MOST-based vehicles are now being manufactured worldwide, including North America, Asia and Europe.

MOST has been built from the ground up, in cooperation with automakers and their premier suppliers, to address the special challenges that result from the more extreme environment and long lifecycles required of automobiles. Microchip is 100% committed to its future.

Henning Wriedt: How do you judge the importance of Wide Band Gap Power Semiconductors?

Steve Sanghi: Today, wide band gap semiconductors have very limited adoption outside of a few niche applications. That is the reality, due to the cost of the devices and the stage of technology development. They could grow. These technologies have great potential in high power applications with critical efficiency requirements, but at the same time they will never displace silicon for general use electronics.

When we design our control and drive solutions, we certainly think about the kinds of loads our customers will be using, and some of our customers do use wide band gap devices in their systems alongside Microchip products. However, the broader market really isn't there yet.

Henning Wriedt: What role does power electronics play for renewable energy and electric cars?

Steve Sanghi: Electric cars and renewable energy are complex power electronics. The semiconductors don't just play a role, they define the capabilities of the end product. The electric vehicle, or even hybrid electric vehicle, is more of an electronic system than a mechanical system.

Similarly, solar power (and other distributed renewable systems) requires networks of power conversion to intelligently squeeze out as much energy as possible. The leaders in these markets will be the companies with better electronics. At Microchip, we are actively helping our customers control and drive these applications. They are very exciting, dynamic markets.

Henning Wriedt: From the smartphone to the automated factory, power management is an ongoing challenge for the system designers. How does Microchip help?

Steve Sanghi: We help in many ways. Microchip has a very large power offering, everything from tiny boost converters for battery powered portable applications, to dsPIC DSC solutions for bus balancing in electric vehicles. We have reference designs, evaluation boards, application notes, and field experts in all areas of power electronics.

We even have code examples and code generation tools for digital power control with our PIC microcontrollers and dsPIC DSCs. Microchip makes some of the most innovative power management solutions available today.

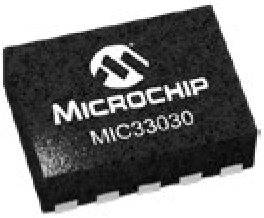

Figure 5: The MIC33030 is a high-efficiency, 8 MHz, 400 mA synchronous buck regulator with an internal inductor and HyperLight Load® mode.

Henning Wriedt: About half of your revenue flows through the distribution channel. Does that limit your marketing access to your customers and their feedback?

Steve Sanghi: Just the contrary. We work with them in partnership to meet customer needs and support and hear from channel partners regularly. Microchip is highly diversified, with more than 90,000 customers and countless applications—our top 10 customers make up less than 10% of our business, and no one customer is more than 3% of our business, so channel partners are important.

However, we also have unmatched internal support and a worldwide sales team to obtain feedback. In fact, we have the semiconductor industry's only non-commission sales force, which is focused on meeting customers' needs instead of territorial design wins. They are a critical source of information and feedback.

Henning Wriedt: From which sectors of the electronics market do you expect major growth?

Steve Sanghi: As I look forward, I see significant growth drivers coming from the following markets and applications: automotive (smarter, connected, self- driving and electric cars); energy efficient and connected appliances; medical instruments; and, for the risk of using buzzwords, Internet of Things (IoT). Over time, more and more things will keep getting connected and wireless connectivity with the MCU will be a necessary feature to play in the MCU game.

Henning Wriedt: What is your take on the so called 'chip consolidation' - or is this kind of phenomenon always around?

Steve Sanghi: I don't know whether you mean "chip integration" or you mean the consolidation of the industry. So, let me address both.

The chip integration has been going for 35 years. Today a high end microcontroller has a CPU, memory, analog, power management, interface peripherals, I/O ports and all the firmware needed for control. It is in fact a computer on a chip. The amount of integration will continue to increase. Multi-chip modules will take this integration much farther as we are able to combine chips built of dissimilar technologies in a single module.

Regarding the consolidation of the industry, it is a by- product of slowing growth in a mature industry. In an industry of $350B a year, there seems to be no visible new killer market that will accelerate the growth of the market like PCs and mobile phones did in prior decades. Therefore, the industry is consolidating at a record pace. Microchip is in the middle of it and is continuously acquiring other semiconductor companies and doubling our growth rate.

Henning Wriedt: Thank you Mr. Sanghi for your time and the information for our readers.

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Solving Power Capacity Challenges with Software Defined Power™

Running out of power is a constant concern for the operators of data centers and similar IT and communications infrastructure. The fight for footprint optimization while boosting processing and storage capabilities is a never-ending battle. However, the inefficiencies and underutilization of current power supply infrastructures that are designed to meet peak demand can now be avoided using a combination of hardware and software to even out supply loading and optimize the available capacity.

By Mark Adams, Senior Vice President, CUI Inc.

This intelligent use of available power can be realized with software tools that profile usage and recognize priority tasks. Utility power can then be supplemented with battery storage to supply peak demand using power stored during low utilization periods. Similarly, low-priority workloads can be assigned to server racks that are only powered when there is sufficient supply capacity. In this way the system can respond to peak demand while managing other tasks to spread the power load.

In much the same way that Software Defined Data Centers allow self-serviced users to deploy services and workloads in seconds, this approach to Software Defined Power® unlocks the underutilized power capacity available within existing systems. This allows a data center's server processing and storage capacity to expand without increasing power supply capacity and achieves considerable capital expenditure savings by not overprovisioning power. Furthermore, the use of battery storage to provide peak shaving and load leveling can also enable UPS functionality within a data center or server rack to protect it from power outage.

Understanding the data center 'power challenge'
The demand for Cloud data services continues apace as businesses and individual consumers become ever more reliant on remotely stored data that can be accessed over the Internet from almost anywhere. In addition, Cisco has estimated that the emergence of the Internet of Things will result in some 50 billion "things" connected to the Internet by 2020 as a myriad of sensors and controls enable smart homes, offices, factories, etc. Combined with more established applications, this is forecast to require a daily network capacity in excess of a zettabyte (10^{21} bytes) as early as 2018.

Servicing this demand and scaling up the capacity of networks and data centers is inevitably challenging, especially as customer requirements can turn on rapidly. While the IT industry faces pressure to scale data centers, one of the most constrained resources is power. It is often the case that the power capacity of existing data centers is exhausted well before they run out of storage or processing capacity. The two main factors of this power capacity limitation have been the need to provide supply redundancy and the way power is partitioned within data centers, both of which take up significant space but more importantly leaving untapped power sources idle. And this is despite the fact that current server designs are far more power efficient than previous generations and have significantly lower idle power consumption.

Providing additional power capacity within a data center is also time consuming and expensive even assuming that the local utility can supply the additional load, which IDC forecasts could double from 48GW in 2015 to 96GW by 2021 for a typical data center. From a capital expenditure standpoint, as shown in figure 1, the power and cooling infrastructure cost of a data center is second only to the cost of its servers.

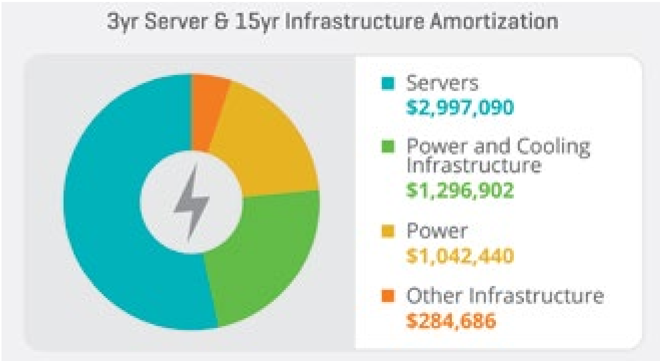

Figure 1: Data center monthly-amortized costs (source: James Hamilton's blog)

The nature of Cloud services also means that demand can fluctuate dramatically with a significant difference between the peak and average power consumed by a server rack. Consequently, providing enough power to meet peak-load requirements will clearly result in underutilization of the installed power capacity at other times. Also, lightly loaded power supplies will always be less efficient than those operating under full-load conditions. Clearly any measure that can even out power loading and free up surplus supply capacity has to be welcome in enabling data center operators to service additional customer demand without having to install extra power capacity.

With regard to efficiency considerations, servers and server racks use distributed power architectures where the conversion of power from ac to dc is undertaken at various levels. For example, a rack may be powered by a front-end ac-dc supply that provides an initial 48 Vdc power rail. Then, at the individual server or board level, an intermediate bus converter (IBC) would typically drop this down to 12 Vdc leaving the final conversion, to the lower voltages required by CPUs and other devices, to the actual point-of-load (POL). This distribution of power at higher voltages helps efficiency by minimizing down-conversion losses and also avoiding the resistive power losses in cables and circuit board traces, which are proportional to current and distance.

The more recent migration to digitally controllable power supplies has allowed the introduction of Software Defined Power® techniques that can monitor and control the loading of all the power supplies. This allows intermediate and final load voltages to be varied so that the various supply stages can always operate as efficiently as possible. Nevertheless, further improvements in hardware performance are reaching their limits and other solutions are needed.

The problem with existing data center power provisioning

Traditional data center power supply architectures are designed to provide high availability using supply redundancy to cope with mission critical processing workloads. This is illustrated by figure 2, which shows a 2N configuration that provides the 100% redundancy requirements expected of a tier 3 or tier 4 data center. As can be seen, for a dual-corded server this provides independent power routing from separate utility supplies or backup generators with the additional protection of intermediate redundant uninterruptable power supplies. Even single-corded servers have the security of a backup generator and uninterruptible power supplies (UPS).

However, implicit in this approach is the usually false assumption that all the servers are handling mission critical tasks and that the loading on each (and hence the power demand) is equal. In reality up to 30% of the servers could be handling development or test workloads meaning that half the power provisioned for them is not really required i.e. 15% of the total data center power capacity is blocked from use elsewhere.

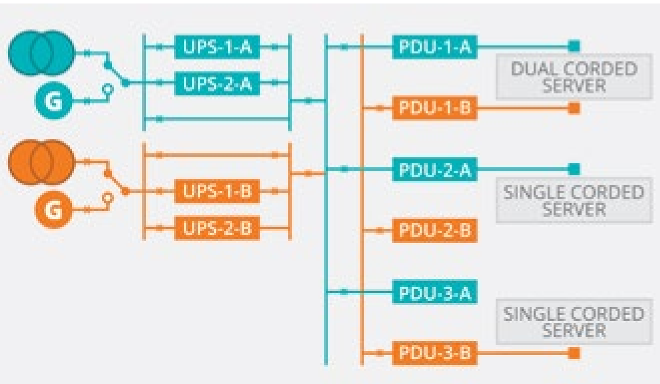

Figure 2. A 2N 100% redundancy power architecture for a tier 3/4 data center

The other issue is that, conventionally, supply capacity is designed to provide sufficient power for peak CPU utilization. The variability in server power consumption that this results in can be simply modeled by the following linear equation:

$$P_{server}=P_{idle}+u(P_{full}-P_{idle})$$

where Pidle is the server power consumed when idle and u is the CPU utilization.

With new technology delivering lower idle consumption the difference between idle and full power becomes ever more significant. This spread becomes larger still at the rack level, making power capacity planning based on an assumed CPU utilization figure very challenging. Furthermore, the type of workload exacerbates the variability in power consumption. For example, Google found that the ratio between average power and observed peak power for servers handling web mail was 89.9% while web search activity resulted in a much lower ratio of 72.7%. So provisioning data center power capacity based on the web search ratio could result in underutilization by up to 17%.

Unfortunately, it does not end there. The fear is that actual peaks might exceed those that have been modeled, potentially overloading the supply system and causing power outages. This leads planners to add additional capacity to provide a safety buffer. Consequently it is not surprising to find that the average utilization in data centers worldwide is less than 40% purely by taking account of peak demand modeling plus the additional buffering - this figure drops further when redundancy provisions are also included.

Unlocking underutilized power supply capacity

The peak versus average-power consumption issue discussed above clearly locks up considerable power capacity. Where peaks occur at predictable times and have a relatively long duration, data centers typically use local power generating facilities to supplement their utility supply, akin to how power utilities ramp up and down their generating capacity throughout the day to meet expected demand from consumers and business.

Unfortunately, the use of generating sets does not address the problem of peaks arising from more dynamic CPU utilization that is characterized by a higher peak to average power ratio, which is of shorter duration and occurs with a higher frequency. For this the solution is to provide battery power storage. The principle here is simple, the batteries supply power when demand peaks and are recharged during periods of lower utilization. This approach, referred to as peak shaving, is illustrated by figure 3, which shows how a server rack that would normally require 16kW of power can operate with 8-10kW of utility power. Indeed, if utility power is constrained, the power step from 8kW to 10kW could be taken care of with locally generated power, holding the utility supply to a constant 8kW.

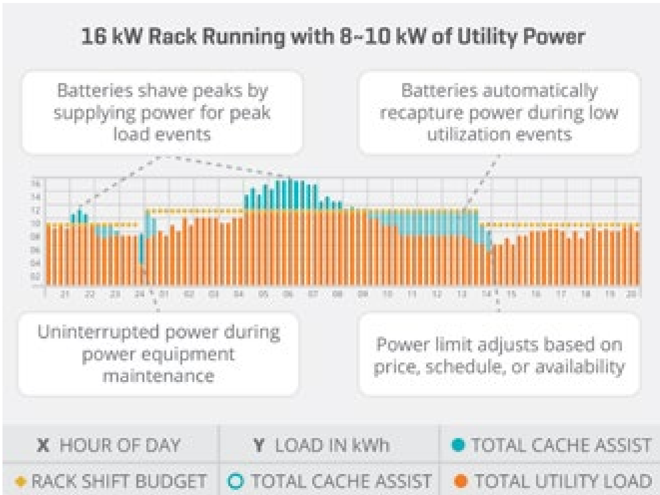

Figure 3. By profiling power demand and employing battery storage it is possible to manage peak demand using power stored during low utilization periods

Optimization through dynamic redundancy

The false assumption, mentioned earlier, that all servers in tier 3/4 data centers are handling mission critical workloads can be mitigated by assigning non-critical tasks to specific low-priority server racks. This allows additional server capacity to be installed in the data center up to a limit defined by the maximum non-critical load. So, for example, in a full data center where the maximum server rack load of 400kW for all racks nominally requires dual 400kW supplies to

provide 100% redundancy, it could be possible to provide additional low-priority server racks to service perhaps 100kW of non-critical workload. Then in the event that one of the 400kW supplies fails, power is cut to the low-priority server racks to ensure that the mission-critical racks receive full power from the alternate 400kW supply.

Using intelligent load management in this way can free up redundant supply capacity, which has no value-add, to provide a significant increase in a data center's workload capacity - in this instance adding 25% without the need for provisioning more power. Once again, a combined software and hardware solution can provide this dynamic management of power, monitoring and detecting a supply disruption and immediately switching the alternative supply to ensure continued operation of the mission-critical server racks.

The Intelligent Control of Energy (ICE®) solution
CUI has partnered with Virtual Power Systems to introduce the concept of peak shaving in a novel Software Defined Power® solution for IT systems. The Intelligent Control of Energy (ICE®) system uses a combination of hardware and software to maximize capacity utilization and optimize performance. The hardware comprises various modules, including rack-mount battery storage and switching units, which can be placed at the various power control points in the data center to support software decisions on power sourcing. The ICE software consists of an operating system that collects telemetry data from ICE and other infrastructure hardware to enable real-time control using power optimization algorithms.

Figure 4. CUI's rack-mount ICE hardware for intelligent power switching and battery storage

To illustrate the system's benefits, figure 5 highlights an ICE system trial at a top-tier data center. The trial has shown the potential to unlock 16MW of power from an installed capacity of 80MW. Furthermore, the capital expenditure in adding ICE is not only a quarter of the cost that would have been incurred in installing an additional 16MW of supply capacity but the time taken was a fraction and the ongoing operating expenditure is reduced.

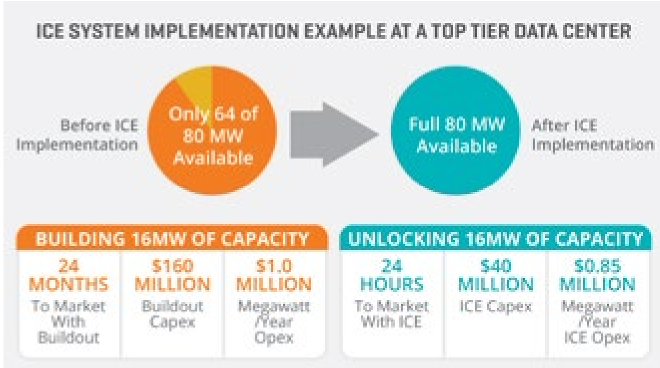

Figure 5. The value proposition from installing ICE to unlock unused power capacity

Conclusion
Expanding the capacity of data centers to address the increasing demand for Cloud computing and data storage can often be constrained by available power. Sometimes this can even be a limitation of the utility supply in a particular location but, even if it isn't, the ability to add more server racks may be restricted by the existing power and cooling infrastructure. Provisioning additional power capacity is costly, second only in cost to adding servers, so any means to improve the utilization of existing power sources has to be welcome.

Through its Intelligent Control of Energy (ICE®) solution, Virtual Power Systems, partnered with CUI, provides a complete power management capability for data centers and similar network and IT infrastructure applications. It maximizes capacity utilization through peak shaving and releases redundant capacity from systems that aren't totally mission-critical. Importantly its power switching and Li-ion battery storage modules can be readily deployed in both existing and new data center installations with a dramatic reduction in total cost of ownership, up to 50%.

For more information on the ICE® Platform, visit

www.cui.com/sdp-infrastructure-solutions

Mark Adams – Senior Vice President, CUI Inc.

Mark Adams has over 25 years of industry experience and has been instrumental in reorganizing CUI's sales structure and moving the company into advanced power products. Before joining CUI in 2009 Mark was a Sales Director at Zilker Labs for the 3 years leading up to their acquisition by Intersil, during which time Mark secured numerous design wins with some of the largest communication OEMs in the world. Prior to that Mark's sales experience includes 7 years working in distribution with Future Electronics and a further 7 years as a manufacturer representative primarily supporting Xilinx FPGAs. Mark attended Central Washington University where he studied Business Marketing, received his commission from Army ROTC and served in the Army National Guard for 13 years. As Senior Vice President at CUI, Mark is involved in business development and strategic customer engagement.


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„All-In-One“ DIPIPM+™ Series for Compact Inverter Designs

A novel family of compact Intelligent Converter-Inverter-Brake-modules was developed. This new DIPIPM+™ series incorporates optimized IGBT- and FWDi-chips, low voltage and high voltage driver ICs in a compact transfer molded dual-inline package. The new DIPIPM+ ™ series is providing smart answers on the 2 key questions a designer is facing when developing a new inverter design: How to reduce the system cost? How to reduce the inverter size by compact design?

By Muzaffer Albayrak; Eckhard Thal and Kosuke Yamaguchi,
Mitsubishi Electric Europe, Germany
and Teruaki Nagahara, Mitsubishi Electric Power Device Works, Japan

Introduction

The newly developed DIPIPM+™ series was introduced recently [1]; [2]. It consists of 6 different module ratings in 2 selectable configurations: Converter-Inverter-Brake-topology (see Figure 1) or Converter-Inverter-topology (see Figure 2).

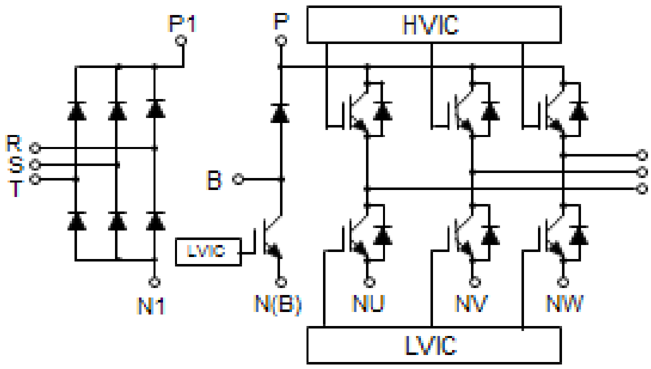

Figure1: DIPIPM+™ line-up and circuit diagram with brake

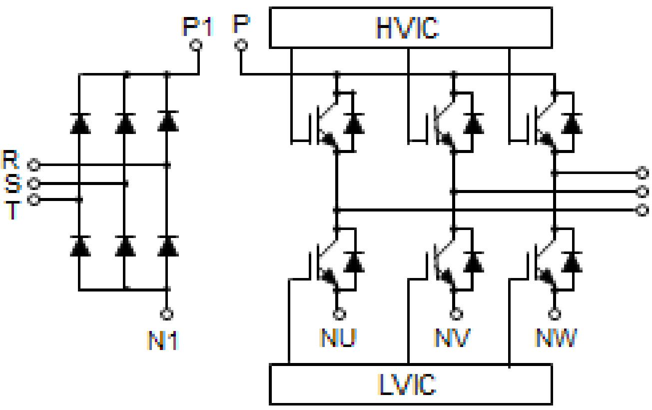

Figure 2: DIPIPM+™ line-up and circuit diagram without brake >

All the DIPIPM+™ modules are encapsulated into the same very compact dual-inline package according to Figure 3.

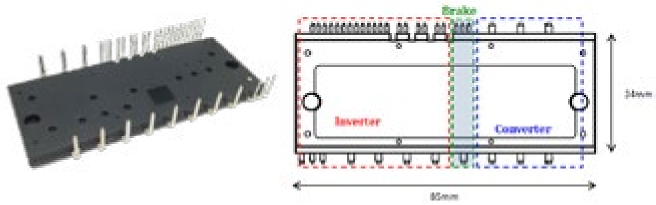

Figure 3 DIPIPM+™ photo & dimensions

An overview of the implemented DIPIPM+™ functions [2] is shown in the block diagram in Figure 4:

- The P-side IGBTs are driven by a HVIC with input signal conditioning, level shifter and under voltage lock out
- The P-side control power is provided from a single external 15V supply via integrated bootstrap diodes and resistors
- The N-side IGBTs are driven by LVIC with input signal conditioning, SC-protection and under voltage lock out
- The LVIC also contains an analogue temperature signal VOT and is generating a fault output Fo in case of protection trip

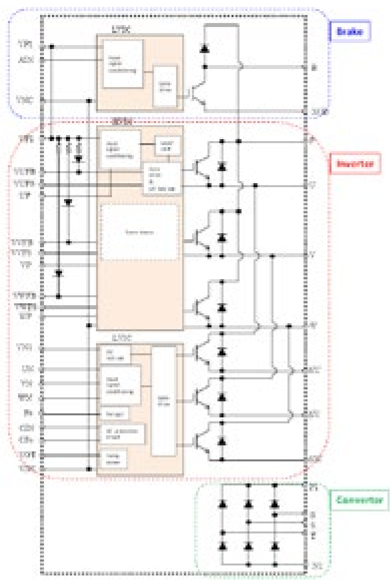

Figure 4: DIPIPM+™ internal block diagram

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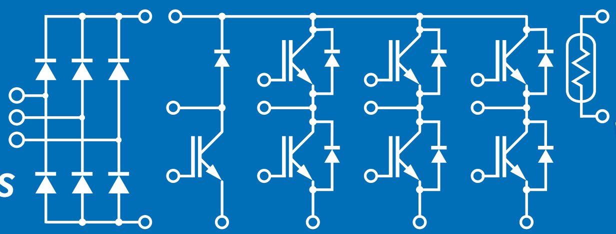

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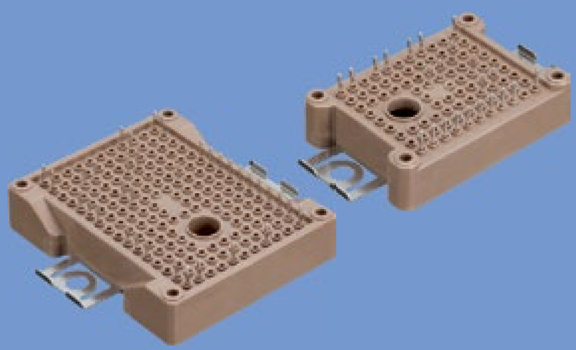
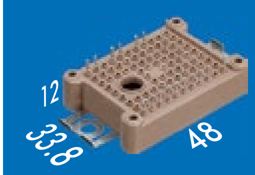
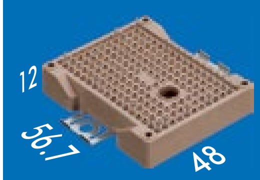
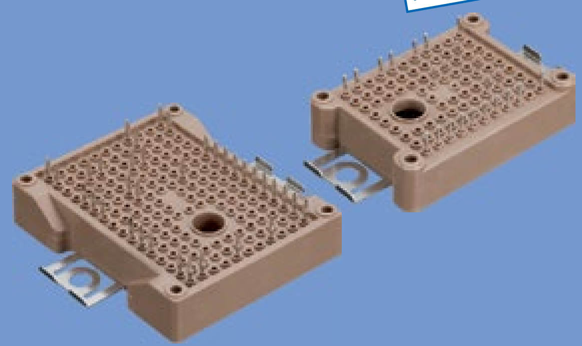
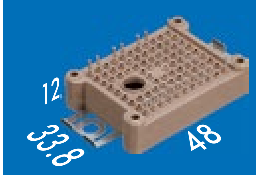
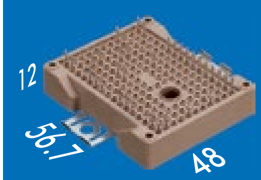


With Solder Pins

Package	I_C	600V	650V	1200V
	10A	6	7	6 7
	15A	6	7	6 7
	20A	6	7	
	25A			7
	30A	6	7	
	15A			6 7
	25A			6 7
	35A			6 7
	50A	6	7	



With PressFit Contacts

Package	I_C	600V	650V	1200V
	10A	6	7	6 7
	15A	6	7	6 7
	20A	6	7	
	25A			7
	30A	6	7	
	15A			6 7
	25A			6 7
	35A			6 7
	50A	6	7	

6 : V-series/6th Generation IGBT

7 : X-series/7th Generation IGBT

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Cost reduction

When developing a new general purpose inverter reducing the system cost is a key motivation. Basically 3 cost factors must be considered: a) development cost; b) material cost and c) manufacturing cost. All 3 factors are addressed by the new DIPIPM+™ series.

Reducing Development Cost and Time

The DIPIPM+™ is an "all-in-one" inverter module, consisting of a 3-phase input rectifier, a brake chopper and a 3-phase output inverter having all dedicated gate driver and protection functions integrated (see Figure 4). For reducing the development cost (and respectively the time to market of the new inverter) a plug-and-play evaluation board has been developed [3], see Figure 5.

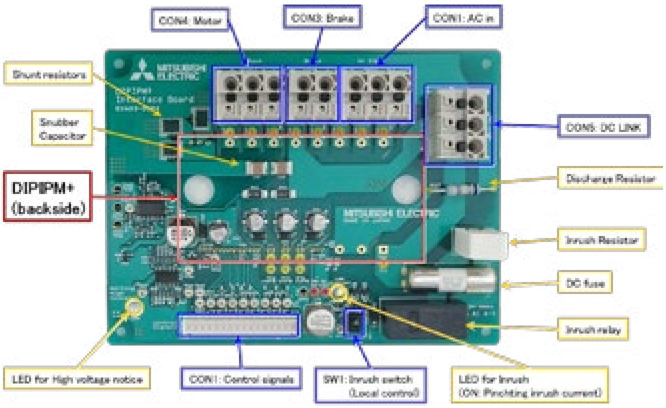


Figure 5: DIPIPM+™ evaluation board. The position of DIPIPM+™ backside the PCB is indicated with red color

It contains all required peripheral components to get quickly an inverter prototype running with the DIPIPM+™: snubber capacitor; non-isolated interface connector to the microcontroller; shunt resistors and comparators for overcurrent protection; bootstrap capacitors for p-side IGBTs; inrush current limiter and numerous test points for acquiring the signals. An easy test setup with the DIPIPM+ ™ Evaluation Board is shown in Figure 6.

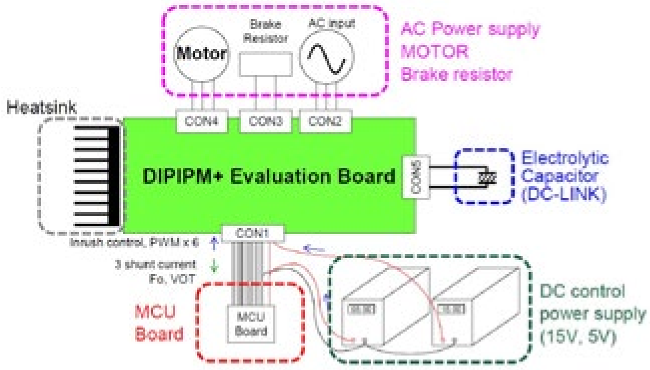


Figure 6: Test setup using the DIPIPM+™ evaluation board

All power connections to AC-line; brake resistor; motor and DC-link capacitor can be done solder-less. The DIPIPM+™ is the only component mounted from the bottom side of the PCB. Thus, even with such first functional prototype arrangement, the best fitting heat sink structure can be verified experimentally in real inverter operation. Particularly such early heat sink confirmation may help reducing the total development time of a new inverter design.

Material Cost Reduction

Several aspects how to reduce material cost by using DIPIPM+™ will be discussed next.

A. By using HVIC with level shifting technology and bootstrap power supply only one external +15V control power supply is needed. As the microcontroller is operating DC-link N-potential no isolation is needed between high voltage part and low voltage control part of the inverter. In this way the additional cost for individual +15V control power supplies and signal isolation for each IGBT-channel is eliminated. Only 3 bootstrap capacitors need to be added at the PCB for providing the control power to the p-side IGBTs. The safety isolation to the outside world should be implemented by the inverter designer into the HMI (human-machine-interface), which can be done much more cost-efficiently, than individually for each IGBT-channel.

B. For vector control the instantaneous values of inverter output currents must be monitored. By utilizing the open n-side emitters in DIPIPM+™ the inverter phase currents can be measured by shunts in each phase. The same shunt signals can be used to for tripping the DIPIPM+ ™ short circuit protection (see Figure7). In this way the higher cost for individual AC-current sensors in each inverter output can be avoided.

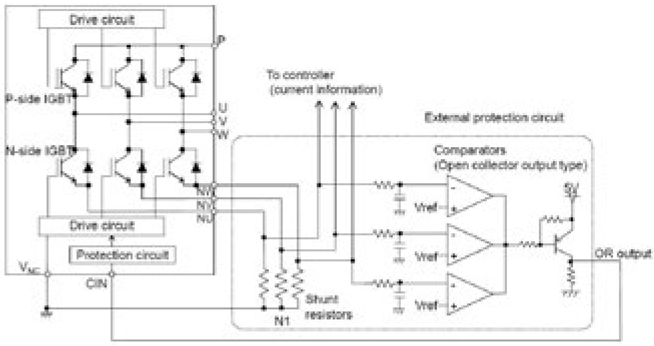


Figure 7: Using open emitter shunts for SC-protection and phase current sensing

C. New inverter designs must meet the EMC-requirements according to EN 61800-3. For this purpose either external or inverter-built-in EMC-filters are used. Reducing the EMC-filter cost is an efficient way for reducing the total cost for an inverter system.

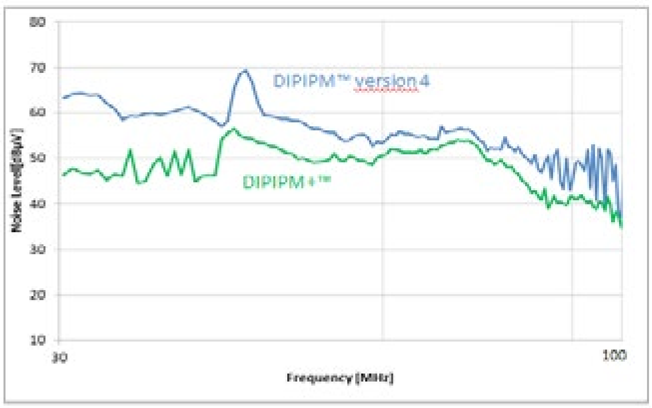


Figure 8: Radiated noise of DIPIPM+TM vs. previous generation DIPIPM ™ Version 4

In Figure 8 the radiated EMI noise of DIPIPM+™ is compared with the previous IPM-generation (DIPIPM ™ Version 4) under real inverter operation conditions. Due to the reduced noise emission of the new DIPIPM+™ a remarkable reduction of EMI-filter efforts can be achieved.

D. The package size of DIPIPM+™ is about 35% reduced compared with today's state-of-the-art 1200V DIPIPM ™. The well-organized pin out of the DIPIPM+™ permits using a low cost double layer PCB to ensure low inductive connection of the power stage to the DC-link capacitor. Furthermore, the Dual–Inline structure itself enables an easy signal and power terminals separation at the PCB (see Figure 9) thus allowing a very compact and thereby low cost PCB-design.

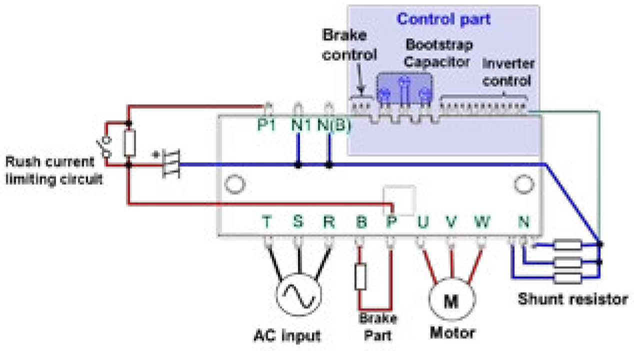


Figure 9: Pin terminal assignment of DIPIPM+™

E. The package of DIPIPM+™ is the same for all current ratings between 5A and 35A/1200V. This allows the use of the same PCB-platform for different inverter ratings and topologies. Reducing the variety of inverter frame sizes is one way of reducing material cost.

F. The all-in-one DIPIPM+™ concept reduces the space needed for the 3-phase inverter part by about 50% compared with today's state-of-the-art 1200V DIPIPM, see Figure 10. In combination with optimized low loss IGBT-and FWDi-chips this leads to a remarkable reduction of heatsink size and thereby also to reduced dimensions of the inverter housing itself. As result the cost for mechanical parts in the inverter construction can be reduced.

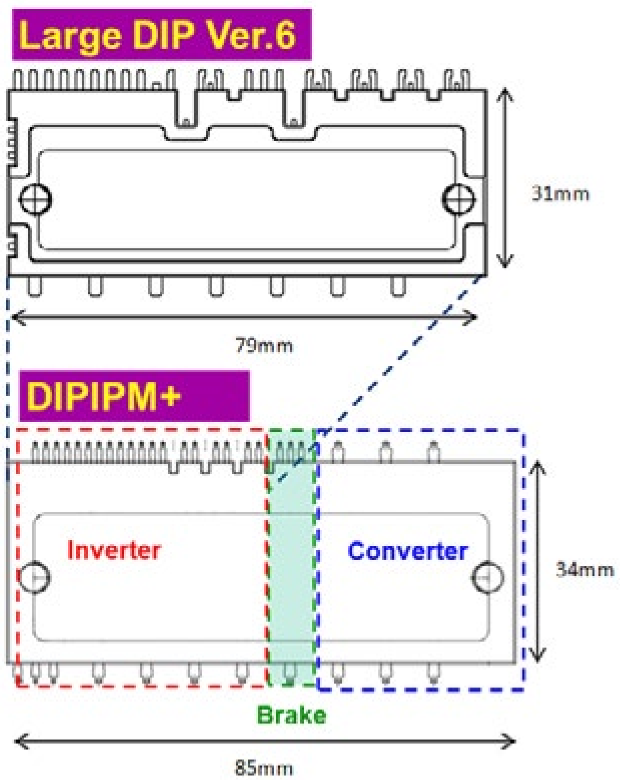


Figure 10: Conventional Large DIPIPM Ver.6 versus DIPIPM+™

Reducing the manufacturing cost

A. The high integration rate of DIPIPM+™ drastically reduced the parts count. Compared with an inverter design using a conventional 7in1 IGBT-module with separate driver ICs and a 3-phase input rectifier module the number of components to be placed at the PCB is reduced to about half, thus reducing the PCB-manufacturing cost.

B. Another cost reduction factor is the simple flow soldering process that can be used for the DIPIPM+™ assembly to the PCB. As the inverter bridge, the brake transistor and the input rectifier are integrated into the same module package no special care for height adjustment during soldering must be taken for controlling the distance between PCB and heat sink; simple spacers will be sufficient. If for example 2 separate power modules for inverter and input rectifier are used at the same PCB, in this case individual height adjustments for each module are necessary during soldering process for ensuring an equal distance between PCB and module's baseplates and thus a good thermal contact of both modules to the heat sink. This complicates the assembly process.

Inverter size reduction (increasing the power density by compact inverter design)

The inverter compactness is the second key objective when doing a new inverter design as the power density (kVA/dm³) is one of the key benchmarking criteria for comparing general purpose inverters from different manufacturers. Basically most of the discussed in chapter 2.2 aspects of reducing the material cost are in a similar way also relevant for increasing the inverter power density:

- Using the bootstrap-technology for control power supply of p-side IGBT
- Substituting the inverter output current sensors by emitter shunts
- Reducing the EMI-filter size
- Very compact PCB design
- Reducing the heat sink size

Besides for compact general purpose inverters the DIPIPM+TM is an interesting solution when the inverter needs to be incorporated into a pre-defined limited space, for example for motor integrated inverters ("Klemmkasten-Umrichter"). For those applications the high integration rate of DIPIPM+™ series is a big benefit.

Increasing the inverter performance

The allowable inverter output currents Io(rms) for different DIPIPM+TM module types are calculated in Figure 11 for different PWM carrier frequencies fc based on the assumption of ΔT(j-c)=25K for the conditions Vcc=600V; Tc=100°C; Tjavg=125°C cosφ=0,8; sinewave PWM; Modulation Ratio=1; Rth(j-c)=max. Based on this quite conservative approach the motor ratings given in Table 1 are derived [4] assuming a 150% overload capability for 1min.

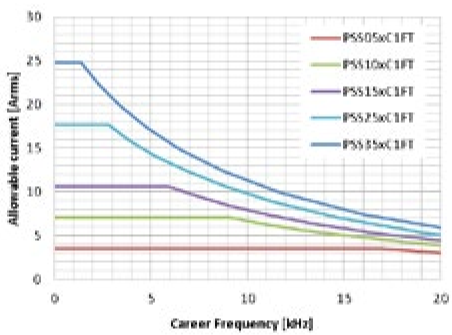
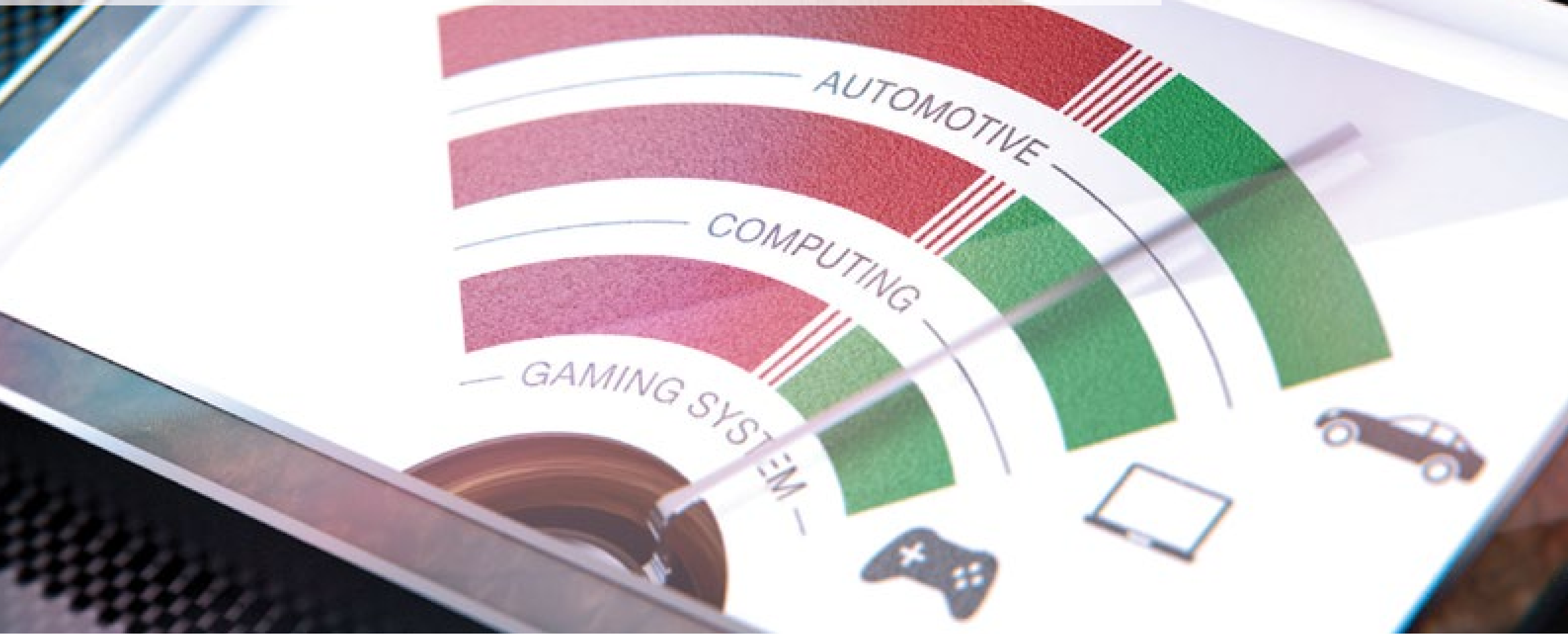
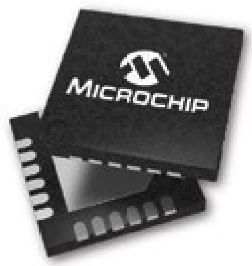


Figure 11: Inverter output current Io(rms) versus PWM switching frequency

Advanced and Broad Power Management Portfolio



Microchip Technology has an expansive offering of power management solutions to fit virtually every type of design criteria. From the smallest form factor needed for mobile devices to complex industrial power management designs to automotive standards, you are sure to find a highly integrated solution to meet your needs. If you are looking for greater flexibility in your design, Microchip's digitally enhanced power analog devices integrate a microcontroller (MCU) or digital signal controller (DSC) for a fully programmable and flexible solution.



Applications:

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- Power MOSFET drivers
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Recently it became popular to specify dual (or multiple) inverter ratings for different overload capabilities: if a low overload (LO) capability is required the maximum motor rating can be selected one rank bigger than for a drive with high overload (HO) capability. By this approach the thermal impedance (capacitance) of the heatsink is utilized for absorbing the dissipated excess-power during short overload situations. In this way more output power can be obtained for a short time from a given inverter hardware by using the built-in thermal system margins. For doing this an accurate information about the actual temperature of power module is needed. Usually this is done by putting an NTC to the heatsink (or to use a power module integrated NTC). The DIPIPM+™ is offering an analog temperature output signal VOT having a linear transfer characteristic over the whole operation temperature range, see Figure 12. By using this accurate analogue VOT-signal it's possible to allow significantly higher inverter output currents than indicated in Figure 11 without the risk of tripping the thermal inverter protection.

Type name	Rated current	Rated voltage	Motor ratings
PSS05xC1FT	5A	1200V	0.75kW/400VAC
PSS10xC1FT	10A		1.5kW/400VAC
PSS15xC1FT	15A		2.2kW/400VAC
PSS25xC1FT	25A		3.7kW/400VAC
PSS35xC1FT	35A		5.5kW/400VAC

Table1: Motor ratings vs. DIPIPM+TM types

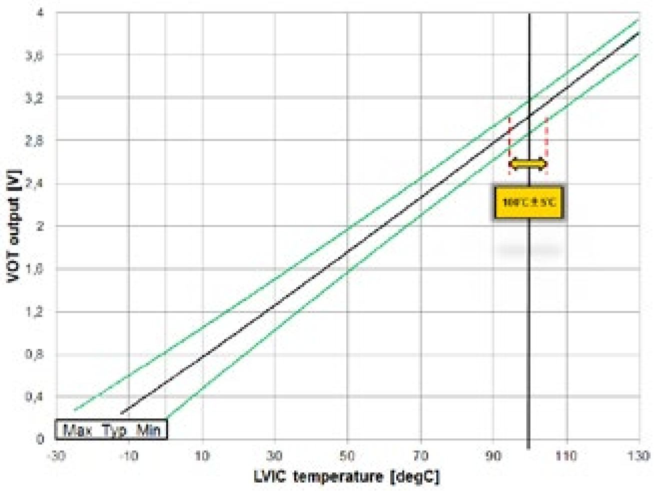
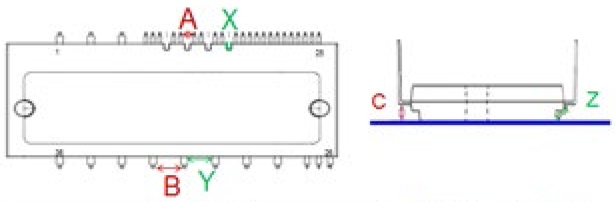


Figure 12: Analogue temperature output signal VOT from DIPIPM+™

The analogue VOT-signal of DIPIPM+™ can also be used to increase the robustness of the inverter against harsh environmental conditions. Usually the inverter specification is given for maximum ambient temperature of Ta=+40°C. For higher ambient temperatures an inverter de-rating has to be considered when installing the drive. By using the VOT-signal several options can be activated for an adaptive inverter de-rating during operation in case of reaching a critical device temperature before the over-temperature protection would turn-off the drive: for example by reducing the switching frequency fc or by reducing the inverter output current as a function of the VOT-signal.

The DIPIPM ™ technology was originally developed for the needs of high volume inverterized white goods applications like washing machines, air-conditioners, refrigerators etc. Over the past 20 years more than 450Mio pieces DIPIPM have been manufactured by Mitsubishi Electric in different packages, voltage and current ratings [5]. For industrial drive applications usually 1200V DIPIPMs are being used. The new DIPIPM+TM series was developed for the specific needs of compact industrial 400VAC-inverters. It is compliant with Viso = AC2500V industrial isolation standards and meets all relevant industrial creepage and clearance requirements, see Figure 13.



PSSxxMC1FT	Clearence		Creepage	
Between control terminals (High voltage terminal to Low voltage terminal)	A	2.5mm	X	6.4mm
Between power terminals	B	5.8mm	Y	6.0mm
Between terminals and Earth (Terminal to Heatsink)	C	2.5mm	Z	4.3mm

Figure 13: Creepage and clearance distances of DIPIPM+TM package

The DIPIPM+™ package is siloxane free and therefore well suited for applications where IGBT modules with silicone gel are not allowed. The DIPIPM+™ series is UL-approved (UL1557 File E323585) and ROHS compliant.

Summary

The new DIPIPM+™ series is an excellent answer to the needs of compact AC400V inverters in the power range between 0,75kW… 5,5kW. It helps to reduce both cost and size of a new inverter design. A plug-and–play evaluation board is available for shrinking the inverter development time. Based on 20 year experience with manufacturing of dual-in-line packaged IPMs for white good applications, with the new DIPIPM+™ series Mitsubishi Electric is now introducing an "all-in-one" DIPIPM-solution that meets all requirements of an industrial inverter design.

References:

[1] Mitsubishi Electric Corp.: "Mitsubishi Electric to launch DIPIPM+ Series" Press release No. 2928; May7, 2015
[2] M. Honsberg et al.: "A novel Transfer Molding Intelligent Convert Inverter Brake IGBT module (DIPIPM+) with integrated level shifting control ICs", PCIM Europe 2016, Conference proceedings p.889-894
[3] Mitsubishi Electric Corp.: DIPIPM+ Evaluation Board User manual (Application Note dated 2015.07)
[4] Mitsubishi Electric Corp.: DIPIPM+ Series Application Note DPH-12856 (publication date: July 2016)
[5] S. Noda et al.: "A novel Super Compact Intelligent Power Module", PCIM Europe 1997, Conference proceedings p.1-9

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Novel 100V Power MOSFET Technology with Soft Body Diode Recovery

This increases system efficiency while reducing peak voltage stresses in switching applications.

MOSFET power stages designed for switching converters or for motor drives often generate relatively large voltage and current spikes. It is common knowledge to most power electronic engineers that MOSFET drain-source voltage ringing is a result of drain current transients (di/dt's) that occur during MOSFET switching interacting with unclamped power loop inductance (Lstray).

By Jon Gladish and Mike Speed, Fairchild Semiconductor

Even though a well designed, low loss MOSFET power stage can be realized with minimized loop inductance and snubber circuitry, it is common to see a power MOSFET generate drain-source voltage spikes that approach (or even exceed) the maximum rated value listed in the MOSFET datasheet. Exceeding the datasheet "absolute maximum ratings" (AMRs) can result in decreased system efficiency and reliability or result in catastrophic failure of the MOSFET components.

Many times, the culprit behind the largest voltage spikes is the MOSFET body diode. Many modern power converter or inverter topologies operate the power MOSFET as either a synchronous rectifier, utilizing third quadrant operation or simply use the MOSFET body diode in a non-synchronous mode as a clamping or free-wheeling diode. Both operating modes require some body diode conduction and often a body diode recovery when used an inductive hard-switching environment.

The MOSFET body diode recovery time (tRR), recovery charge (QRR), and reverse recovery softness factor (RRSF) play an important role in determining peak voltage spikes and ringing levels. One common issue is that the diode recovery characteristics change as the power stage operating conditions change, especially as the diode forward current varies. Many modern power MOSFET technologies have body diodes with poor recovery characteristics that can vary QRR by a factor of two or more over the useable load current range of power converter. In order to understand how the peak drain-source voltage stresses vary, the body diode recovery must be characterized in situ at all known power stage operating conditions, especially at the high current (full load) range. It is often required to slow the power MOSFET switching edge rates or add snubber circuitry to maintain safe peak voltage levels. One common issue is that MOSFET technologies with high QRR and abrupt diode recovery require large lossy snubber circuitry or large external MOSFET gate resistors to drastically slow switching at the expense of higher MOSFET switching loss. The snubber must be sized to suppress the peak voltage spike during the worst case operating mode.

A better solution to this issue is to design a power MOSFET with a low QRR and soft recovery that is stable and predictable across a wide load current range. This will allow for minimized external snubber circuitry and minimized external gate resistors. This article will introduce a novel power MOSFET technology with best-in-class diode recovery that is optimized for use in low loss motor drive power stages as well as most switching converter synchronous rectifiers.

MOSFET body diode recovery effects:

The body diode recovery characteristic of a power MOSFET device influences the voltage switching spikes and amount of circuit noise or EMI. An un-optimized body diode recovery tends to have a "snappy" recovery characteristic; where the diode current rate of change during the reverse recovery tB phase (diR/dt) will be much faster than the rate of change of current during the tA phase (diF/dt), refer to Figure 1 for definitions.

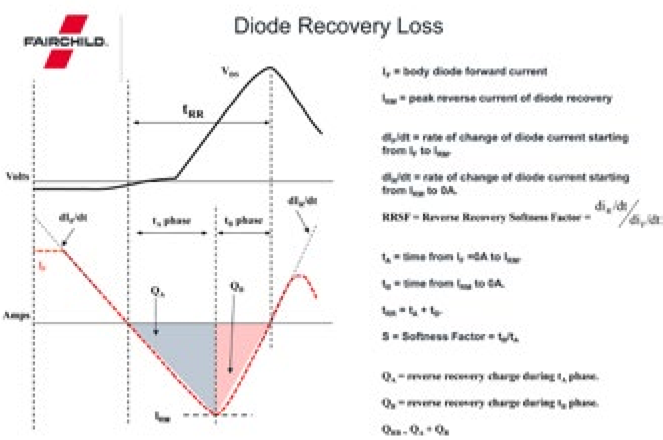

Figure 1: Diode Reverse Recovery Definitions

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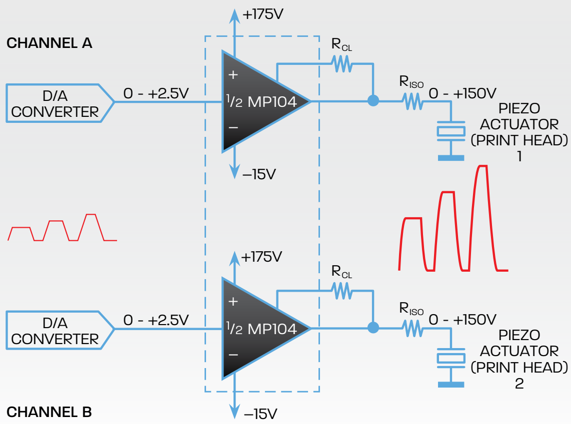
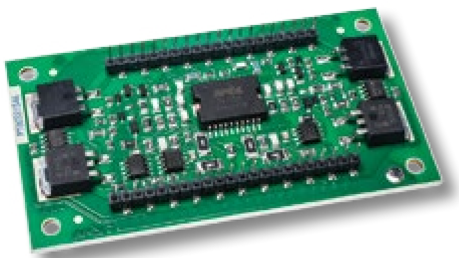
PROVIDES SPACE SAVINGS, COST SAVINGS

The Apex MP104 is a low cost, dual channel power amplifier designed to drive multiple piezoelectric loads with a single, space saving device. The enhanced circuitry of the MP104 delivers a balanced performance in providing >10A PEAK output current per channel as well as a reduction in crosstalk. The MP104 operates on supply voltages up to 180V and references the output to ground and not the negative supply rail (+V_S to GND) to reduce the requirements for expensive power supplies. The MP104 also features a low current negative supply (≤50mA) to allow input to zero volts without violating the common mode input range.



A SINGLE, DUAL CHANNEL MP104 DRIVES TWO PRINTER HEADS
(For Design Discussion Purposes Only)



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APEX MICROTECHNOLOGY

The “snappy” characteristic of the diode recovery will lead to high VDS stress placed on the MOSFET terminals, Figure 2. In some cases, the VDS stress will be high enough to exceed the rated drain-source breakdown of the MOSFET (i.e avalanche breakdown).

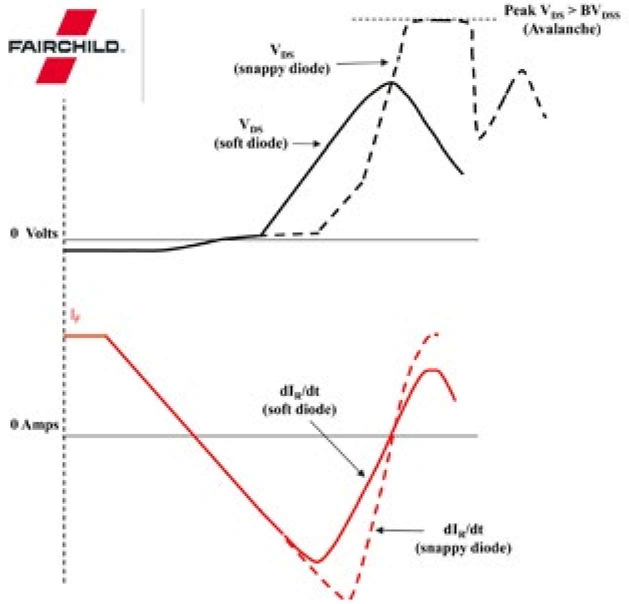

Figure 2: “Soft” versus “Snappy” Diode Reverse Recovery Comparison

Many power MOSFETs are robust enough to protect against an avalanche event. However, there are two concerns when avalanching a MOSFET.

MOSFET Avalanche SOA

First, the MOSFET avalanche current and energy must abide by the MOSFET avalanche SOA. A typical MOSFET datasheet will commonly include a single pulse “Unclamped Inductive Switching (UIS)” curve to define the safe operating area of avalanche events, Figure 3. The MOSFET avalanche SOA curve is defined by two distinct regions. Region 1 is an energy related region where SOA is defined by the peak MOSFET junction temperature. Region 2 is a current limited region, where the peak avalanche current is clamped, regardless of energy backing avalanche pulse. The failure mechanism is this region is often due to large avalanche current density flowing through parasitic bipolar. The main issue here is that it is difficult to determine the peak avalanche during a diode recovery event when the MOSFET is operating within a power converter. Care must be taken to carefully assess the avalanche situation.

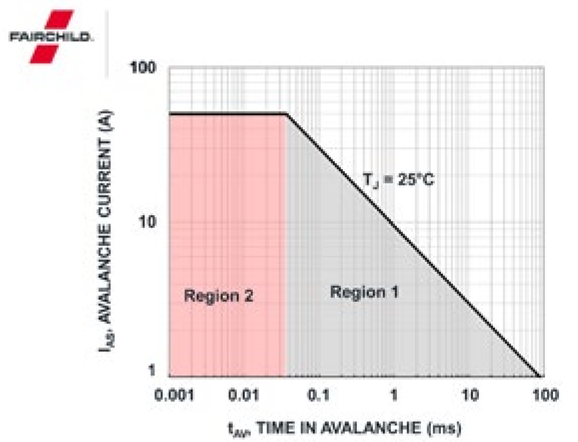

Figure 3: Power MOSFET (FDMS86181) avalanche rating (SOA) curve

Repetitive Avalanche

A second concern is repetitive avalanche. Repetitive avalanche can degrade the MOSFET over time by causing parametric shifts in important parameters such as: threshold voltage, VTH; breakdown voltage BVDSS; drain-source leakage, IDSS; or on-state resistance, RDS(ON). This can be true even if every single event avalanche pulse abides by MOSFET avalanche SOA curve, Figure 3. It is highly advised to not operate a power MOSFET in a long term repetitive avalanche mode unless the datasheet specifies this operation is safe.

Novel 100V MOSFET technology from Fairchild:

The latest generation 100V MOSFET technology from Fairchild focuses on optimizing the MOSFET characteristics for switching power stages. The technology achieves an excellent figure-of-merit (FOM) for the product of on-state resistance times total gate charge, RDS(ON) x QG(TOT) = 164 mW-nC as well as best-in-class body diode recovery characteristics. Diode recovery was optimized for both recovery charge and recovery softness across a large operating current range.

A comparison of the latest technology from Fairchild (FDMS86182) is shown versus a competitive solution, Figure 4. Measured diode recovery characteristics are shown in Figure 5, where the body diode recovery waveforms show the reduced QRR and more optimized Softness factor (S) from the FDMS86182 versus the competitive part. Plots of QRR versus IF (diode forward current) are plotted in Figure 6. These plots clearly show the more stable QRR and softness of the FDMS86182 versus current.

Part	Rds (mohm)	Qgtot(10) (nC)	Qgd (nC)	Qgs (nC)	Rg (ohms)
FDMS86182	6.1	24.7	7.0	7.5	0.8
Competition	6.3	39.0	9.0	10.5	1.2

Figure 4: FDMS86182 vs Competition

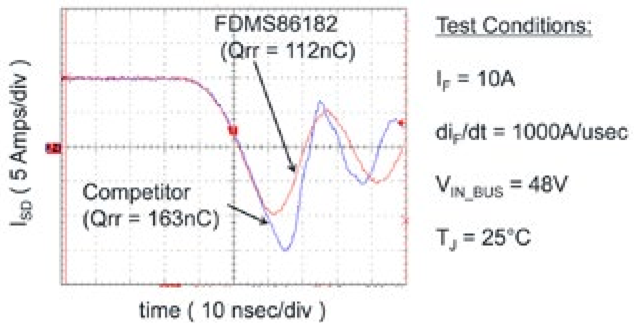

Figure 5: Diode Recovery Waveforms

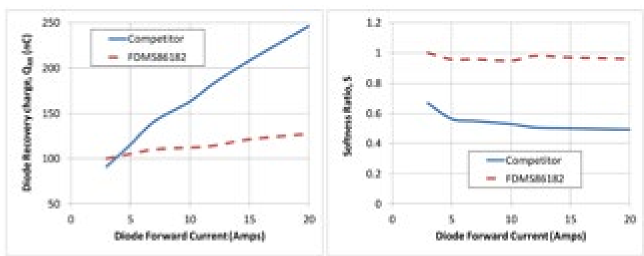

Figure 6: Diode Recovery Charge and Softness - PTNG versus Competitor

48Vin to 12Vout case study:
In order to demonstrate the advantages of the latest 100V MOSFET technology, the FDMS86182 was tested for thermals and power loss versus a competitive part using a synchronous buck converter, Figure 7. The synchronous buck is a simple and convenient topology for evaluating MOSFETs being used as synchronous rectifiers (Q2). Testing was performed by fixing high side FET (HS FET) as FDMS86182 and just replacing low side FET (LS FET) with FDMS86182 versus competition. Test1: FDMS86182 (HS FET) and FDMS86182 (LS FET). Test 2: FDMS86182 (HS FET) and competition (LS FET). This evaluation focuses on synchronous rectifier operation.

Test conditions:
VIN = 48V, VOUT = 12V, Lout = 10uH, Rg_HS=0 ohm, Rg_LS = 0 ohm, Fsw = 250kHz and 500kHz, gate drive = UCC27201, TA = 25C (natural convection cooling).

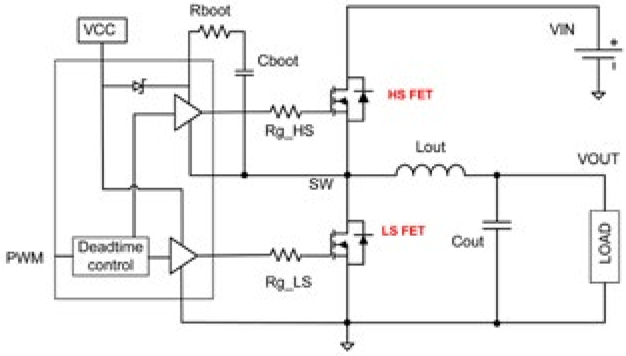

Figure 7: Synchronous Buck Test Schematic

As mentioned earlier, the body recovery characteristics will play an important role in Switch Node (SW node) ringing, where a "snappy" diode recovery generates large voltage spikes across the LS FET drain-source (or SW node). An easy method to control SW ringing is to slow the HS FET turn-on edge rate [1]. This will slow the LS FET diode recovery diF/dt and diR/dt and result in lower SW ringing. Slowing the MOSFET switching edge rate reduces peak voltage stress and ringing but also results in higher MOSFET switching loss [1].

One convenient method to slow the HS FET turn-on speed is by increasing the boot resistor (Rboot). Rboot can varied to tune the switch node (SW) ringing to an acceptable level. Rboot was chosen to control SW ringing (versus Rg_HS) since increasing Rboot only slows HS FET turn-on speed and still allows for fast turn-off.

For this experiment, SW peak voltage was allowed to ring up to 90V at 18A (90% of the 100V BVDSS level). To accomplish this, Rboot = 2.5ohms for competition, Rboot = 0.5ohms for FDMS86182. The FDMS86182 required a lower Rboot resistor since the body diode is superior to the competition with much softer recovery. In essence, the low QRR, soft recovery diode of the FDMS86182 allows for a lower loss, faster HS FET switching speed. The advantages of the superior body diode recovery help enable much lower total power loss and operating temperatures versus the competitor's part. The power loss curves are shown below, Figure 8 and the peak MOSFET topside case temperature is shown in Figure 9.

The FDMS86182 provides close to 2 Watts of power savings and 17C lower temperature versus the competition at IOUT=18A, FSW = 250kHz. Similar results were measured at IOUT=12A, FSW=500kHz.

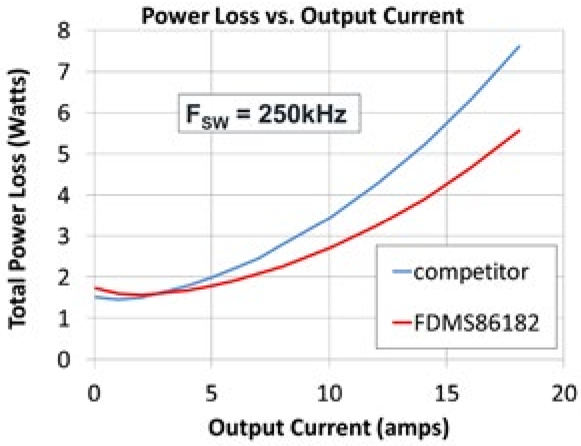

Figure 8: Synchronous Buck Converter Power Loss

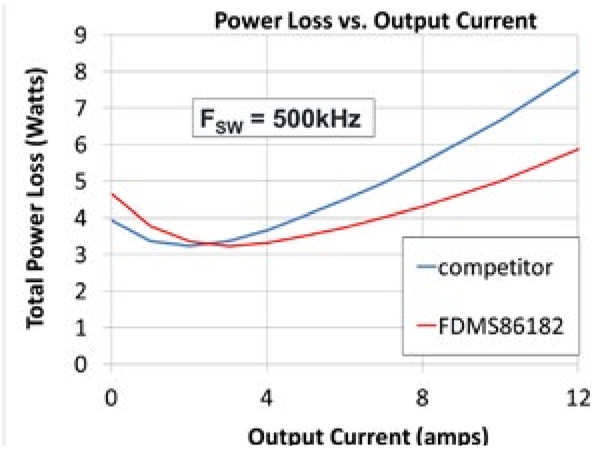

Figure 9: MOSFET Case Temperature versus Output Current (FSW = 250kHz)

In summary, the latest generation 100V MOSFET technology from Fairchild enables low loss, low noise switching converter design. The advanced, best-in-class body diode recovery characteristics provide for stable and predictable ringing and voltage stress across a wide range of operating conditions.

[1] Fairchild AN-4162: Switch Node Ring control in Synchronous Buck Regulators.

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High-Precision Power Measurement of SiC Inverters

Facilitating high-precision measurement of power, efficiency, and loss in SiC inverters and motor drive systems

By Kazunobu Hayashi, Hioki E.E. Corporation

Introduction

Development of higher-efficiency, more compact motor drive systems is a key priority for manufacturers of EVs and HEVs as well as the rail industry, among other sectors of the economy, where companies have started using SiC power semiconductors in order to boost the efficiency and shrink the size of the inverters that are principal components of motor drive systems[1][2][3]. Expected advantages of SiC power semiconductors include smaller passive component dimensions thanks to higher switching frequencies and lower-loss performance thanks to low on-resistance values. Accurate power measurement is a critical precondition for evaluating motor drive systems, but power measurement of SiC inverters requires high-precision measurement across a broader band of frequencies than in the past. This paper introduces a range of topics including expertise related to power, efficiency, and loss measurement of SiC inverters and motor drive systems, along with actual measurement results.

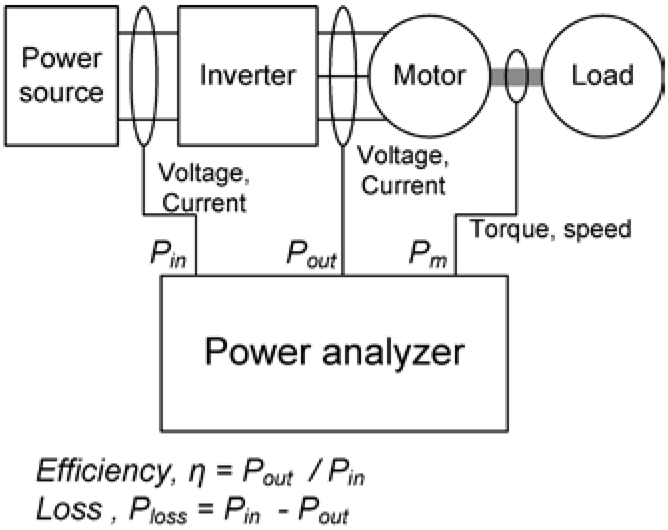

Figure 1: Measuring the efficiency of a motor drive system

Measuring the Efficiency of Inverters and Motors

During evaluation of motor drive systems that incorporate inverters and motors, it is possible to measure efficiency and loss by measuring the inverter's input and output power and the motor's power and then calculating the ratio or differential between the input and output values. Fig. 1 provides a measurement block diagram illustrating the measurement of the efficiency of a standard motor drive system.

The output of inverters and motors fluctuates over time. Consequently, accurate measurement is made difficult by imperfect synchronization of measurement timing and by differences in calculation methods when calculating efficiency and loss by measuring the respective points with separate instruments. Accordingly, it is necessary to take all measurements simultaneously, either by using a single instrument for all of them or through the synchronized control of multiple instruments. This requirement can be met by using a power analyzer. Standard power analyzers provide four to six channels of power measurement along with motor analysis functionality, allowing them to measure efficiency and loss with a high degree of precision.

Looking more closely at the measurement process, results vary depending on how the time period across which power calculations are performed is defined. Power analyzers determine the periods across which calculations are performed by detecting zero-cross events in input waveforms. Generally speaking, the channel corresponding to the signal for which zero-cross events will be detected can be set as desired as the synchronization source. Setting the optimal synchronization source enables stable power measurement, making it possible to measure efficiency and loss with a high degree of precision. For example, if the inverter is fed DC input, the calculation periods can be synchronized by setting the same synchronization source for the input and output channels. In this way, it is possible to measure efficiency and loss in a stable manner. In the example shown in Figure 1, power at two points and motor power at one point are being measured in a stable manner by setting the synchronization source for all channels to the inverter's output current.

Measuring an Inverter's Input Power

To measure efficiency and loss, it is necessary to measure the power being input to the inverter. This input power will serve as the basis for measuring efficiency and loss. Generally speaking, either DC or AC commercial power is used as inverter input. If the values yielded by measurement of the input and output power contain an error component, it will have a significant effect on the efficiency and loss values. Consequently, it is necessary to measure the inverter's input power with a high degree of precision. For example, an error of 0.5% in the input power measured value for an inverter with an efficiency of 99% will result in an error of 50% for the loss. Although it is possible to calculate power using a general-purpose waveform recorder, one must exercise caution to ensure that a sufficient level of accuracy has been defined for the band that you wish to measure.

Caution is especially warranted during DC power measurement, which should be preceded by adjusting the power analyzer and current sensors' DC offsets. If the power analyzer provides a zero-adjustment function, perform zero-adjustment after zeroing out input to the power analyzer and current sensors. In this way, it is possible to awable accurate DC measurement by canceling out the instrument's DC offset.

Measuring an Inverter's Output Power
Inverters generate PWM-modulated output that includes the switching frequency and its harmonic components. Consequently, power measurement must be performed over a wider band than when measuring DC or commercial frequency power.

Let's study the band that is needed in order to measure power at the switching frequency and its harmonics. Figure 2 provides an equivalent circuit for a motor that is driven by an inverter. Since the motor's windings have an inductance component, high-frequency current is less likely to flow to the motor. Since the voltage is a PWM waveform, it can be approximated as a rectangular wave. At this time, the current will take the shape of a triangular waveform. When calculating RMS values for the triangular waveform over the frequency domain, measurement can yield RMS values with an error of 0.1% or less if harmonics can be measured to the 5th order. Here the active power Pf can be expressed as a function of the voltage Uf, the current If, and the voltage-current phase difference θf as follows:

$$P_f = U_f \cdot I_f \cdot \cos\theta_f \quad (1)$$

Consequently, if either the voltage or current is 0, the active power for that frequency component will be 0. Assuming measurement at a precision of 0.1%, current at 7th order and higher harmonic components can be ignored, as noted above. Therefore, the ability to measure voltage, current, and phase difference accurately within the band of 5 times to 7 times the switching frequency is sufficient in order to measure power at the switching frequency and its harmonics with an error of 0.1% or less. However, loss in an actual motor includes the magnetic material's core loss as well as losses from factors such as wire skin effects in addition to the resistance portion shown in Figure 2. Consequently, a somewhat wider frequency band is needed in order to more accurately measure power at the switching frequency and its harmonics. The band that is actually needed is affected by factors such as the frequency characteristics of the respective losses.

Figure 3 shows the actual voltage and current waveforms of a motor driven by an SiC inverter, as well as associated FFT results. Table 1 provides detailed information about the measurement targets. Since the voltage is a PWM waveform, an examination of the FFT results reveals frequency components in excess of 1 MHz. Standard power analyzers do not provide a sufficient measurement band to measure voltage waveforms with the required degree of accuracy. Looking at the current, it is apparent that the current components do not exceed about 200 kHz. In addition, the waveform closely resembles a sine wave. This shape derives from the fact that the motor's inductance component makes it less likely that high-frequency current will flow, as described above.

In this way, it is desirable to use a power analyzer with favorable characteristics for voltage, current, and phase difference characteristics in the frequency band of at least 5 to 7 times the switching frequency in order to allow accurate measurement of the inverter's output power. Use of increasingly high switching frequencies for SiC inverters has the effect of requiring a higher-frequency band in this regard.

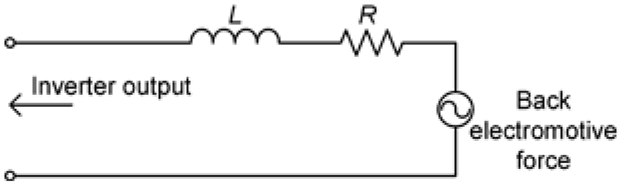

Figure 2: Equivalent circuit for a motor (1 phase)

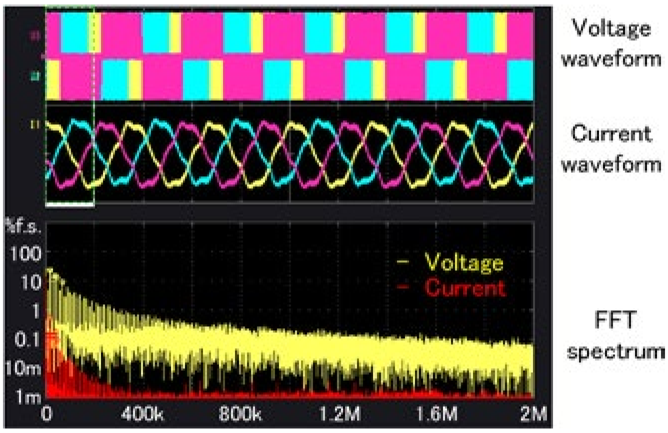

Figure 3: Waveforms and FFT results for an actual inverter-driven motor (measured with the Power Analyzer PW6001)

Inverter		Motor	
Switching element	Switching frequency	Inductance	Resistance
SiC-MOSFET SCH2080KE (ROHM)	20 kHz	3.6 mH	0.9 Ω

Table 1: Specifications of measured SiC inverter and motor

sGenerally speaking, current sensors are used when measuring current in a motor drive system. In such applications, the current sensors' phase error becomes problematic. All current sensors exhibit a tendency toward increased phase error at higher frequencies, and this tendency becomes a source of error when measuring high-frequency power. As shown in Figure 2, the motor windings' inductance component is dominant at high frequencies. As a result, power at the switching frequency and its harmonics is characterized by a lower power factor. Based on Equation (1), phase error has an extremely large impact on power measurement error at low power factor values (θ values of approximately 90°). Consequently, it is not possible to measure power at a high degree of precision unless the current sensors' phase error can be corrected. Hioki's Power Analyzer PW6001 provides functionality for compensation for current sensor phase error, as shown in Figure 4. This phase compensation function makes it possible to measure inverter output power more accurately.

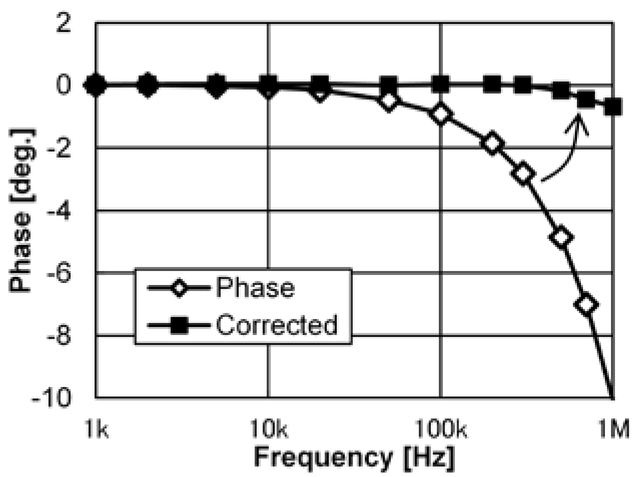

Figure 4: Compensating a current sensor's phase error

Measuring a Motor's Power

In order to measure the overall efficiency and loss of a motor or motor drive system, it is necessary to measure the motor's power. To calculate motor power using Equation (2), we all need to measure torque and rpm.

$P_m = T \cdot 2 \cdot \pi \cdot n / 60$ (2)

P_m [W]: Motor power

T [N·m]: Torque

n [rpm]: Motor rpm

The motor's rpm is measured using a tachometer or pulse encoder, while torque is measured using a torque meter. In order to measure efficiency and loss, it is necessary to measure power and motor power at the same time. Consequently, we need to use a power analyzer that can accept signals from a tachometer, pulse encoder, and torque meter as input.

Example Measurement of the Efficiency of an Inverter with SiC Power Semiconductor

Figure 5 illustrates the results of measuring the efficiency of an SiC inverter that is driving a motor. The setup uses a Hioki Power Analyzer PW6001 and Current Box PW9100, and the figure illustrates the results of measurement while varying the cutoff frequency of the PW6001's LPF from 1 kHz to 2 MHz. The measurement targets are the same as those described in Table 1. The measured efficiency values change dramatically around a cutoff frequency of 10 kHz to 50 kHz. This change reflects the difference in whether power at the switching frequency and its harmonic components are being measured. In short, efficiency values at and below 10 kHz derive from measurement of only the power at the fundamental frequency, which is synchronized with the motor's rpm, and its harmonic components.

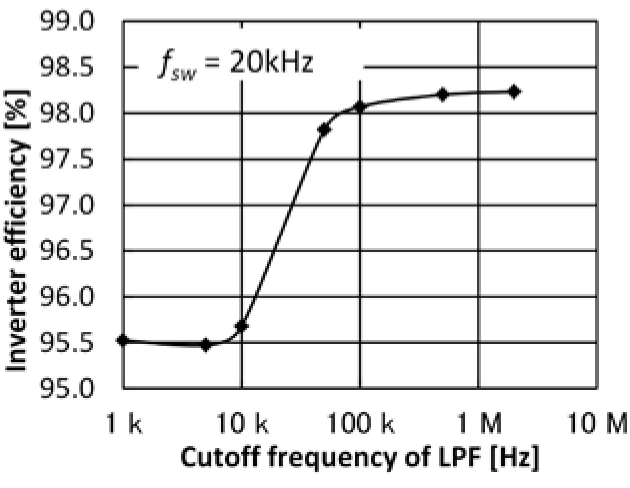

Figure 5: Efficiency measurement results of an SiC inverter while varying the Power Analyzer PW6001's LPF cutoff frequency

On the other hand, efficiency values at and above 50 kHz derive from also the measurement of power at the switching frequency and its harmonic components. At and above 50 kHz, efficiency values increase as the cutoff frequency increases. This change is a result of the ability to measure the higher-order harmonic components of the switching frequency.

In this way, the PW6001 Power Analyzer is capable of high-precision, high-stability measurement of motor drive system efficiency and loss up to the 2 MHz band, indicating that the instrument can measure efficiency and loss based on accurate measurement of power at the switching frequency and its harmonic components.

Effects of Common-Mode Voltage

Figure 6 provides a voltage wiring schematic describing measurement of the output power of a 3-phase/3-wire inverter. Since the power analyzer will measure line voltage, a large common-mode voltage will be applied across its channels. In addition, this common-mode voltage includes switching frequency and associated harmonic components. Consequently, it is necessary to make measurements with a power analyzer that has a high common-mode rejection ratio (CMRR) for high frequencies. A CMRR of 80 dB has an effect of 0.01% of the common-mode voltage on the displayed values. In other words, if a common-mode voltage of 100 V is input, there would be an effect of 0.01 V on display values.

Figure 7 illustrates the results of measuring the line voltage and common-mode voltage of an SiC inverter. The FFT results are similar to the results shown in Fig. 3, making it clear that the common-mode voltage includes switching frequency and associated harmonic components. Consequently, it can be concluded that as the frequency of the switching frequency increases, so does that of the common-mode voltage. Inverters that use SiC power semiconductors are being designed with increasingly high switching frequencies. As a result, it is desirable to choose a power analyzer with a high CMRR for higher frequencies.

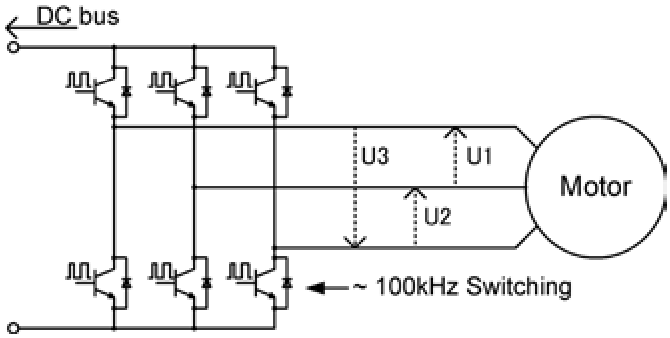

Figure 6: Wiring connections when measuring inverter output power (3P3W3M)

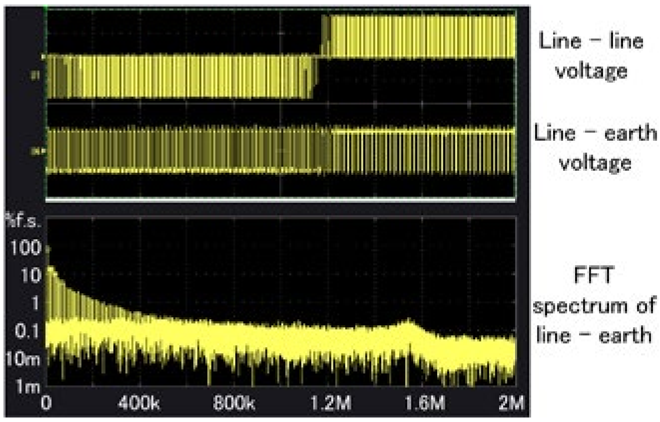

Figure 7: Common-mode voltage of inverter output voltage

Countermeasures for Current Sensor Noise

When measuring a motor or inverter with a high rated capacity, it is necessary to measure large currents on the order of several hundred amperes. It is standard practice to use current sensors when measuring large currents. Inverters produce large amounts of noise, and it is essential to implement measures to address the effects of noise on the sensors themselves and on the route along which the current sensors' output signals are transmitted in order to ensure accurate power measurement. Hioki offers a line of high-precision current sensors with such features for use with power analyzers. Consequently, it is possible to perform power measurement in a manner that is highly resistant to noise simply by connecting the power analyzer and current sensors with a dedicated connector[4][5].

Power Analyzer Frequency Band and Sampling Frequency

Figure 8 illustrates the relationship between sampling frequency and analog band in a typical power analyzer. The analog band of most power analyzers' input circuitry is greater than half the sampling frequency fs (i.e., fs / 2). In such instruments, the voltage and current components that exist in frequencies higher than (fs / 2) appear in the low-frequency domain as folding noise. This phenomenon is generally known as aliasing.

When measuring targets that include frequency components across a broad band like a PWM waveform, it becomes impossible to distinguish between the folding noise and the actual signal. The result of this phenomenon is additional measurement error and reduced repeatability in power measurement. Moreover, it becomes impossible to distinguish between the folding noise and actual harmonics in harmonic analysis. The result is that accurate analysis becomes impossible, and, for example, detection of false harmonic components more likely.

As shown in Figure 3, inverter output voltage includes components in excess of 1 MHz. Standard power analyzers have sampling frequencies ranging from 100 kHz to about 5 MHz. Consequently, there are voltage components at frequencies in excess of (fs / 2). In such cases, accurate measurement is not possible when the analog band and sampling frequency are related as shown in Figure 8. To enable accurate measurement, it is necessary to limit the analog band to less than (fs / 2). In other words, the band that can actually be used is less than half the sampling frequency.

In this way, when measuring and analyzing inverter output power, it is necessary to use a measuring instrument that has been designed in accord with sampling principles. Hioki's power analyzers are designed in this way. For example, the Power Analyzer PW6001 has a sampling frequency of 5 MHz, versus an analog band of 2 MHz/-3 dB. Consequently, the instrument is capable of simultaneous broadband power measurement, accurate harmonic analysis, and accurate FFT analysis.

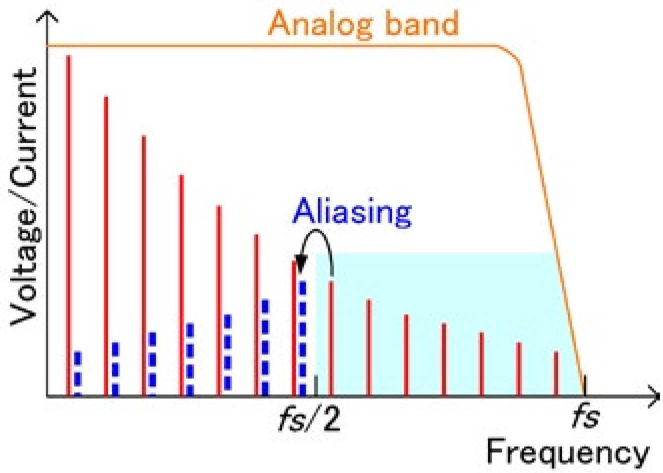

Figure 8: Relationship between analog band and sampling frequency in a standard power analyzer

Summary

This article has introduced key considerations that come into play when measuring the efficiency and loss of inverters and motors while offering actual measurement examples, as well as related topics such as requirements for measuring instruments used in such applications. It has devoted special attention to considerations that apply when measuring SiC inverters, which have been entering into increasingly widespread use in recent years, as compared to conventional inverters. We also presented actual measurement results to demonstrate how the efficiency and loss of SiC inverters can be measured with a high degree of precision and stability by eliminating various sources of error. It is the author's hope that the discussions will serve as a useful guide in power, efficiency, and loss measurement of SiC inverters and motor drive systems.

References

[1] Thal, E., K. Masuda, and E. Wiesner, "New 800A/1200V Full SiC Module" Bodo's Power Systems, April 2015, pp.28-31.

[2] Fuji Electronic, "Joint Development of Converter-Inverter for The Tokaido Shinkansen Cars Using SiC Power Semiconductor Modules" http://www.fujielectric.com/company/news/2015/20150625120019879.html

[3] Mitsubishi Electric, "Mitsubishi Electric's Railcar Traction Inverter with All-SiC Power Modules Achieves 40% Power Savings" http://www.mitsubishielectric.com/news/2015/0622-a_print.html

[4] Yoda, H., H. Kobayashi, and S. Takiguchi, "Current Measurement Methods that Deliver High Precision Power Analysis in the Field of Power Electronics" Bodo's Power Systems, April 2016, pp.38-42.

[5] Ikeda, K., and H. Masuda, "High-Precision, Wideband, Highly Stable Current Sensing Technology" Bodo's Power Systems, July 2016, pp.22-28.

How Off-Board Charger Can Benefit from the Rapid Implementation of Power Semiconductors

The market for electric vehicles (EVs) has entered a phase of fast growth, boosted by a combination of vigorous support from governments and growing consumer appreciation for electric passenger vehicles. The latest forecasts suggest that EVs (that is, hybrid electric, plug-in hybrids and fully electric vehicles) will account for 30 % of new car sales by the year 2021.

By Stefano Gallinaro; Product Marketing Manager, Vincotech

A consequence of this growth in EV numbers on the road is that the number of public and private charging points will also grow fast. EV drivers will see a rapid build-out of charging infrastructure, including charging posts on-street and at workplaces and other public locations, low-power charging units at drivers' homes, and very high-power fast-charge units at fuel filling stations. Also called off-board chargers – that is, static charging points to which a driver can connect their EV, in contrast to on-board chargers mounted inside a vehicle, which may be supplied with power by an ordinary 120 V/240 V wall socket or by a charging point.

Power Level Types	Charger Location	Typical Use	Power Level	Vehicle Technology
Level 1 120 Vac (US) 230 Vac (EU)	On-board 1phase	Home/office	1.4 kW (12 A) 1.9 kW (20 A)	PHEVs (5-15kWh) Evs (16-50 kWh)
Level 2 240 Vac (US) 400 Vac (EU)	On-board 1phase or 3phase	Private or public outlets	4 kW (17 A) 8 kW (32 A) **19.2kW (80A)**	PHEVs (5-15 kWh) EVs (16-50 kWh) EVs (3-50 kWh)
Level 3 **208-600 Vdc**	**Off-board** **3phase**	**Commercial, same as a gas station**	**50 kW** **100 kW**	**EVs (20-50 kWh)**

Figure 1: the EV industry categorizes chargers in levels according to their power rating. The Vincotech range of power modules is intended for use in the power levels marked in bold type.

The power delivery capability of charging points is commonly classed by reference to 'levels', with level 1 being the lowest-power charger, and level 3 the highest. The power delivery capability of each type is shown in Figure 1.

The growth forecast in Figure 1 has given rise to a huge, and global, opportunity for manufacturers of off-board EV chargers.

Still in its infancy, this market is today highly fragmented, and supports a large number of manufacturers. Over time, consolidation is inevitable. So which factors will determine which companies are the winners and which the losers in the battle for market share?

At least in part, this will be a matter of which suppliers respond best and quickest to customers' requirements. The customers for high-value off-board chargers are, for the most part, large organizations:

- Highway authorities or other governmental organizations responsible for sponsoring the build-out of EV infrastructure
- Vehicle service providers such as fuel (gas) station operators and highway (motorway) service station operators
- Electric utilities

These customers' primary requirements are for:

- High power efficiency. By maximizing efficiency and minimizing conversion losses, customers can control their energy cost, which makes up a large proportion of their operating expenses, and minimize the CO2 emissions associated with generating the electricity they provide.
- The lowest possible purchase (capital) cost while maintaining a specified level of quality and reliability.

These requirements define the ground on which the battle between charger manufacturers will be fought. And this brings into the spotlight a strategic decision of crucial importance to the engineering teams designing the next generations of EV chargers. This decision is over the best way to implement the power circuit in each of the three power stages of an off-board EV charger: the input PFC (power factor correction) stage, the converter stage and the output rectifier stage.

Continual innovation in power semiconductors

If a priority for customers is high power efficiency, the principal driver of efficiency improvements in all types of power systems is semiconductor technology.

Advanced power semiconductor manufacturers such as Infineon, STMicroelectronics, Fairchild, ROHM Semiconductor and Wolfspeed are constantly innovating both in the fields of semiconductor materials and of circuit topologies, and continually introduce new products – such as IGBTs, MOSFETs and diodes – which offer incremental improvements in efficiency, as well as in other operating parameters.

Breakthroughs such as the commercialization of the high-performance silicon carbide (SiC) semiconductor material are bringing rapid improvement to the operation of MOS-

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FETs and diodes. SiC is a near-ideal semiconductor material for the manufacturers of power ICs. Compared to silicon, it:

- Enables devices to switch faster, allowing the use of smaller, cheaper passive components
- Suffers from lower switching losses, resulting in more efficient power-conversion operation
- Withstands higher operating temperatures, which enables the user of smaller heat sinks, reducing the host system's size and bill-of-materials cost

The semiconductor manufacturers' continual innovation in materials such as SiC, and their many new product introductions provide charger manufacturers with a means to meet customers' demand for ever higher power efficiency. But the question for the manufacturers is, what is the best way to take advantage of the stream of new, improved power ICs that continually come on to the market, while maintaining tight cost control?

Rapid, low-cost implementation of new charger designs

This is a strategic question for charger OEMs: they will benefit from a long-term commitment to a specific plan for upgrading their products.

The problem for the charger OEM is that technology leadership in power ICs is not in the grip of a single supplier. At any given time, the most efficient power IC for any given application may be manufactured by STMicroelectronics, by Infineon, or by another semiconductor manufacturer.

In order to optimize the efficiency of their products, then, charger manufacturers need to continually modify and upgrade their designs to incorporate the latest new components. But the development and production costs associated with the introduction of brand-new product designs are very high. Normally, this limits the frequency with which OEMs can introduce new products to the market.

But what if new power ICs could be integrated into a charger's design as often as every three months, at almost no development or production cost?

This is the promise of the Vincotech family of power modules, which includes products supporting various topologies used in each of the three power stages in a high-power off-board charger. The use of power modules is already common among charger OEMs. By implementing power circuits with modules, rather than 'home-grown' circuits developed by the OEM itself with discrete ICs and other components, OEMs gain several benefits:

- Modules allow OEMs to get to market faster, since they provide a complete, ready-made power circuit that can be dropped into a product design
- A module is supplied with full documentation, and is tested and verified, so it offers guaranteed performance in the application and eliminates development risk
- A module combines multiple power components in a single, thermally-efficient package. This makes tooling and production simpler and cheaper than a system populated with multiple discrete components. It also simplifies the manufacturer's supply chain, dramatically reducing vendor and component count.

Charger OEMs derive all of these benefits when they use modules from Vincotech or from any other reputable module manufacturer. But Vincotech solves the crucial question for charger manufacturers: how to implement the latest, most efficient power semiconductors in charger designs rapidly, and at low cost?

There are two key elements to this proposition: first, Vincotech is supplier-independent. Unlike module manufacturers such as STMicroelectronics, Fairchild and ROHM Semiconductor, it is not tied to the used of just the house brand of power ICs. Instead, it can use the best semiconductors available on the market, from any manufacturer.

Second, Vincotech maintains long-term, strategic product platforms. Within each platform, every module shares a common footprint and pin-out. This means that users of Vincotech modules can replace an older module with a new, upgraded module in an existing design with little or no requirement for a board re-spin or for new tooling or assembly modifications.

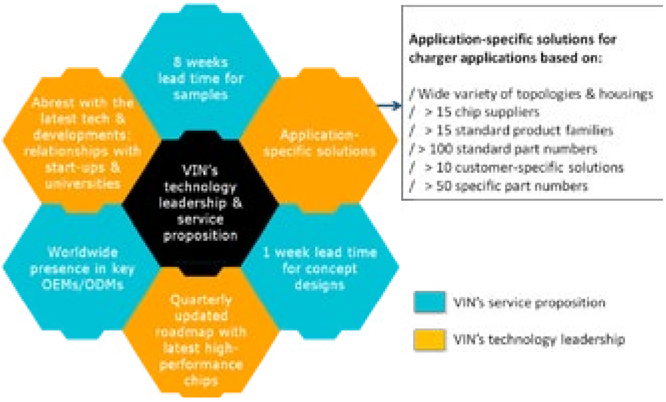

Figure 2: the Vincotech operating model helps EV charger manufacturers to implement short product upgrade cycles

To enable rapid implementation of new semiconductor technology by charger manufacturers, Vincotech implements a quarterly product upgrade schedule, integrating new ICs into its module product families almost as soon as they are released to market by their manufacturers. As a dedicated power module manufacturer, Vincotech can bear the costs associated with this short product-development cycle, amortizing them over a broad customer base and high production volumes.

And as a specialist in the design and implementation of highly integrated power systems, Vincotech has the experience and expertise to optimize the performance of popular power topologies and to take advantage of new topologies developed by semiconductor manufacturers. The elements of its service and technology leadership are illustrated in Figure 2.

This operating model enables Vincotech to offer the newest semiconductor technology in modules with market-leading efficiency. This is demonstrated by the specifications of the latest Vincotech modules aimed at off-board EV chargers, which are described below.

Efficiency up and cost down in the PFC stage

The new symmetric three-phase PFC power module, *flow*SPFC 0, is designed to deliver extremely high efficiency of up to 99.2 %, and is marketed at a remarkably low price. This PFC module is the first building block in an EV charger application: Optimal specifications at this stage can help the whole system design benefit from cost

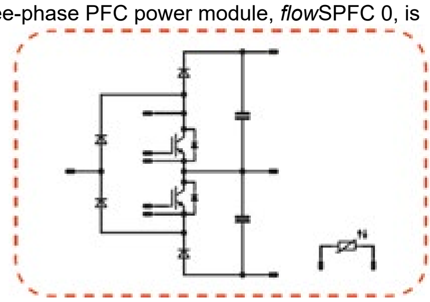

Figure 3: PFC module is the first building block in an EV charger application

savings. It enables operation at fast switching frequencies of up to 75 kHz, and is based on ultra-fast and efficient IGBTs built with the latest bipolar transistor technology.

It comes in a compact, low-inductance *flow* 0 housing, and offers various maximum current ratings, making this one module suitable for many applications.

New H-Bridge helps applications switch faster

The new *fast*PACK 0 SiC power module is the fastest representative of a new family of H-Bridge products which are designed to be faster, cooler and more efficient. In this module, Vincotech has integrated a 900 V SiC MOSFET, which has better switching performance than 1200 V SiC MOSFETs and a higher safety margin than 650 V MOSFETs. This power module supports applications switching at up to 400 kHz. It also achieves a much higher efficiency than comparable IGBT solutions, offering an 8 % increase in efficiency at light loads and a 3 % increase at full load.

It comes in a compact, low-inductance *flow* 0 housing with Press-fit pins for high electrical performance, reduced EMI and easy assembly on the production line.

Alongside this flagship 900 V power module, Vincotech offers a complete portfolio of 650 V and 1200 V IGBT, silicon MOS and SiC MOS modules, to cover all operating conditions and designs.

Small, compact and cheap companion module

From Q4 2016, Vincotech will provide a companion module for the output rectifier stage of an EV charger. The *flow*OR family of products is integrated output rectifier power modules containing 650 V or 1200 V ultra-fast diodes made from silicon or SiC, and offering maximum current ratings ranging from 30 A to 100 A.

Customers which use a *flow*OR module alongside the *flow*SPFC 0 and *fast*PACK 0 will benefit from a simplified mounting process on the assembly line, because they share a common housing design. This enables the charging point manufacturer to reduce the number of steps in the assembly process, save production time, and devote fewer engineering resources to the application's mechanical design.

The *flow*OR family will be available in the compact *flow* 0B and *flow* 0 housing styles.

Competitive advantage through rapid deployment of new technology

By basing new product designs on a strategic platform provided by Vincotech, then, charger OEMs can benefit from constantly upgraded products using the latest, most efficient semiconductor technology, without incurring the high development and production costs normally associated with a short product lifecycle. New Vincotech modules featuring the latest SiC and silicon semiconductor technology are described above.

The Vincotech platform gives the charger OEM an edge over slower-moving competitors offering products based on older technology.

By standardizing on Vincotech modules, a charger OEM can maximize its design, production and supply-chain efficiency and expect to benefit from the wave of consolidation that the charger manufacturing market is set to experience in the coming years.

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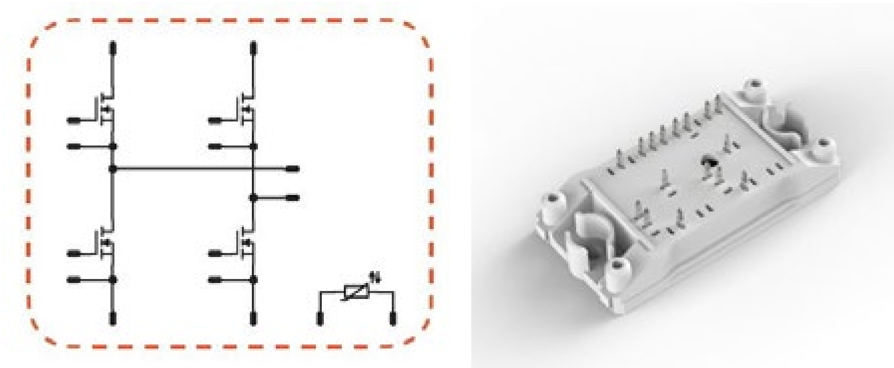

Figure 4: Complete portfolio of 650 V to 1200 V modules

Blowing Hot and Cold

How to compensate for temperature sensor accuracy at hot and cold extremes

Analogue and serial output IC temperature sensors may be accurate at room temperature, but at hot or cold extremes the accuracy can decrease nonlinearly. Normally, that nonlinearity has a parabolic shape, which means an equation can be derived to describe the typical nonlinear characteristics of the sensor.

By Ezana Haile from Microchip Technology explains

This, in turn, can be used to determine compensation for the sensor's accuracy error over a specified range of operating temperatures.

Silicon characterisation data can be used to determine the nonlinear sensor characteristics. From these data, an equation can be derived that describes the typical performance of a sensor. When the corresponding coefficients for the equation are determined, the coefficients can be used to compute the compensation for the typical sensor's nonlinearity.

In this case, a total of 100 devices were used as representative for the Microchip MCP9700 and MCP9701 analogue-output temperature sensors and 160 devices were used for the MCP9800 serial-output temperature sensor.

Figure 1 shows the typical sensor accuracy before and after compensation. It illustrates that the compensation provides an accurate and linear temperature reading over the sensor operating temperature range. A PIC microcontroller was used to compute the equation and compensate the sensor output to provide a linear temperature reading.

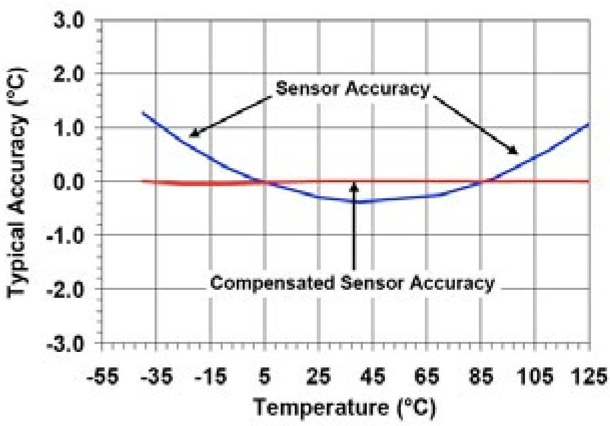

Figure 1: Typical sensor accuracy before and after compensation

Accuracy and Theory

The typical sensor accuracy over the operating temperature range has an accuracy error curve. At hot and cold temperatures, the magnitude of the error increases exponentially, resulting in a parabolic-shaped error curve.

Due to the sensor nonlinearity at temperature extremes, the accuracy specification limits are widened. The reduced accuracy at temperature extremes can be compensated to improve sensor accuracy over the range of operating temperatures.

The temperature sensors use a fully turned-on PNP transistor to sense the ambient temperature. The voltage drop across the base-emitter junction has the characteristics of a diode. The junction drop is temperature dependent, which was used to measure the ambient temperature.

A constant forward current was used to bias the diode, which makes the ambient temperature the only changing variable in the equation. However, the saturation current varies significantly over process and temperature. The variation makes it impossible to measure reliably the ambient temperature using a single transistor.

To reduce dependency on the saturation current, two diodes were used. If both diodes are biased with constant forward currents of IF1 and IF2, and the currents have a ratio of N (IF2/IF1 = N), the difference between the forward voltages (ΔVF) has no dependency on the saturation currents of the two diodes; ΔVF is also called voltage proportional to absolute temperature (VPTAT).

VPTAT provides a linear voltage change. The voltage is either amplified for analogue output sensors or is interfaced to an analogue-to-digital converter for digital sensors.

The accuracy of VPTAT over the specified temperature range depends on the matching of both forward current and saturation current of the two sensors. Any mismatch in these variables creates inaccuracy in the temperature measurement. The mismatch contributes to the temperature error or nonlinearity. The nonlinearity can be described using a second order polynomial equation.

The accuracy characterisation data were used to derive a second order equation that described the sensor error. This equation can be used to improve the typical sensor accuracy by compensating for the sensor error.

The accuracy error magnitudes are not the same at hot and cold temperatures. There is a first order error slope, or temperature error coefficient, from -55 to +125˚C. The error coefficient can be calculated using an end-point-fit method.

Once the error slope is calculated, the corresponding offset can be determined at cold by adjusting the error at cold temperature.

To capture the parabolic-shaped accuracy error between the temperature extremes, a second order term and the corresponding coefficient must be computed.

The second order temperature error coefficient was solved by specifying an ambient temperature where the calculated second order error was equal to the known error at ambient temperature. When the ambient temperature was equal to the hot or cold extreme, the second order term was forced to zero with no error added to the first order error term. This is because the error at the hot and cold temperature extremes is included in the first order error.

Results

The average sensor accuracy with the second order error compensation for all tested devices indicated that, on average, the sensor accuracy over the operating temperature could be improved to ±0.2˚C for the MCP9800, and ±0.05˚C for the MCP9700 and MCP9701.

Among the compensations, the second order temperature coefficient variable was evaluated at +25˚C. For most applications, the compensation characteristics at this temperature are adequate. However, changing the temperature at which the variable is evaluated provides relatively higher accuracy at narrower temperature ranges. For example, Fig. 2 shows the MCP9700 evaluated at 0, +25 and +90˚C.

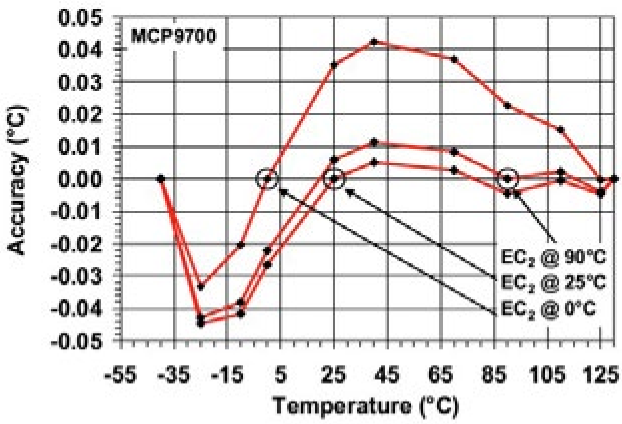

Figure 2: MCP9700 average accuracy with varying second order temperature coefficient variable

When comparing this at 0 and +25˚C, accuracy is higher at cold rather than hot temperatures. However, for temperatures higher than +25˚C, accuracy is higher at hot rather than cold temperatures. However, the magnitude of accuracy error difference among the various values is not significant. Therefore, evaluating at +25˚C provides practical results.

Calibration of individual IC sensors at a single temperature provides superior accuracy for high-performance, embedded-system applications. If the MCP9700 is calibrated at +25˚C and the second order error compensation is implemented, the typical sensor accuracy becomes ±0.5˚C over the operating temperature range.

Compensation

A PIC MCU can implement the second order accuracy error compensation for embedded temperature-monitoring systems. The equation is relatively easy to implement in a 16bit core MCU since built-in maths functions are readily available. However, 12 and 14bit cores require firmware implementation of some maths functions, such as 16bit add, subtract, multiply and divide. Figure 3 shows the firmware flowchart.

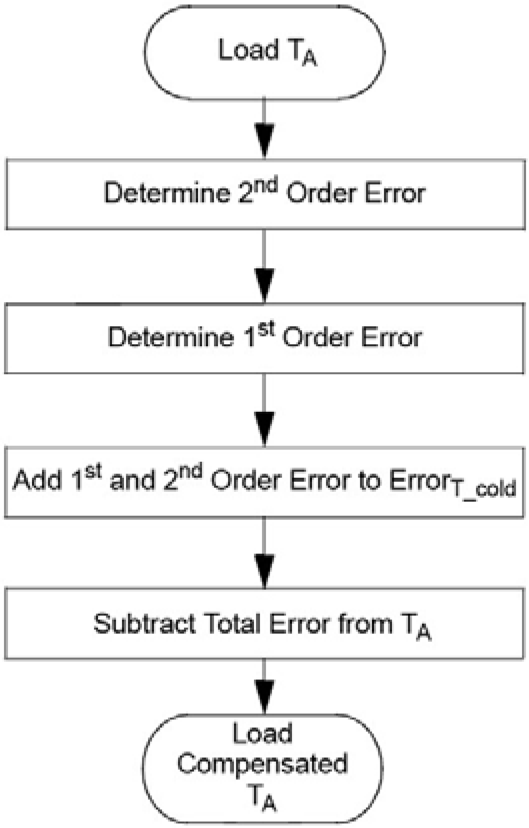

Figure 3: Firmware flowchart

MCP9800 and MCP9700 demo boards (MCP9800DM-PCTL and MCP9700DM-PCTL, respectively) were used to evaluate the compensation firmware. A constant temperature air stream was applied directly to the temperature sensors. A thermocouple was used to measure the air stream temperature and compare the sensor outputs.

The test results show the accuracy improvement achieved using compensation firmware routines. At hot and cold temperatures, accuracy is improved by approximately 1 to 2˚C, respectively

Conclusion

The nonlinear accuracy characteristics of a temperature sensor were compensated for higher-accuracy embedded systems. The nonlinear accuracy curve has a parabolic shape that was described using a second order polynomial equation. Once the equation was determined, it was used to compensate the sensor output. On average, the accuracy improvement using compensation is ±2˚C for all tested devices over the operating temperature range.

The compensation also improves the wide temperature accuracy specification limits at hot and cold temperature extremes. A PIC MCU can compute the equation and compensate the sensor output using firmware.

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Slide-By Linear Position Sensing Using Angle Sensor ICs

There are many applications, especially in automotive systems, where it is required to measure the horizontal motion of an object with high accuracy and good reliability. Some common solutions are based on potentiometers, LVDTs (linear voltage differential transformers), and magnets with a magnetic field sensor. Potentiometer based solutions are prone to mechanical wear-out, LVDTs are large and expensive, and magnet plus sensor solutions are often low accuracy.

By Alex Latham and Wade Bussing, Allegro MicroSystems, LLC

However, by using magnetic field angle sensor ICs instead of the traditional single-axis sensor, the major error sources associated with magnet plus sensor solutions are nearly eliminated, resulting in a low-cost, high-reliability, and high-accuracy method for linear slide-by position sensing.

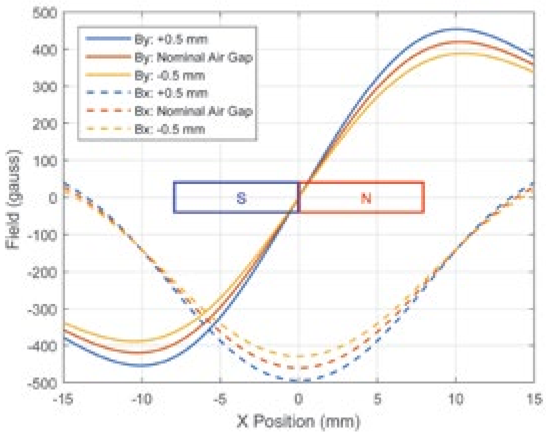

Figure 1a: Magnetic field plotted against position of a bar magnet for multiple air gaps. Magnet length is drawn to scale in all plots

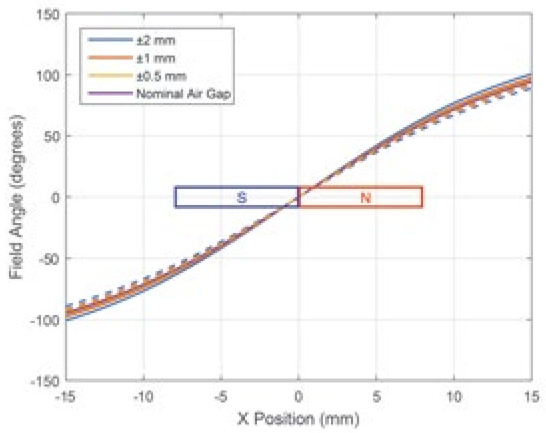

Figure 1b: Magnetic field angle plotted against position of a bar magnet for multiple air gaps

Magnet plus magnetic sensor solutions are very basic in construction. A bar magnet is attached to the moving object, and the sensor IC is positioned such that the magnet slides by it. The fields seen by the sensor IC are shown in Figure1a. As the magnet slides by in the x direction, the field in the y direction, which is what is typically sensed, looks like a sine wave with the magnetic-field/position relationship being linear around x = 0, the centre of the magnet. In this region, the output of the sensor gives the user a linear output relative to position.

There are a few challenges to this approach, including:

1. Air-gap changes between the sensor and the magnet can cause measurement errors, which is an issue for both installation and variation over product life.
2. The magnet strength changes over temperature, which can cause measurement errors if it is not compensated for. While one can include a temperature sensor on the magnetic sensor IC to do this compensation, the magnet and the sensor IC may not always be at the same temperature.
3. The range of measurement over which the magnetic field is linear with position is limited to around 50% of the magnet length, resulting in the need for magnets which are significantly longer than the distance being measured.

All three of these issues are addressed by measuring the angle of the magnetic field versus its position as follows:

1. The field angle versus position is nearly identical with respect to the air gap over a typical tolerance, as seen in Figure 1b and Figure 2.
2. The field angle is independent of the field strength.
3. The field-angle versus position curve is linear over most of the magnet length, and with piecewise-linearisation, stroke lengths of 150% or more of the magnet length can be sensed. Fig.2 shows the error/position relationship over air gap, after applying piecewise-linearisation at the nominal air gap, for both the case where B_y (the magnetic field in the y direction) is measured (traditional approach) and the case where the magnetic field angle is measured. With the B_y method, only 10 mm of stroke with ±0.5 mm of accuracy (for a ±0.5 mm air-gap tolerance) can be sensed for the 16 mm magnet shown. However, with the angle method, more than 30 mm of stroke with ±0.5 mm of accuracy can be sensed for the same physical configuration, essentially tripling the linear sensing range.

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Fundamentally, the angle method of linear position sensing offers much higher accuracy over air-gap and temperature than the traditional single-axis sensing approach, with the only constraint being that one needs a high-accuracy magnetic angle sensor IC instead of a single-axis sensor.

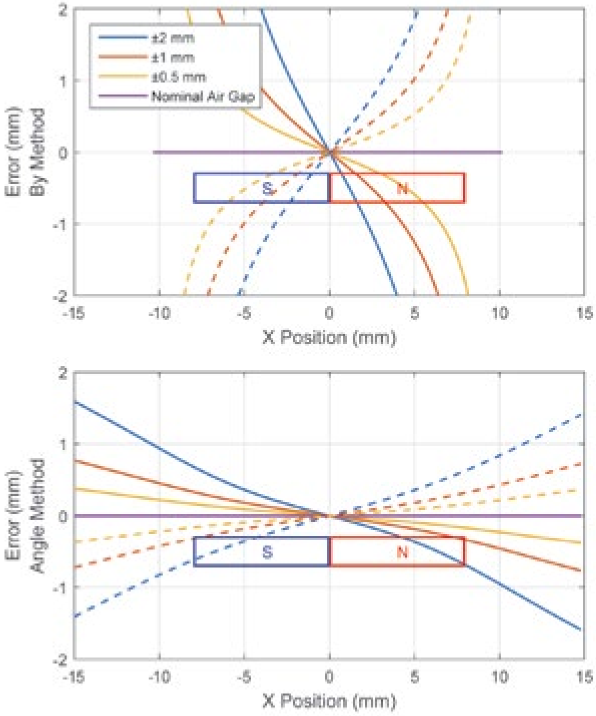

Figure 2: Error plotted against position for B_y field and angle sensing after linearisation at nominal air gap

An ideal sensor for this application is the automotive-grade Allegro A1335 magnetic angle sensor IC, based on CVH (Circular Vertical Hall) technology. Beyond providing high-accuracy angle measurement, it includes advanced features such as:

- **Piecewise linearisation of the angle measurement:** This allows compensation for the nonlinearity of the angle/position curve near the ends of the magnets, extending the linear sensing region beyond the edges of the magnet. This also allows for adjustment of the slope of the angle-output/position curve to any desired value.
- **Addressable SENT/SPI/I2C outputs:** This allows for multiple ICs in an array to be on the same bus.
- **Angle output clamps and low field detection:** These features are useful for systems using multiple ICs, as they can be used to recognise which sensor ICs are out of range and which should be used for determining the position.

Basic system configuration

The A1335 is available in a TSSOP-14 package (or dual-die TSSOP-24 for systems needing redundancy) and measures the angle of the magnetic field in the plane of the package. This means that for linear position sensing the IC needs to be oriented perpendicular to the magnet motion, as shown in Figure 3. This is simply done by placing the sensor at the edge of a PCB and having the magnet slide by the side of the PCB. The effective air gap is the distance from the centre of the magnetic sensing array, the CVH, to the edge of the magnet.

Magnetic system for linear sensing

The appropriate magnet size and nominal air gap must be chosen for the stroke length being measured to create a system with the desired accuracy. This involves the system being designed so that:

1. The magnetic angle is generally linear with position.
2. The magnetic angle is constant enough versus the air-gap tolerance of the system.
3. The magnetic field strength is above the minimum needed for CVH based sensor ICs, which is around 300 Gauss.

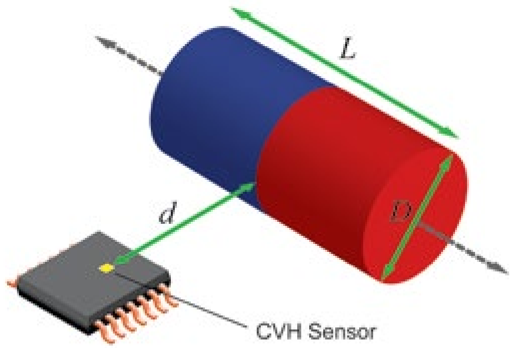

Figure 3: System configuration using A1335 angle sensor IC

Each variable in the magnetic system has a specific impact on the accuracy, allowing many degrees of freedom to improve performance or reduce cost. These include:

- **Magnet Length (L):** As a rule of thumb, the magnet length should be at least 60% of the stroke length (LS), meaning a stroke of 20 mm requires a 12 mm magnet. The linearity and accuracy over air-gap tolerance degrade further past the edge of the magnet so, in general, the longer the magnet is, the lower the error will be for a given stroke length.
- **Nominal air gap (d):** The air gap needs to be chosen so that the angle versus position is nearly linear. With very small air gaps, especially on longer magnets, the x and y fields will become non-sinusoidal, and the angle/position relationship will not be linear or as consistent over air-gap tolerance. In general, an air gap in the range of L/3 to L/2 works well.
- **Magnet diameter (D):** In general, the larger the diameter of the magnet, the stronger the field will be. Making the diameter roughly equal to or slightly less than the air gap usually works well for neodymium magnets, weaker types of magnets will require larger diameters.

Overall, for a given stroke length (L_S), a reasonable design to start with is:

$L = L_S \times 0.65$

$d = D = 0.4 \times L$

From there, these parameters can be increased or decreased in order to meet the goals of the application.

To determine whether the system will meet the design goals, the magnetic fields need to be modelled. While using advanced 3D magnetic modelling software will yield the most accurate result, it is not necessary in most cases. Fields can be modelled accurately enough using free 2D simulation software available online. Alternatively, the fields can be fairly easily computed in the case where a cylindrical magnet is used, and a bar magnet of similar size will result in nearly identical fields.

Depending on the needs of the system, different linearisation or calibration methods may be used. When using the A1335, programming software is available which will guide the user through calibration/ linearisation of a linear sensing system.

Extending the sensing range with multiple sensors

Extending the sensing range can be done either by increasing the magnet size, following the guidelines above, or by adding more sen-

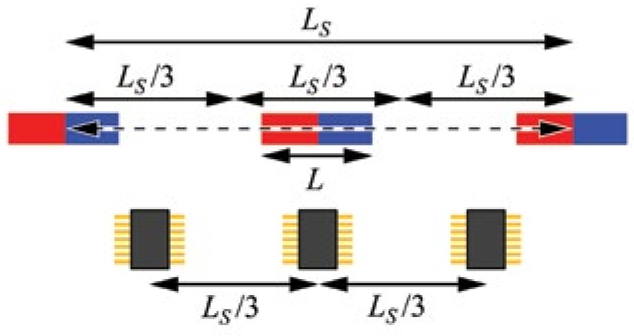

Figure 4: Using multiple A1335 angle sensors to extend the measurement range

sor ICs to the system. As the desired stroke length gets larger, the cost and size of the larger magnet will drive the solution towards using multiple sensors. A configuration using multiple sensors is shown in Figure 4. Here, three sensor ICs are used, but this can be extended to any number. One can use the low field detection feature of the A1335 to determine which sensor the magnet is over, and then use the output of that sensor to determine the exact magnet position.

Conclusion

Overall, magnetic angle sensor ICs work significantly better for linear slide-by position sensing than single-axis magnetic sensor ICs for the magnet plus sensor approach, making this method an ideal alternative to the unreliable and/or high-cost traditional solutions. The Allegro line of CVH-based angle sensor ICs, including the A1335, are well-suited for these applications, providing advanced features such as piecewise linear (PWL) linearisation, multiple digital output protocols, and automotive grade ICs with dual IC options for safety critical systems. Through the use of these sensor ICs and by following the guidelines provided, users can simply create robust, accurate, and low-cost linear position sensing solutions for any application.

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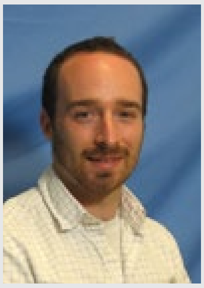
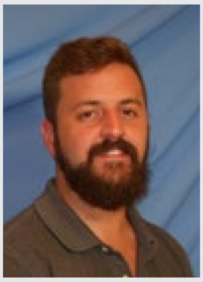
Alex Latham



Alex Latham is a Principal Systems Engineer in the Advanced Sensor Technologies division of Allegro MicroSystems, LLC. Since joining Allegro in 2011, Alex has helped to define and bring many next generation magnetic sensor ICs to market. Alex is a graduate of Dartmouth College, where he earned both his Bachelor's and Master's degrees in Electrical Engineering with a focus on power electronics and magnetics.

Wade Bussing



Wade Bussing is a Systems Engineer in the Advanced Sensor Technologies division of Allegro MicroSystems, LLC. Wade joined Allegro in June of 2012, and has spent the past several years working on projects within the following portfolios: Linear Hall-Effect Sensor ICs, Hall-Effect Angular Position Sensor ICs, and Hall-Effect Current Sensor ICs. Wade recently graduated from the University of New Hampshire (UNH) in 2015 with a Bachelor's degree in Electrical Engineering Technology.

Busbar Handles More Power without Adding More Size

Electronic power distribution has long been a function of laminated busbars. They typically provide a compact design improving system reliability and have low inductance and impedance. As requirements for power distribution in electric vehicles, from solar inverters and from wind turbine inverters, grow more complex, developers of laminated busbars are challenged to handle higher power levels with greater power density—in effect, to make smaller and lighter busbars that can channel higher power levels than ever before. More power usually implies wider conductors and larger busbars.

By Dominik Pawlik, Technical Marketing Manager, Rogers Corp., Power Electronics Solutions (PES)

Nowadays the requirements for high power density and increased reliability are not only important for busbars but also for complete inverter design. That's why a combination of special **Power Ring Film Capacitors™** and busbar assemblies offers a new solution for demanding applications. Compared to current available solutions, the combination reduces total system costs, improves reliability and increases power density.

Electronic systems rely on efficient combining and distribution of voltages from different sources. In higher-power applications such as solar and wind inverters and the powertrains of electric vehicles (EVs) and hybrid electric vehicles (HEVs), energy must be channeled with minimal combining and distribution loss. An ongoing challenge for these inverter systems is to develop power distribution components such as laminated busbars that are rugged enough to handle high power levels without simply making them larger than existing laminated busbar designs.

A solution lies in a different approach to busbar design, using an assembly configuration of laminated busbar from Rogers Corporation and Power Ring Film Capacitors™ from SBE, Inc. The resulting solution is a metallized polypropylene film capacitor in a low-profile, ring-shaped form. It adds minimal volume and weight to the busbar-capacitor assembly while dramatically increasing power density. With this approach, it has been possible to reduce significant equivalent series inductance (ESL) and keep the compact design due to a high aspect ratio form factor and increased power density.

Keeping Busbars Small in Size but Powerful Enough

Busbars are indispensable circuits for routing power to many circuit branches and components within an electronic design. As an example, they are visible on solar panels as the circuit lines running from one photovoltaic (PV) cell to another, with the voltages added in series to achieve the final output voltage of a solar panel. They are not as visible but just as essential for power distribution with solar- or wind-based power-generating systems. They must be compact to fit within the circuitry of equipment enclosures, and have low inductance and loss to minimize performance degradation or even breakdowns from power surges and potential overheating caused by ripple currents.

Busbars are essential components in energy storage and distribution systems, including for connections of solar panels and wind turbine inverters to the electric grid. As solar and wind inverters for home and industrial applications continue to achieve higher power levels, busbars are required to channel higher voltages and currents but without adding size to previous busbar solutions. The problem lies in developing physically small busbars capable of handling the higher power presented by solar and wind inverters as well as the power distribution systems in EVs and HEVs.

Handling Power Surges

The high power density and capability to survive power surges caused by ripple currents for high-voltage power-switching applications usually requires banks of large-value electrolytic capacitors along with high-frequency bypass capacitors to handle cases of ripple currents. Adding such components to a busbar typically increases size and weight. But because of the low profile of the annular Power Ring Film Capacitor, very little size and weight is added to the RO-LINX busbar, although voltage and current carrying capacities are dramatically increased. The film capacitor features inherently low equivalent series inductance (ESL) and equivalent series resistance (ESR) to handle high power levels while minimizing the thermal degradation and heating effects suffered by circuits with higher losses.

Figure 1: This novel busbar assembly combines a laminated busbar with a low-profile, annular capacitor for improved power-handling capability in a compact form factor.

Attaching the Capacitor

An important step in making this busbar/capacitor combination practical is the method of attaching the capacitor to the busbar. The combination of materials in each component exhibits a complex coefficient of thermal expansion (CTE) not only between each layer of material in the busbar and the capacitor. In addition, the interface between the busbar and the capacitor is subject to stress caused by vibration and changes in temperature—both environmental temperature and heating induced by high conducted power levels. With low ohmic resistance and good heat-transfer characteristics, the capacitor contributes a stable thermal interface to the busbar assembly. The capacitor is attached to the busbar assembly by means of spot welding. The interconnection method contributes low resistance and inductance for low ESL of the combined assembly.

These integrated busbar-capacitor assemblies can switch voltages from 450 to 1500V and current of 1000A or more, with maximum power rating approaching 1 MW. The capacitance ranges from 75 to 1600µF, with capacitance values maintained to a tolerance of ±10%. These enhanced busbars are rated for minimum operating temperatures from -40 to +85°C for use at the maximum voltage rating, but can typically handle operating temperatures of -40 to +105°C.

The attachment method used to combine the busbar and capacitor is critical in maintaining low resistance at high power levels since excessive contact resistance of all connection points along a busbar leads to thermal junctions which can jeopardize reliability at high power levels. Welding has proven a reliable attachment method for connecting battery packs in EVs and HEVs and can be performed in high-volume production using automated assembly techniques.

Choice of Materials

The choice of materials was also critical in determining the ultimate high-power performance from the new busbar-capacitor component. For the busbar, for example, the cross-sectional size as well as the choice of conductor material will determine the busbar's current-carrying capacity. Laminated busbars usually employ aluminum or copper conductors, which may be plated with an additional metal such as silver, tin, or nickel. The choice of busbar materials, such as conductors and insulators, will also limit process manufacturing temperatures for interconnecting circuits to a busbar. Solder-free attachment methods, for example, require high processing temperatures and busbar materials capable of withstanding those temperatures during manufacturing. Insulation materials separating busbar conductors should exhibit stable dielectric constant with temperature, to minimize variations in capacitance and voltage.

An Innovative Annular Capacitor

Annular capacitor technology makes possible dramatic improvements in the power-handling capabilities of the busbar/capacitor combination components, but, like the busbar itself, materials must be carefully chosen in consideration of potential thermal effects at high power levels. One goal is low inductance in combination with the busbar, and the capacitor's use of polyester and polypropylene dielectric materials contribute to low ESR and ESL. The impressively low inductance, for example, makes it possible for these capacitors to work at high voltages and currents with only microfards of capacitance. In testing, the Power Ring film capacitors have achieved ESL values as low as 5nH for a 600V, 1000µF link. The ring shape of the capacitors (See Fig. 2) enables short, symmetrical interconnection distances to electrodes to minimize connection distances and help achieve the low ESR characteristics.

Polypropylene film metallized with zinc alloy, for example, has been used for capacitors in EV and HEV drivetrain applications where it was important to maintain consistent performance even under the severe temperature conditions found in vehicular electronic applications. Film capacitors with 1000 µF value have withstood short-term power levels to 100 kW and provided more than 20,000 hours operating time in automotive drivetrain applications with only engine coolant fluids as a means of dissipating excessive temperatures in the capacitors. The annular form of these capacitors provides an effective shape for dissipating any heat generated internally while also optimizing thermal flow from external heat sources.

The excellent thermal characteristics of the materials used in the ring-shaped capacitors, spot-welded to busbars which are formed of thermal conductive metals and dielectric materials, provides an almost continuous thermal path that is essential for avoiding hot spots at high power levels. In this choice of materials for both components, the combination provides a busbar with integrated capacitor that is well equipped for the higher voltages and currents found in many modern applications, such as EVs, HEVs, as well as solar and wind-turbine inverters.

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Output Ceramic Capacitor Roles in POL Applications

Today's power supply design engineers have many design aspects and priorities that need to be considered. Design priorities tend to be in the following order: topology, controller, FET switch(es), drivers (if stand-alone), magnetics, power passives, and finally, which multi-layer ceramic capacitors (MLCCs) to use and how many.

By Chris T. Burket, Sr. Applications Engineer, TDK Corporation of America

As long as MLCCs are available that meet design needs, at least on the data sheet, MLCCs remain a low priority. Granted, all of the devices in the power converter are important, however MLCCs play multiple roles within power supply designs with numerous parameters being involved. All of these roles end up being important to the converter's performance, and especially in high density POL power applications with complex output capacitor solutions.

MLCC Background

MLCCs are known for their small size, high capacitance density, and low equivalent series resistance (ESR) and inductance (ESL) values. However, typical parameters provided by MLCC suppliers are: case size, capacitance and tolerance, temperature characteristics, and voltage rating. The power supply designer needs to know effective capacitance (actual in-circuit capacitance), ESR and ESL values, ripple current (RC) handling and cost. Some power designs specifically target a minimum capacitance (C value), and maximum ESR and ESL values for a given output capacitor solution. This is especially true in high transient applications.

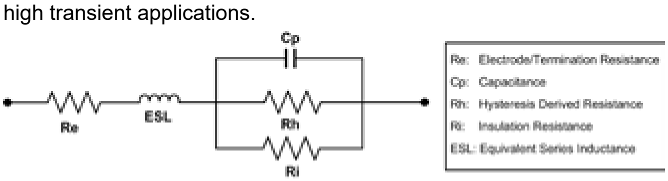

Figure 1: Equivalent Circuit Model of a MLCC

Figure 1 shows the MLCC equivalent circuit model where the hysteresis resistance (Rh) is a frequency dependent value (which relates to the dielectric material used and its respective polarization delay) and is reflected as a changing ESR value in the ESR- /Z/ versus frequency curve shown in Figure 2:

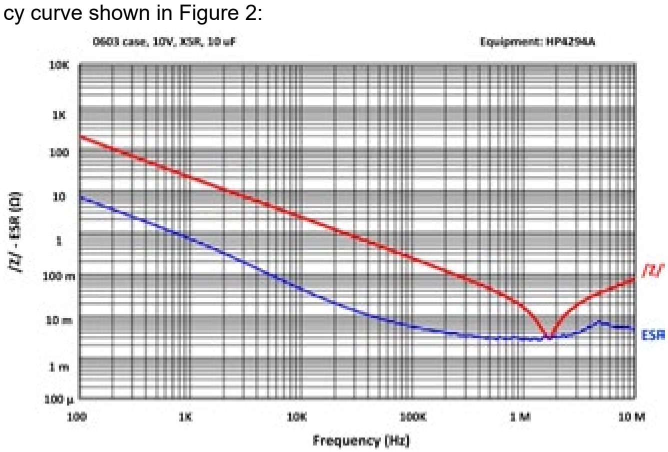

Figure 2: ESR, /Z/ vs. Frequency

The well documented capacitance change due to temperature is dependent on the dielectric material, and yields a known capacitance change over a defined temperature range. However another contributor that affects effective capacitance is the applied DC voltage, typically called the "DC Bias effect". As the applied DC voltage increases, the dielectric constant (K) and capacitance both decrease as a temporary phenomenon. Additionally, as any applied AC voltage decreases, the effective C value also decreases. This AC related decrease is important in low voltage applications where ripple voltage control is critical such as in Vcore designs for CPUs. See Figure 3.

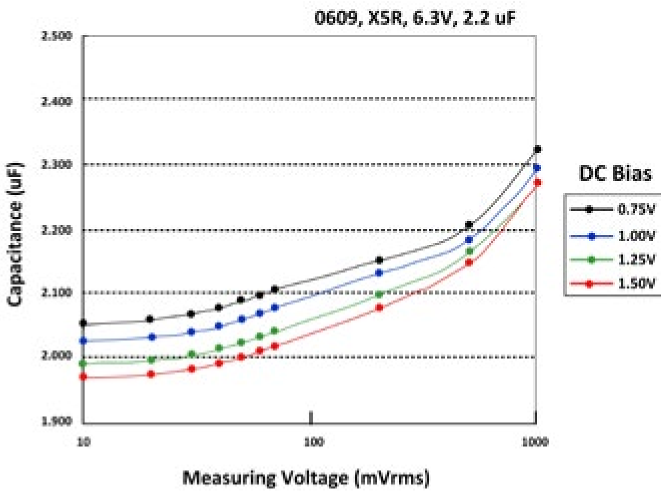

Figure 3: DC/AC Voltage Effects on MLCCs

ESR values of MLCCs are dependent on many parameters. Key factors include: case size; number of layers; inner electrode material, thickness, co-planarity, density, and length/width aspect ratio; applied DC voltage (like with capacitance); and frequency.

ESL values for MLCCs are dominated by the case size and their length/width aspect ratio of the inner electrodes. ESL values are typically given per case size. Additionally, the number of external terminations and their configuration also impact ESL.

Ripple current rating, though no industry standard exists, relates to a specific self-temperature rise due to I^2 x ESR losses which create heat. Therefore, the ripple current value is dependent on frequency and DC voltage and its curve is the inverse of the ESR curve. A typical MLCC RC versus frequency curve is shown in Figure 4a:

which is for a specified self-temperature rise (ΔT) maximum. The maximum allowable ΔT may vary supplier to supplier. Figure 4a lists the ΔT as +20°C which is very conservative for capacitors rated up to +85°C or +125°C. In lower ambient temperatures, the MLCCs can be subjected to higher ripple current and still meet the rated temperature ($T_{operating} = T_{ambient} + \Delta T$). In this example, the MLCC ripple current capability ranges from 0.25A (1000 Hz) to 2.25A (1 MHz). Having accurate capacitor frequency dependent information is a must in order to design in the proper output capacitor solution. Also, MLCC suppliers may provide RC vs. temperature rise but must specify at which frequency the curve is being generated for. An example of this is shown in Figure 4b.

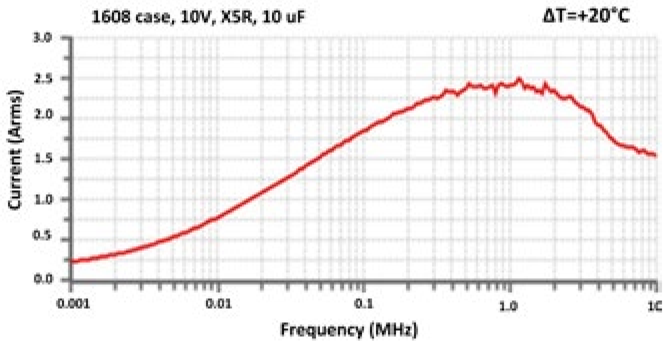

Figure 4a: Ripple Current vs. Frequency

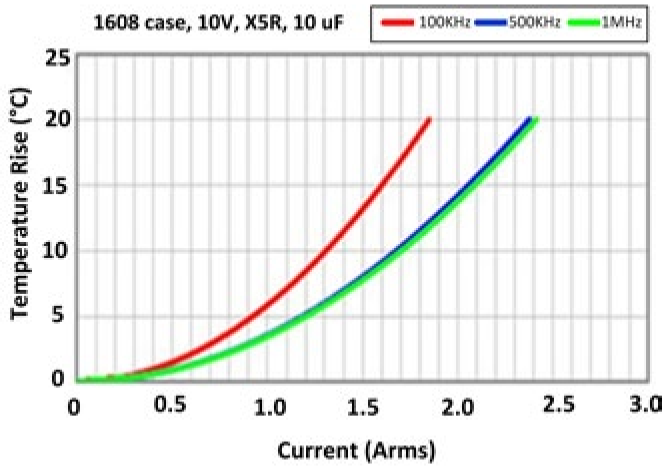

Figure 4b: Temp Rise vs. Ripple Current

With this understanding, the following sections will address a few of the many key roles that the output MLCCs perform in a typical POL Buck power supply (used for simplicity). Highlighted roles are: 1) low-pass filter, 2) ripple voltage suppression, 3) ripple current handling, 4) energy storage, 5) transient response, 6) load dumping, and 7) transient voltage spike suppression.

Low-Pass Output Filter (sometimes called RF Output Filter)

In the Buck converter, the value of the output inductor (L), along with the equivalent output capacitors' C value, form a low-pass filter (LPF). The frequency response of this filter has a corner frequency, fc, at:

$$fc = \frac{1}{2\pi\sqrt{LC}} \qquad \text{(Eq. 1)}$$

which is used to remove the converter's fundamental switching frequency (Fsw), its subsequent harmonics and also to decouple any AC content and switching transients from the desired DC current flowing to the output load. This also includes helping to smooth out the triangular current waveform of the output inductor. For proper performance, the corner frequency of the low pass filter needs to be well below the Fsw. Due to this, the C value of the output MLCC(s), its tolerance and stability over various conditions, including DC Bias effects, all need to be considered.

Ripple Voltage Suppression (Smoothing)

Ripple voltage, assuming a steady state load, is the difference in output voltage across the load and output capacitors during the ON time and OFF time of the Buck converter. During the ON time, where AC + DC current is being supplied through the inductor, the AC current flows into the output capacitor for recharging (to some maximum voltage level) and the DC current flows to the load. During the OFF cycle, the energy starts to drain from the output inductor (through the collapsing of the magnetic field) since no input current is being sourced and the output capacitors become the secondary (if in continuous conduction mode, CCM) or sole energy source (if in discontinuous conduction mode, DCM). With a stored energy of $E = ½CV^2$, the output capacitors supply the current to the load, and as they do, the voltage level starts to drop (aka voltage droop or Vdroop) as the energy is being drained from the capacitors for the remainder of the OFF cycle. The droop amount is dependent on the load current, the output inductor's value, the OFF time and the total C value (higher = better suppression) and ESR value (lower being better since this reduces the internal voltage drop V = I x R) and the ESL (lower = faster response) of the output capacitors. The designer needs to know each of these per MLCC in order to determine the system C, ESL and ESR values. One of many equations used to calculate the minimum C value is:

$$Cout_{min} = Iripple/(8 \times Fsw \times Vripplemax) \qquad \text{(Eq. 2)}$$

where Iripple is the allowable ripple current and Vripple is the allowable ripple voltage. Higher Cout value means higher costs.

Ripple Current Handling

Ripple current is the difference of current flowing into, and out of, the output capacitors during the ON cycle (into the capacitor) and the OFF cycle (out of the capacitor). The internal varying capacitor AC current, causes self-temperature rise due to I^2 x ESR power losses. To accommodate higher ripple current, the designer would need to use either lower ESR capacitors (i.e., higher capacitance or specialty MLCCs) or use more pieces of the existing capacitor, which also reduces the amount of current subjected to any one capacitor. Depending on how much temperature increase, the ambient temperature and the time duration, potential MLCC failures could occur if sufficient ripple current handling capability isn't designed in.

For many Buck converter applications, the controlling factor for output capacitor selection is ripple current handling capability. Therefore, the key parameters of the MLCCs are ESR (maximum) values and ripple current (minimum) ratings.

Energy Storage

As mentioned, the energy stored within a capacitor is $E = ½CV^2$. The larger the C value, the more energy that is stored. But the designer needs to compare energy storage needs versus size, weight, quantity, board space, frequency response, product life span (aging effects) and cost trade-offs. Ripple voltage, ripple current, voltage droop, system ESR values, and ripple current handling per capacitor all will affect the C value needed and therefore, impact the energy storage of the output capacitors. Energy storage, in terms of the voltage and the capacitance, determine how long the "hold up" time will be during the OFF cycle or in the event of loss of power. For this key function, the C value, tolerance, temperature and DC Bias effects are the key MLCC parameters.

Transient Response

In the complex real world of power electronics, the load can be varying and have load step-ups (i.e. the load increases) that equate to hundreds of amps per micro second (di/dt) or higher (ex: server CPUs). For these cases, the converter (or voltage regulator, VR) cannot respond as it needs to wait for some feedback signal notifying it that there is a load change. Likewise, the current through the output inductor cannot change instantaneously and thus, cannot react fast enough since it needs to build up its magnetic field prior to being able to supply the additional needed current demanded by the load. The only energy sources that can react to these extreme requirements are the output capacitors in the Power Distribution Network (PDN).

Due to their low ESR and ESL values, MLCCs are one of a few capacitor technologies that can provide the performance needed during high di/dt events. However, standard configuration MLCCs still cannot provide the needed performance in the most stringent applications. The internal ESL of the capacitor must first be “saturated”, that is, build up the small magnetic field (H) which inhibits current flow, prior to being able to start responding to the load change. Therefore, specialty capacitors like reverse geometry capacitors, where the terminations are placed on the MLCC sides or MLCCs with special internal electrode configurations and multi-terminations, reduce both ESR and ESL dramatically.

Until the MLCCs can react to the load change, the system voltage level will begin to drop and may fall below a critical minimum level (e.g. Vcc tolerances of CPUs) if the output capacitors cannot source the load current for enough time until the other energy sources begin to react as well. The low ESR/ESL MLCCs are the first line of defense to minimize the voltage droop but may not have enough bulk energy storage to do it completely on their own.

During the transient event, the MLCC response is first limited by its ESL, which initially prohibits the current flow out of the (nearest-to-the-load) capacitors. The next phase of response is dominated by both the ESL and ESR and involves the next bank of capacitors. The third stage is ESR and C value dependent involving the bulk storage capacitors and finally, recovery occurs by other storage devices and the VR beginning to source more current. The basic equations for voltage droop contributors within the output capacitors are:

$\Delta V_{ESL} = ESL * di/dt$ (high frequency transients) (Eq. 3)

$\Delta V_{ESR} = ESR * I$ (Eq. 4)

$\Delta V_{C} = {}^{1}/_{C}\int I dt$ (Eq. 5)

with a simulated response for a multiple capacitor technology solution in Figure 5a, for the PDN network shown in Figure 5b:

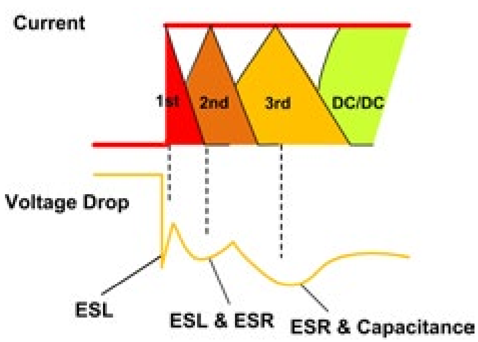

Figure 5a: Voltage Drop During Transient

In transient response scenarios, ESL is critical and MLCC suppliers continue to strive for lower solutions. Designers target a maximum value for each output capacitor technology and also reduce PCB layout stray inductances. Another key parameter is ESR and usually the focus is to minimize this value to meet a maximum target. Lastly, the capacitance value and its bulk energy storage are needed to supply energy until the converter’s control loop can respond and the converter starts to supply energy to the load and recharging the capacitors in the PDN. Here, the designer requires a system minimum value typically for each capacitor technology.

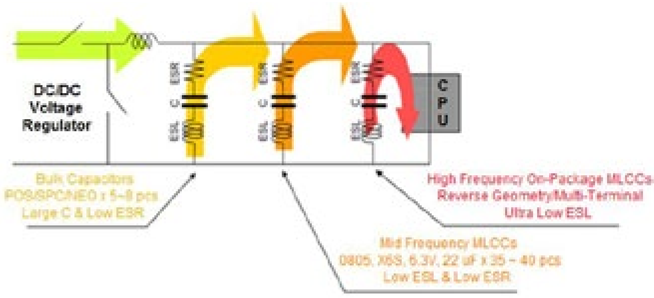

Figure 5b: High di/dt Capacitor Scheme of PDN

Load Dumping

Another extreme scenario is load (energy) dumping which occurs when there is an abrupt decrease in the current demand (load step-down) … like when the CPU goes into idle mode. Here, the magnetics are saturated with stored energy ($E = ½LI^2$) during high load current demand. When there no longer is a load path to source, the only remaining outlet for the current to take is through the output capacitors. Due to this, the design engineer needs to consider trade-offs in the inductance value. Too small of a value allows too much ripple and too high of a value potentially stores too much energy, requiring additional output capacitors to handle the load dump.

The increased current going to the capacitors creates higher power losses ($P_{loss} = I^2 \times ESR$) and may cause thermal issues much like for high ripple current mentioned above. Also, with the increased current being dumped into the capacitors, there may now be an excessive voltage spike. Therefore, the designer needs to balance the inductance value and its stored energy with the output capacitance and its energy storage capability and ensure that there is enough capacitance, low enough ESR to handle the energy being dumped by the inductor.

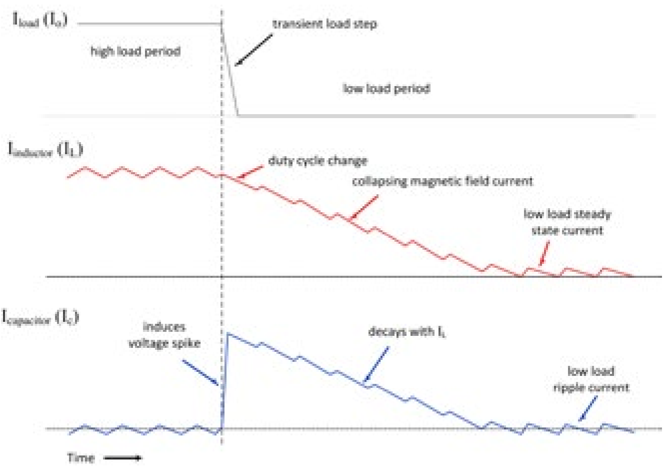

Figure 6 – Load, Inductor, Capacitor Currents During Load Step-down

Transient Voltage Spike Suppression

As mentioned above, transient events can be a load step-up or a load step-down. Since the slew rate of the output inductor current increases faster than it decreases (when Vin > Vout), the transient during step-down is more critical. During the step-down change, and like for load dumping, the inductor current no longer flows 100% to the load since its demands have dropped substantially. Therefore, a large percentage of the current now must flow through the output capacitors, since:

$$I_L = I_O + I_C \qquad \text{(Eq. 6)}$$

where I_L is the inductor current, I_O is the output load current and I_C is the current through the capacitor(s). These are shown in Figure 6.

Also, just before the step-down transient event, the voltage of the output capacitors would be at or near their maximum value if at a constant high load. Therefore, with the pre-existing capacitor voltage and the voltage drop due to large current flowing through the capacitor across both the internal ESR and ESL, this introduces a voltage spike across the capacitor and load during the transient. The output voltage waveform during the step-down transient can be calculated as:

$$v_o(t) = i_c \cdot ESR_c + ESL_c \cdot \frac{d}{dt} i_c(t) + \frac{1}{C_0} \cdot \int_0^t i_c(t) \cdot dt \qquad \text{(Eq. 7)}$$

which are the combined Vdroop equations previously given but for current now flowing into the output capacitors and causing a voltage increase. Looking at what occurs at a micro-level, the slower reacting inductor current I_L cannot follow the fast-changing load current I_O demand, therefore I_C goes through the output capacitor's ESR_C and its ESL_C. Both the pre-existing capacitor charge and the ESR_C and ESL_C voltage drops form the output voltage spike that is created during the transient period. This voltage spike then lasts until the energy is drained from the output inductor I_L and the voltage regulator has now adjusted itself to provide reduced current.

Smart systems, such as CPUs + VRs, incorporate functions like Adaptive Voltage Positioning (AVP) which help reduce the effects of a transient voltage spike in sensitive applications, but much of the burden still falls upon the output capacitors and therefore, their ESR and ESL values are critical in minimizing the peak value of the transient voltage spike. The lower these values, the lower the voltage spike peak.

Conclusion

All of the above roles are meant to provide the designer with a basic understanding of the importance of multi-layer ceramic capacitors and relevant key parameters. Each of the functions and respective capacitor solutions need to be calculated, modeled, simulated and tested prior to design completion. Additionally, it is important to know that all of the capacitor parameters can vary significantly supplier to supplier, even if similar on paper, so it is also important to compare actual samples with supplier data curves and those from other suppliers.

As experienced power engineers know, there are many other considerations for which MLCCs play a major role which cannot be addressed here due to limited space. Some other key roles are: 1) control loop compensation and stability, 2) Phase and Zero setting, 3) EMI suppression and load bypassing, 4) load line impedance matching, 5) load noise filtering, and 6) efficiency improvement. If interested, please contact the author for the complete article at chris.burket@us.tdk.com.

References/Sources

- Jeff Boylan – TDK-Lambda Americas, EVP of AC-DC and DC-DC Power Supply Product Group
- Ed Stanford – CTO of Power Delivery Consultants, LLC, ed.stanford@pwr-delivery.com
- Gus Mehas – Integrated Device Technology, Director of Technical Staff, power guru
- Dissertation Paper – "High-Frequency and High-Performance VRM Design for the Next Generations of Processors" – Kaiwei Yao, Virginia Polytechnic Institute and State University, 2004

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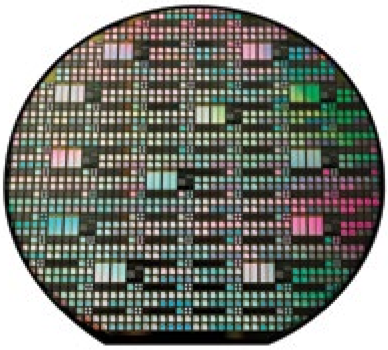
150 mm SiC Wafers Are the Key to Building Higher Reliability Power MOSFETs at a Lower Cost



Since their initial release to the market four years ago, several factors have slowed the commercial adoption of silicon carbide (SiC) MOSFETs, including their high cost (more than five times that of silicon IGBTs) and uncertainty toward their reliability, parametric stability and lifetime.

By Sujit Banerjee, Ph.D., CEO, Monolith Semiconductor Inc. and Kevin Speer, Ph.D., Global Manager, Technology Strategy - Power Semiconductors, Littelfuse, Inc.

Despite these concerns, a growing number of power electronics systems manufacturers are turning to SiC power MOSFETs to balance their needs of greater efficiency, power density, and reliability with the natural desire for lower cost devices.

To encourage broader use of this revolutionary technology, SiC MOSFET manufacturers must be able to provide power electronics designers with devices that bring together a stable threshold voltage, a suitably long gate oxide lifetime, and last but not least, competitive pricing. For some manufacturers, this may require a fundamental rethinking about how and where to produce their products.

This rethinking may involve two central approaches. First, developing design and process techniques that are compatible with processes in a conventional silicon CMOS fab will serve the dual purposes of eliminating the capital expenses associated with launching a dedicated SiC facility as well as leveraging economies of scale in an incompletely filled fab. Second, producing devices on 150 mm (6 inch) SiC wafers rather than 76 mm (3 inch) or 100 mm (4 inch) SiC will allow two to four times as many devices produced per wafer (assuming yields and substrate thickness are the same).

Indeed, more than ninety percent of SiC device processes are compatible with processes already available in a silicon CMOS fab. By integrating the process flows for both silicon and SiC wafers and running them in parallel, one may take advantage of substantial economies of scale. The approach, which was recently employed to produce 1200 V SiC MOSFETs in an automotive-qualified 150 mm CMOS fab, has created devices that demonstrate high manufacturability, excellent device performance, highly reliable gate oxides, and robust parametric stability at operating junction temperatures of 175 °C.

Although SiC is fundamentally compatible with most CMOS fab processes, a number of significant hurdles must be overcome in order to realize this approach, particularly including requirements for high-temperature processing. Other challenges include integrating CMOS- and SiC-specific process steps, as well as making metal and dielectric stacks used in the SiC MOSFET compatible with a conventional CMOS fab. Whenever possible, standard process steps available in a CMOS foundry should be used with SiC wafers, such as implantation masks and top-level interconnects.

For steps such as gate oxidation and metallization, SiC-specific processes may be developed using CMOS production tools such as high-temperature furnaces and Rapid Thermal Processing ovens, but dedicated tools are required for implant activation and certain ion implantation steps. Mechanical wafer handling procedures also require modification due to the semi-transparency of SiC wafers. For example, sensors set up for use with opaque materials respond incorrectly when used with SiC, leading to wafer breakage during loading/unloading. Automated defect detection tools can confuse sub-surface features with surface defects, and differences in wafer thickness can further complicate wafer handling. Nevertheless, with proper process modifications, SiC and Si wafers can be run in parallel in a high-volume production environment, taking advantage of the less costly production processes running in the CMOS fab.

Producing rugged SiC MOSFETs with wide process margins requires ensuring stable and uniform avalanche breakdown in the device unit cells, avoiding high fields in the oxide, and breakdown in the edge termination. Optimally, device termination should achieve close-to-ideal parallel plane breakdown voltage over a broad dose range,

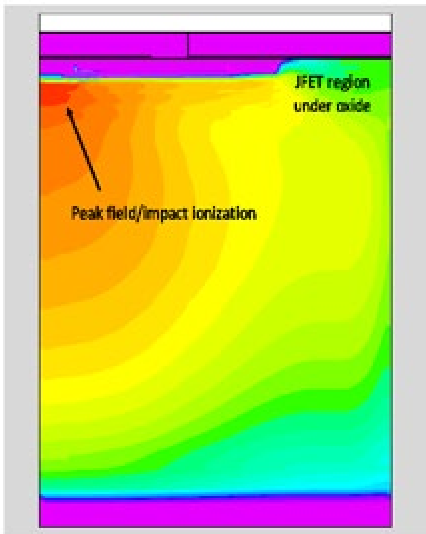


Figure 1: Impact ionization contours at device breakdown. To ensure stable avalanche breakdown, the device was designed to break down at the center of the unit cell.

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providing a wide process margin. In addition, the JFET region of the device under oxide must be optimized with proper doping concentration and physical dimensions.

Figure 1 shows an example of impact ionization contours at device breakdown. In this case, the device was designed to preferentially break down at the center of the unit cell, ensuring uniform avalanche conditions and a low peak field in the oxide. Other important device and process design modifications include optimizing the channel and P-well designs to ensure the device remains off over the entire voltage and temperature envelope.

Figure 2 presents the typical off-state IV (VGS = 0) characteristics of the fabricated MOSFETs from 25 °C to 175 °C with low leakage current (<100 µA) over a worst-case voltage and temperature envelope. Figure 3 compares the forward characteristics of these devices at 25 °C and 175 °C. The typical on-resistance of these MOSFETs at VGS = 20 V, 25 °C is 65 mΩ. Although these devices were optimized for robustness and manufacturability, the typical specific ON-resistance, Rsp, (normalized to the devices' active area) is competitive with that of other 1200 V SiC MOSFETs now on the market. With more aggressive processes and designs, it has proven possible to achieve Rsp of 3.1mΩ-cm2 on an identical process platform.

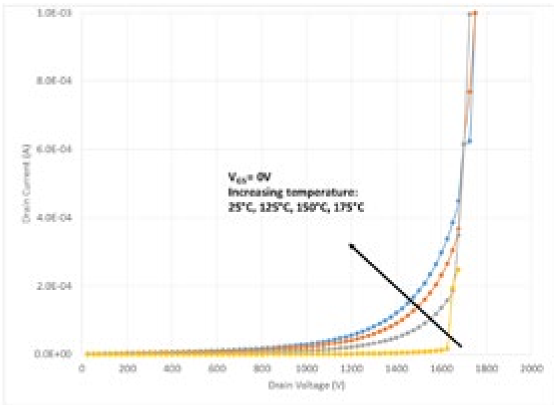


Figure 2: Typical forward characteristics (IDSS; VGS = 0) of manufactured MOSFETs for temperatures from 25 °C to 175 °C. Low leakage current up to 1200 V and 175 °C, entire operating envelope.

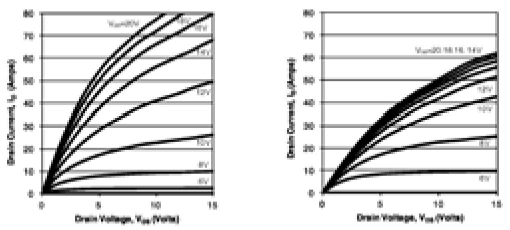


Figure 3: Forward characteristics at 25 °C (left) and 175 °C (right).

Reducing SiC MOSFET production costs requires a highly manufacturable process with sufficient margin. To evaluate the manufacturability of the process, the breakdown voltage distribution of a large quantity of devices from multiple wafers from different fab lots was analyzed. The analysis showed that the process provided sufficient margin to accommodate a wide range of epilayer doping variations. Because 100 mm SiC wafers remain more common than 150 mm SiC wafers, the diode leakage current of the fabricated devices was also investigated to assess defect density and device yields. Diode leakage wafer maps revealed only randomly located failures and yields of greater than ninety percent.

The ruggedness of the devices produced was evaluated with various techniques, including sourcing a constant current of 10 mA into the drain for 10 seconds in the OFF state and in avalanche condition. Results showed the devices were extremely robust with stable and uniform avalanche (Figure 4).

Because gate oxide quality is a common concern for SiC MOSFETs, Time Dependent Dielectric Breakdown (TDDB) measurement of capacitors at high temperatures was previously used to study the fundamental quality of the gate oxide process. Charge-to-breakdown (QBD) measurements in large area DMOSFETs produced QBD values well above 10 C/cm2 and no defective tail that would indicate intrinsic failure modes. High-temperature Gate Bias (HTGB) testing at VGS of -10 V and +20 V showed excellent threshold voltage stability. When the MOSFETs were subjected to 1400 hours of high-temperature (175 °C) reverse bias (HTRB) testing at VDS = 960 V and VGS = 0 V, stable breakdown voltage characteristics were observed.

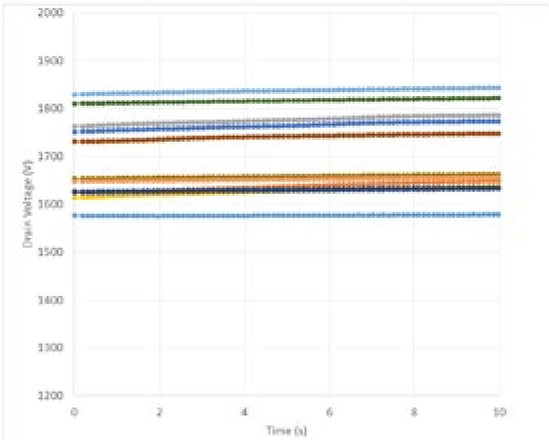


Figure 4: Breakdown voltage vs. time testing demonstrated that the process produced robust devices with stable avalanche characteristics.

High power SiC MOSFETs hold enormous promise for the continuing development of compact, high efficiency power conversion systems in applications like photovoltaic inverters, datacenter power supplies and electric vehicle chargers. Looking further ahead, there will likely be opportunities in automotive traction inverters and motor drives. However, to turn these opportunities into reality, prices must come down substantially. Innovative techniques like producing them in high-volume, automotive-qualified 150 mm CMOS fabs could cut SiC MOSFET costs by 80 percent within five to eight years, allowing them to achieve price parity with silicon IGBTs and encouraging their wider adoption.

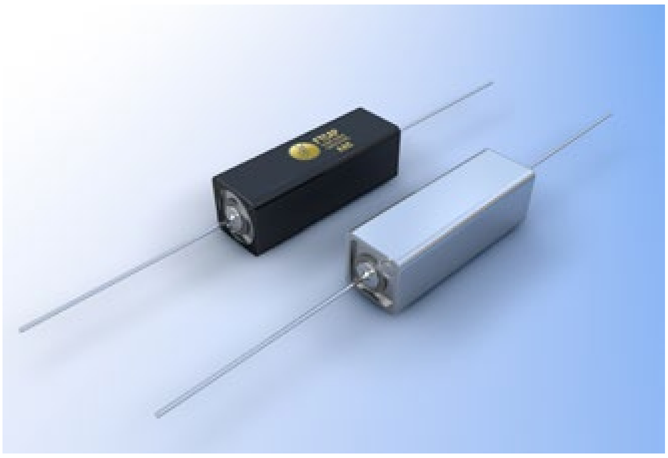
Sujit Banerjee is CEO and founder of Monolith Semiconductor Inc., which focuses on commercializing and enabling widespread adoption of SiC power semiconductors. He holds a PhD from Rensselaer Polytechnic Institute, and has been awarded more than 25 patents for his work in power semiconductors.

Kevin Speer joined Littelfuse in January 2015 as Global Manager of Technology Strategy, providing direction for the growth and trajectory of the company's power semiconductor business and roadmaps. He holds a BSEE from the University of Arkansas, and an M. Eng. and a PhD from Case Western Reserve University.

www.littlefuse.com

Cubic Electrolytic Capacitors

FTCAP presents axial electrolytic capacitors in an innovative cubic design, which offers significant advantages especially with respect to cooling. Compared to the traditional designs, axial aluminum electrolytic capacitors with the innovative cubic design have a 28 % larger surface. This large contact surface has positive effects on cooling, since in some applications the capacitors are mounted directly on the cooling modules. “This larger contact surface allows better connection of the cube-shaped capacitors to the cooling systems, which results in improved cooling capacity,” explains Dr. Thomas Ebel, Managing Director of FTCAP. “That, in turn, results in significantly better current-carrying capacity – this design allows it to be duplicated.” The hermetic laser sealing of the cover also makes it possible to double the service life.
Another advantage of the cubic design of aluminum electrolytic capacitors is the high degree of space utilization: the capacitors are designed for flat mounting and can even be stacked. Dimensions between 10x10x20 mm and 18x18x49 mm and voltages of 25 to 100 volts make them ideal for use in the automotive industry.
The capacitors are designed for combination in a modular system and the capacities can be adjusted individually. The innovative components feature internal multiple contacts with up to four lugs.



http://www.ftcap.de/produkte/elektrolytkondensatoren/axial-long-life-kondensatoren/

www.ftcap.de

Modular high Current Rectifier up to 3000A for Optimized Cabinet Integration

The CLASSICS stacks of SEMIKRON offers a broad portfolio of rectifier stacks. The new Z5 stack is a high current rectifier which thanks to its modularity can be used for different types of topologies and power ranges. Using the well established capsule technology, the new Z5 heatsink profile and the power connection optimization, simplify the cabinet integration and improves the serviceability.
The high performance axial fans with IP54 rating, set for each phase leg, ensure maximum power density. With 15% less size and 30% less weight, the new Z5 offers an integrate able, scalable and service optimized rectifier stack up to 3000A.

www.semikron.com

DMOS Microstepping Driver with Translator and Overcurrent Protection

Allegro MicroSystems Europe announces a integrated bipolar stepper motor driver IC with built-in translator for easy operation. Allegro’s A5985 is designed to operate bipolar stepper motors from full-step up to 1/32 step modes that are selectable by MSx logic inputs.

This new device has an output drive capacity of up to 40 V and ±2 A and operates with a single supply. It is targeted at the office and industrial automation markets with key applications to include: automatic teller machines, point of sale and laser printers, 3D printers, copiers, CCTV cameras, sewing machines, vending, and robotics. The A5985 motor driver IC introduces a proprietary Adaptive Percent Fast Decay (APFD) algorithm to optimize the current waveform over a wide range of stepper speeds and stepper motor characteristics. APFD adjusts, on-the-fly, the amount of fast decay with the goal of maintaining current regulation while minimizing current ripple. This adaptive feature improves performance of the system resulting in reduced audible motor noise, reduced vibration, and increased step accuracy. The translator is the key to the easy implementation of the A5985. Simply inputting one pulse on the STEP input drives the motor one microstep. There are no phase sequence tables, high frequency control lines, or complex interfaces to program.

www.allegromicro.com

Rechargeable Coin Cell Batteries with Highest Capacity

Illinois Capacitor RJD Series batteries are different in design from other lithium ion coin-cell batteries. A encapsulation technology significantly increases storage capacity by completely utilizing the space within the cell case. High power density is a significant benefit in IoT wearable applications.
Not only has the energy density per cell been improved, the failure rate is superior to older designs. Encapsulation, unlike conventional stacking construction, has resolved older manufacturing issues which can affect safety and reliability. As a result, RJD Series batteries allow manufacturers to offer new levels of performance without product redesign.
With the increased performance levels, product run time can be increased by 20% or more vs. a conventional lithium rechargeable coin cell battery. Alternatively, if product size is most critical, performance levels can be maintained with a physically smaller cell.
Because of their internal encapsulation construction, UL-Listed RJD cells also offer greater reliability and safety. This is because they are more resistant to overheating than conventional coin-cell batteries; and their patented technology virtually eliminates risk of internal shorts.
RJD Coin Cells are available in eight different capacity levels, leaded or with conventional flat terminals. Each is rated at: 3.7VDC (4.2VDC to 3.0VDC). Operating temperature range is -20°C to +60°C.
Applications include any type of portable product that is currently

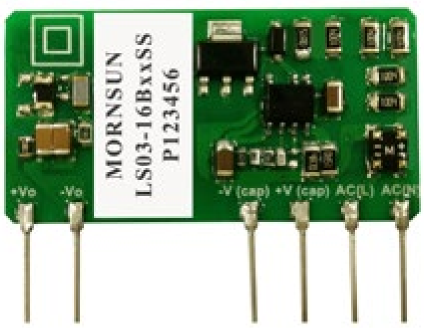
RECHARGEABLE COIN CELL BATTERIES OFFER WORLD'S HIGHEST mAh CAPACITY AND VERY-HIGH RELIABILITY
High density power solutions are a good fit for IoT wearable products.
For more on RJD Series Coin Cells, visit:
www.Power-IoT.com or contact Illinois Capacitor sales@illcap.com

powered by rechargeable coin cell batteries. These include smart watches, fitness bands and other IoT applications, as well as automotive dash cams, key fobs, memory backup, security devices and numerous consumer electronics products. OEM pricing starts at $3.50 each.

http://www.illinoiscapacitor.com/ic_power/

90~528VAC Wide Input voltage AC/DC Converter

MORNSUN released the 3W three-phase four-wire AC/DC converter LS03-16BxxSS and LD03-16Bxx series which meet UL60950/EN60950/FCC part 15 standards. The series offer 90~528VAC wide input range and meet the requirements of 3×220VAC/380VAC nominal voltage and any two-wire connection from three-phase four-wire system.

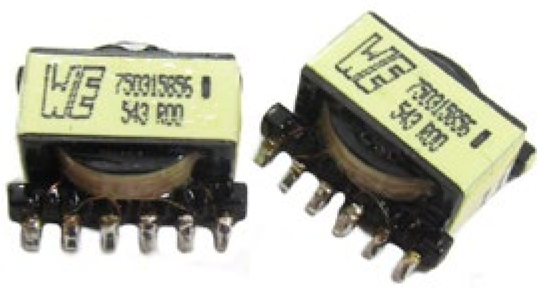


They also provide high efficiency up to 76%, 4000VAC isolation and output short-circuit and over-current protections. Moreover, this series of products remain cost effective while offering high reliability and excellent performance. With SIP and DIP packages available, they are suitable for various applications, especially for space constrained applications.
Three-phase electric meter, industrial control, instrumentation, double power switch controller, fire protection system, etc.
Suitable for any two-wire connection from three-phase four-wire system, AC and DC dual-use (input from the same terminal), Input voltage range: 90~528VAC/100~745VDC, Operating temperature: -40°C~+85°C, Isolation: 4000VAC (SIP)/ 3000VAC (DIP), Efficiency up to 76%, Meet UL60950/EN60950/FCC part 15 standards (pending) and Output short-circuit and over-current protections

www.mornsun-power.com

Flybuck™ Transformer

In partnership with Texas Instruments, Wurth Electronics Midcom developed a new Flybuck™ transformer for TIDA-00550 PLC Analog Input Module. This pick & placeable transformer, 750315856, is built on a low profile ER11.5 package and features outputs of 27V, 5V and -5V, which supplies power to Texas Instruments' TIDA-00550 PLC Analog Input Module. The transformer meets the requirements of functional insulation and offers a wide operating temperature range of -40°C to 125°C with an isolation voltage of 625V at 1 second. Wurth Electronics Midcom's 750315856 transformer is suited for applications including PLC, isolated multi-channel analog input modules, test and measurement, and industrial process control and automation.



www.we-online.com/midcom

240 kHz Bandwidth Field Programmable Linear Hall-effect Sensor IC

Allegro MicroSystems Europe has announced a field programmable linear Hall-effect current sensor IC with features including a 240 kHz bandwidth, integrated voltage regulator, reverse battery protection, user-selectable ratiometry, and uni- or bi-directional output options.

High accuracy is achieved through proprietary linearly interpolated temperature compensation technology that is programmed at the Allegro factory and provides sensitivity and offset that are virtually flat across the full operating temperature range. Temperature compensation is done in the digital domain with integrated EEPROM technology, while maintaining a 240 kHz bandwidth analogue signal path, making the A1367 device ideal for automotive applications, especially HEV inverter, DC-DC converter and electric power steering (EPS) applications.

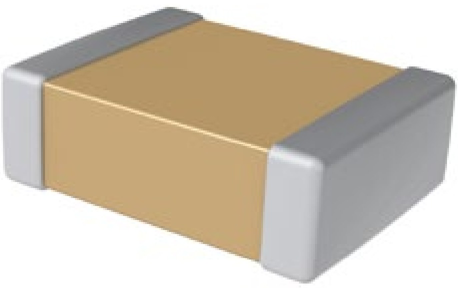
This ratiometric Hall-effect sensor IC provides a voltage output that is proportional to the applied magnetic field. Ratiometry can be disabled if immunity to VCC fluctuations is desired.

The user can configure the sensitivity and quiescent (zero field) output voltage through programming on the VCC and output pins, to optimise performance in the end application. The quiescent output voltage is user-adjustable, around 50% (bidirectional configuration) or 10% (unidirectional configuration) of the supply voltage, VCC, and the output sensitivity is adjustable within the range of 0.6 to 6.4 mV/G.

www.allegromicro.com

Advanced Capacitor Technology

KEMET Corporation, a leading global supplier of electronic components, introduced its advanced U2J Class-I ceramic dielectric capacitors. This U2J surface mount platform offers more than twice the capacitance available in C0G/NP0. It also provides superior temperature performance over X7R, X8R and X5R, rendering it an ideal capacitor solution for many applications including telecom, data acquisition and Internet of Things.



“KEMET continues its leadership position in Class-I dielectric product offerings with the release of this new U2J dielectric technology,” said Abhijit Gurav, KEMET Vice President of Ceramic Technology. “These new U2J capacitors offer the highest capacitance values for Class-I ceramic dielectrics in the industry while providing excellent voltage stability similar to our commercially-successful C0G.”

U2J capacitors are extremely stable with a linear capacitance change with temperature, enabling design engineers to predict the change in capacitance over the operating temperature range. They also retain over 99% of nominal capacitance at full rated voltage and extend the available capacitance of Class-I dielectric MLCCs into a range previously available only in Class-II dielectrics. U2J capacitors are Pb-Free, RoHS and REACH compliant without exemptions.

U2J MLCCs are available now in commercial grade and with a flexible termination option. For more information, please visit.

www.kemet.com/U2J

Thyristor/Diode Modules Address Cost-Sensitive Applications

Infineon Technologies AG extends its product portfolio of thyristor/diode modules in solder bond technology with a 50 mm module. These bipolar modules address the growing market for cost-effective solutions even in demanding applications. Depending on the module, market prices are approximately 25 percent lower than comparable pressure contact variants. Solder bond modules are ideal for applications where the high robustness of pressure contact technology is not necessarily a must. Typical applications for the new 50 mm modules are drives, power supplies and welding.

With the release of the new 50 mm modules Infineon Technologies Bipolar complements the existing product portfolio of bipolar modules. The 50 mm variant covers current ratings from 280 A to 330 A. The 20 mm and 34 mm variants have been in production for more than two years and proven their reliability in the field. All modules have been developed as cost and performance optimized alternative to pressure contact technology. They are packaged in industrial standard housings with an electrically insulated base plate.

www.infineon.com/solderbond

The World's Fastest GaN FET Driver

Peregrine Semiconductor Corp., founder of RF SOI (silicon on insulator) and pioneer of advanced RF solutions, introduces the word's fastest gallium nitride (GaN) field-effect transistor (FET) driver, the UltraCMOS® PE29100. Built on Peregrine's UltraCMOS technology, this GaN driver empowers design engineers to extract the full performance and speed advantages from GaN transistors. Designed to drive the gates of a high-side and a low-side GaN FET in a switching configuration, the PE29100 delivers the industry's fastest switching speeds, shortest propagation delays and lowest rise and fall times to AC-DC converters, DC-DC converters, class D audio amplifiers and wireless charging applications.

GaN-based FETs are disrupting the power conversion market and are displacing silicon-based metal–oxide–semiconductor field-effect transistors (MOSFETs). "Our enhancement-mode GaN (eGaN®) transistors deliver a whole new spectrum of performance compared to MOSFETs," says Alex Lidow, Ph.D., CEO and co-founder at EPC. "GaN FET drivers, like Peregrine's UltraCMOS PE29100, enable design engineers to unlock the true potential of eGaN FET technology. The availability of the PE29100 further enhances our ability to deliver the best possible solution into the power conversion market where size, efficiency and simple design are critical."

Peregrine's UltraCMOS technology platform is the driving force behind the PE29100's industry- leading speed. The technology enables integrated circuits to operate at much faster speeds than conventional CMOS technologies.

http://www.psemi.com

Surface Mounted SO8 Isolated Current Transducers with Integrated Current Conductor

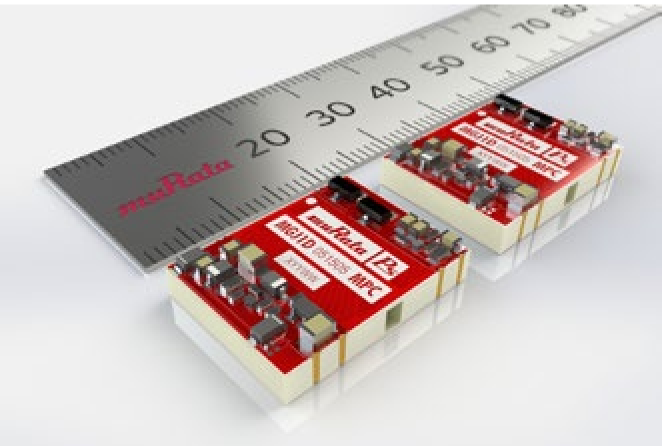
LEM introduces the GHS series: miniature, integrated circuit transducers for AC and DC isolated current measurement up to 100 KHz. These components offer full isolation despite their small size, integrating the primary conductor for nominal current measurements of 10A,

12A, 16A or 20A with a measurement span of 2.5 times the nominal current, they are also able to support high overload currents up to 200 A peak for short durations (1 ms).
The transducers are mounted directly onto a printed circuit board as an SO8 SMD device reducing manufacturing costs and providing appreciable space saving for space-constrained applications.
GHS models are really simple to use as integrate low resistance primary conductors (minimising power losses) within an ASIC to allow direct current measurement and consistent insulation performance, while still providing high creepage and clearance distances.
All the models provide a ratiometric analogue voltage output with different sensitivity levels from 40 to 80 mV/A according to the model, with a typical response time of 5 us.
GHS transducers are not simple Open Loop Hall effect ASIC-based transducers; the series has been designed with unique primary integrated conductors for gradient measurement to provide an excellent immunity against the external fields found in power electronic applications.

www.lem.com

Converter Powers Gate Drives for Optimal Performance

Murata announced the MGJ1 1 Watt DC-DC converter series manufactured by Murata Power Solutions. These compact devices are ideal



for driving high and low-side gate circuits such as those using IGBTs and SiC MOSFETs for optimal efficiency. With high isolation characteristics, up to 5.2 kVDC, the MGJ1 offers the popular nominal output voltage combinations of + 15 / - 5, + 15 / -9 or + 19 / -5 VDC. The series also offers a choice of + 5, + 12 or + 24 VDC input.
The MGJ1 series is characterized for high dV/dt immunity, which aids reliable and continued operation in fast switching circuits, and partial discharge performance that contributes to a long service life. Also, the converter's low input-to-output coupling capacitance, typically 5 pF, assists in reducing the affects of EMI.
The series suits a broad range of medical applications for which certification to ANSI/AAMI ES60601-1 to 2 MOOPs is pending. The converter also conforms to the UL 60950 (pending) for reinforced insulation and by incorporating a 9.3 mm creepage and clearance space helps safety agency approvals for high working voltage applications.

www.murata.com

Waterproof Buzzers Developed for High-Moisture Environments

CUI's Components Group announced additions to its range of waterproof buzzers. The three new models carry an Ingress Protection (IP) rating up to IP68 and feature sound pressure levels (SPL) up to 95 dB at 30 cm, making them ideal for a range of industrial and outdoor applications where moisture and other environmental contaminants are a concern.
The CPT1495C300 and CPT1495CI300 are piezo transducer buzzers housed in a 14 mm diameter package with a height of 10 mm. Specified with a rated voltage of 30 V and a rated frequency of 4.25 kHz, both waterproof buzzers are externally driven and feature an IP67 rating, SPL of 84 dB at 10 cm and an operating temperature range of 30 to 85°C. The CPT1495C300 mounts via wire leads while the CPT1495CI300 is wave solder compatible for high-volume production.

www.cui.com

*fast*Pack 0 SiC Power Module

Richardson RFPD, Inc. announced the availability from stock and full design support capabilities for a new fastpack 0 SiC power module from Vincotech.

The 10-PC094PB065ME01-L637F06Y is a faster, cooler and more efficient power module designed for switching frequencies up to 400 kHz. It features a fast-switching 900V SiC MOSFET that outperforms 1200V SiC MOSFETs (+8% efficiency at a light load and +3% at full load) and provides a higher safety margin than 650V MOSFETs.

According to Vincotech, additional key features include:

- Drain current: 33A
- Drain-source on-state resistance: 65Ω
- Housing: flow 0 12mm
- H-Bridge with split output topology
- Thermistor
- Press-fit technology: reduces PCB assembly time and effort

The 10-PC094PB065ME01-L637F06Y is designed for power supply applications.

To find more information, or to purchase this product today online, please visit the 10-PC094PB065ME01-L637F06Y webpage. The device is also available by calling 1-800-737-6937 (within North America); or please find your local sales engineer (worldwide) at Local Sales Support. To learn about additional products from Vincotech, please visit the Vincotech storefront webpage.

Vincotech's range of power modules are also featured on Richardson RFPD's SiC Tech Hub, a microsite featuring the latest news, product releases, and a broad range of technical resources on silicon carbide.

www.richardsonrfpd.com

Low-Cost Switching Regulator Module

RECOM expands its low-cost, highly-efficient R-78E switching regulator series with modules featuring 9V, 12V, and 15V output voltages.

This series is designed to offer all of the advantages of a standard switching regulator (high efficiency, wide input range, accurate output voltage regulation) but at a lower cost.
Like the existing 3.3V and 5V versions, the new 9V, 12V, and 15V modules are also equipped with short circuit protection. Measuring only 11.6 x 8.5 x 10.4 mm, their compact TO-220-compatible SIP3 package saves valuable board space, and with efficiency up to 91%, these higher power versions of the R-78E still do not require a heat sink.
With a wide operating temperature range of -40°C to +85°C and a wide input range, the R-78E series is flexible enough to handle everything from battery operated systems, controls and sensors, positioning systems, and robotics, to medical-grade applications, cooling systems and fans, telecommunications, and highly sensitive measurement equipment.
The modules are IEC/EN60950-1 certified and carry a 3-year warranty. Samples are available from all of RECOM´s global distributors.

www.recom-power.com

End User Requirements Driving Battery Innovation

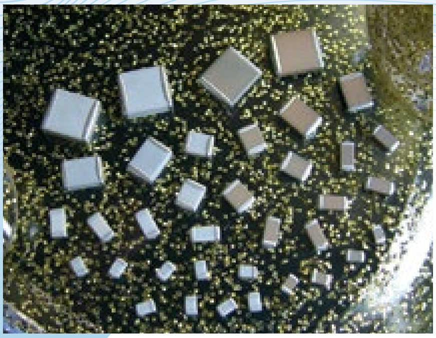
Battery OEMs like Accutronics develop technology to suit the specific requirements and regulations of the application in which the device will be used. However, this is not always a straightforward process. Take the portable defibrillator for example. New materials and technologies are driving the advancement of all portable devices, making them smaller and lighter. As a result, batteries need to keep up. Just look at how much your laptop battery has shrunk in the last decade!
So, a device OEM may produce a design for a more compact machine than has previously been used, but fail to leave enough space for the battery. This is made worse when the device is much smaller than previous models, or is a different shape.
This is where a battery OEM has to get creative to develop an innovative product that meets specifications.
With over 40 years of experience performing this delicate balancing act, we're skilled at innovating to meet specific needs without pricing our clients out of their own innovation. So when you've got a square peg and a round hole, don't force fit and hope for the best. Speak to someone who knows how to reshape the peg for a perfect fit.

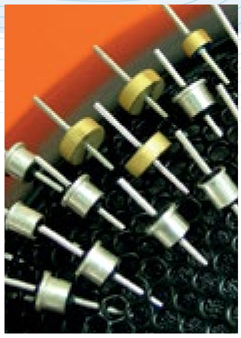
http://www.accutronics.co.uk/index.php

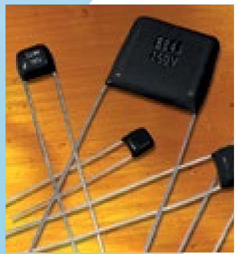
UL 94 V-0 Circuit Material for Cost Effective, High Performance PCB Antennas

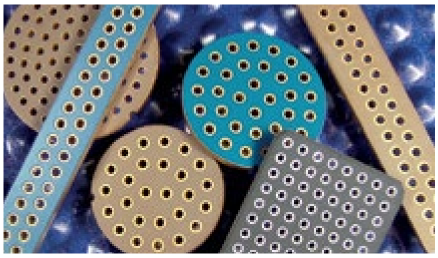
Rogers Corporation introduced RO4730G3™ UL 94 V-0 antenna-grade laminates to meet present and future performance requirements in active antenna arrays and small cells, notably in 4G base transceiver stations (BTS) and Internet of Things (IoT) applications as well as emerging 5G wireless systems.
These flame-retardant (per UL 94V-0),
thermoset laminate materials are an extension of Rogers' dependable RO4000® circuit materials, which are a popular choice for base station antennas. RO4730G3 laminates provide the low dielectric constant (Dk) of 3.0 favored by antenna designers, held to a tolerance of ±0.05 through the thickness (z axis) when measured at 10 GHz.
RO4730G3 laminates are comprised of ceramic hydrocarbon materials with low-loss LoPro® copper foil. They offer excellent passive-intermodulation (PIM) performance (typically better than -160 dBc) that makes them attractive for intermodulation (IM) sensitive, high-frequency antennas. They are 30% lighter than PTFE circuit materials and feature a high glass transition temperature (Tg) of better than +280°C for compatibility with automated assembly techniques.
RO4730G3 circuit laminates exhibit low z-axis coefficient of thermal expansion (CTE) of 30.3 ppm/°C from -55 to +288°C for reliable plated through holes (PTHs) in multilayer circuit assemblies. They are lead-free-process compatible and offer improved flexural strength over RO4000JXR™ materials

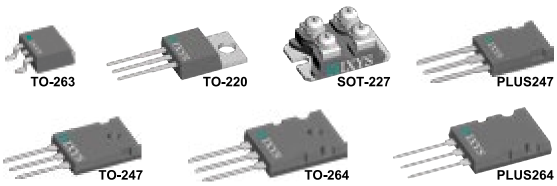
www.rogerscorp.com

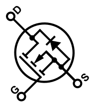


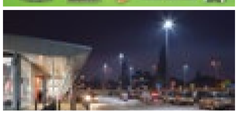












Part Number	V_{DSS} (V)	I_{D25} T_C = 25°C (A)	$R_{DS(on)}$ max T_J=25°C (Ω)	$Q_{g(on)}$ typ (nC)	C_{iss} typ (pF)	t_{rr} typ (ns)	R_{thJC} max (°C/W)	P_D max (W)	Package Type
IXFA22N65X2	650	22	0.145	37	2190	145	0.32	390	TO-263
IXFH22N65X2	650	22	0.145	37	2190	145	0.32	390	TO-247
IXFP22N65X2	650	22	0.145	37	2190	145	0.32	390	TO-220
IXFH34N65X2	650	34	0.1	56	3230	164	0.23	540	TO-247
IXFH46N65X2	650	46	0.069	98	4570	180	0.19	660	TO-247
IXFH60N65X2	650	60	0.052	108	6300	180	0.16	780	TO-247
IXFH80N65X2	650	80	0.038	140	8300	200	0.14	890	TO-247
IXFK100N65X2	650	100	0.03	183	10800	200	0.12	1040	TO-264
IXFX100N65X2	650	100	0.03	183	10800	200	0.12	1040	PLUS247
IXFN120N65X2	650	108	0.024	240	14000	220	0.14	890	SOT-227
IXFK120N65X2	650	120	0.024	240	14000	220	0.1	1250	TO-264
IXFX120N65X2	650	120	0.024	240	14000	220	0.1	1250	PLUS247
IXFN150N65X2	650	145	0.017	355	21000	260	0.12	1040	SOT-227
IXFB150N65X2	650	150	0.017	355	21000	260	0.08	1560	PLUS264

Comprehensive Range of Automotive Grade LDO Regulators

ROHM has recently announced the availability of two LDO regulator families, complementing the existing portfolio of LDOs and bringing the total number of its automotive-grade LDOs up to 184. With its miniaturized package size, ROHM's new BUxxJA2MNVX-C series is the world's smallest Automotive-grade LDO regulator whereas the BD7xxLx series provides unmatched quiescent current features. Customers are now able to choose from multiple voltage and current options as well as packaging solutions to meet the exact requirements of their application, whether in automotive body, power train and infotainment or advanced driver assistance systems (ADAS).

Both line-ups are based on ROHM's vertically integrated product system along with its proprietary analog design process and package technologies to achieve high efficiency in a compact form factor while adding to design flexibility and reliability.

The BD7xxLx series together with the BD4xxMx series is optimized for all applications which are connected to the battery and which require an extreme low quiescent current. Thanks to its wide input voltage range (up to 50V max. voltage) and wide operating temperature range spanning -40° to +125°C, this family is a perfect solution for automotive body, powertrain and infotainment systems.

The BD7xxLx line-up is composed by 8 part numbers, with optional output voltage from 3.3V and 5V, output current capability form 200mA up to 500mA and 3 standard package types.

www.rohm.com/eu

High Performance 120W DC-DC Converters for Harsh Environments

TDK Corporation announces the introduction of the 12V, 24V and 28V output HQA DC-DC converters, with additional output voltage models to be added in the coming months. Packaged in a ruggedized quarter brick form factor, the encapsulated HQA120 models can deliver 120W output power and will operate over a 9V to 40V input range (50V for 1 second). These 89% efficient converters are suitable for use in COTS, communications and industrial equipment.

The HQA120 has been qualified using methods consistent with MIL-STD-883 & 202, and offers a two screening and operating temperature options. The M-Grade has functional testing in cold, hot and room ambient temperatures, and an extended 96 hour burn-in with ten-cycle temperature testing. The S-Grade has functional testing at room ambient temperature and a standard burn-in period. The full load operating temperature for the M-Grade is -55 to +115°C and -40 to +115°C for the S-Grade.

Two baseplate mounting versions are available. All models are fully regulated, have a constant switching frequency for easier system EMC integration and utilise no opto-couplers in the control loop for increased reliability. Full auto-recovery protection is provided and the output can be adjusted ±10% or turned on or off remotely.

Safety certification includes IEC/EN 60950-1, UL/CSA 60950-1 with CE marking for the Low Voltage and RoHS2 Directives. Input to output and input to baseplate isolation is 2250Vdc.

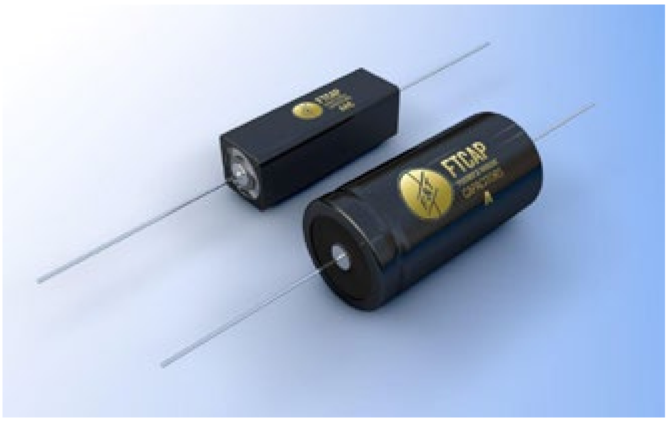
www.uk.tdk-lambda.com/hqa

Axial Aluminium Electrolytic Capacitors

The FTCAP series A, AH and AG are ideal for standard and switched-mode power supplies, computers, industrial electronics, drives and welding equipment. The A series provides a high CV product, while the AH capacitors support a high ripple current. The AG series is designed for a very long life of up to 2,000 hours of operation. These axial electrolytic capacitors withstand temperatures of up to 85°C (series A) and 125°C (series AG, AH). All contacts and many of the axial connections are welded.

The axial electrolytic capacitors of the ATBI and ATBIG series on the other hand feature a bipolar design and are ideal for hi-fi and consumer applications in a temperature range of up to 85°C. The ATBIG series is constructed with a smooth film. These aluminium electrolytic capacitors have welded axial connections for guaranteed reliability.

www.ftcap.de



Maximum Cooling Flexibility on a Standard Footprint

EOS Power's new (M)WLC550 Series offers 550 Watts with Forced Air, Conduction and Convection Ratings

EOS Power released its (M)WLC550 Series of High Efficiency, High Power Density AC/DC products. The (M)WLC550 Series for Medical and Commercial applications, has a power density exceeding 24 watts per cubic inch and offers unrivalled cooling and installation options for all devices, which require small size AC/DC power solutions. The solution is packaged in a 3 x 5 x 1.5 inch standard profile. The (M)WLC550 Series offers customers the possibility of using a 3 x 5 inch AC/DC product in conduction cooled, forced air or even convection cooled environments. The 550 watt product release is available in Medical and Commercial versions and will again satisfy the market with specifications like:

Efficiencies up to 93%; - 40 to 70 Degree Operation; Medical Version is Edition 4 EMC Compliant; 3 x 5 x 1.5 inch Industry Standard Profile; 550 Watt Forced Air Cooled Rating; Conduction & Convection Power Ratings; Multiple Mounting Options; Low Standby-Power.

The (M)WLC 550 Series from EOS Power expands upon the already class leading open frame medical and commercial grade power solutions from EOS Power. The EOS Power focus and strategy is to continue designing market leading AC/DC
products and start developing products from 2016 onwards for other AC/DC market segments. "EOS Power is one of very few power companies globally who design and manufacturer all their own power conversion products.

Medical customers will benefit from the BF design including risk management and from compliance to the 4th edition IEC 60601-1-2:2014 EMC requirements. Optimizing space, efficiencies and cooling capabilities the new (M)WLC550 series will allow end customers maximize the operational capabilities of the applications.

www.eospower.com

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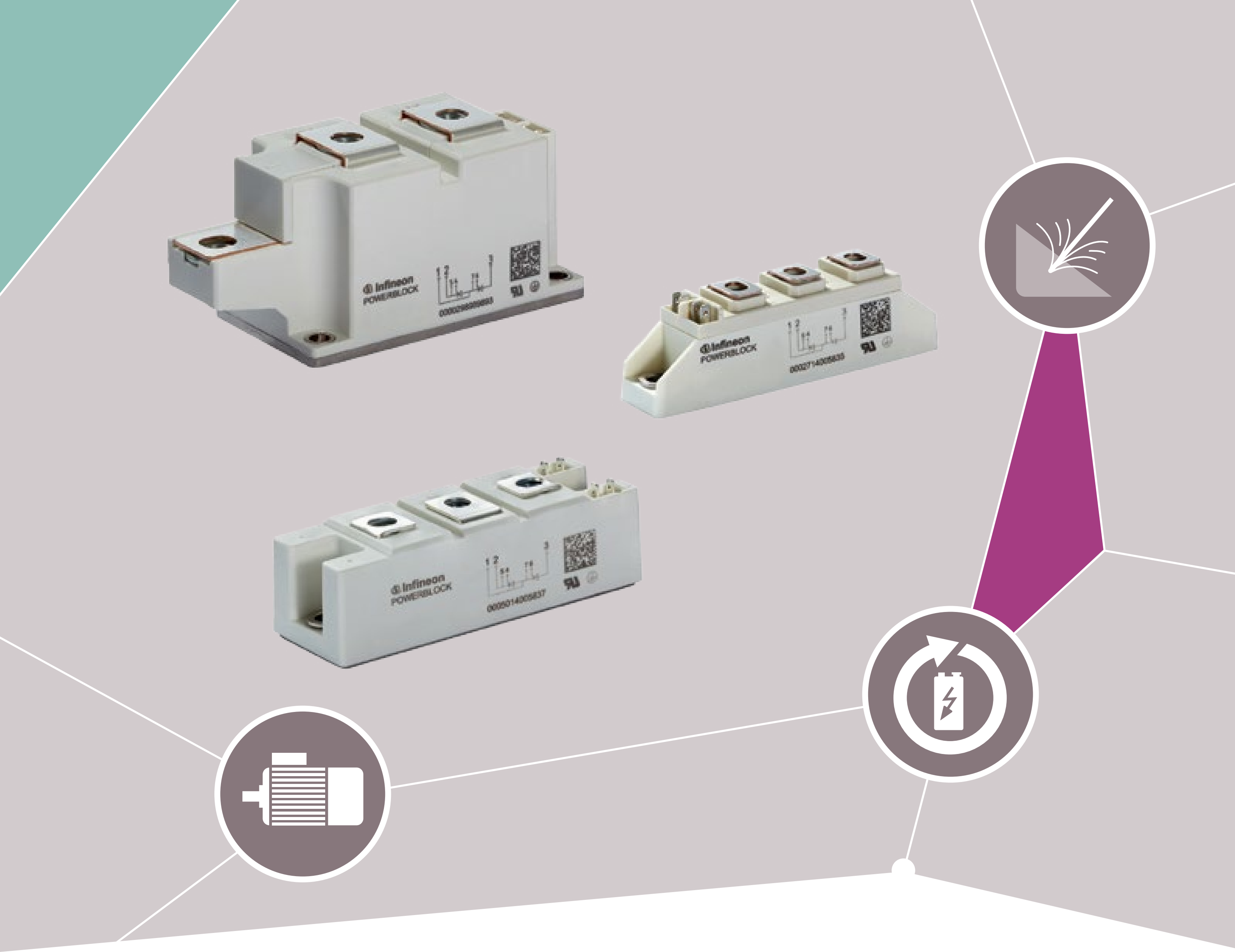
Web Search Tool for GHS Safety Data Sheets

Alpha Assembly Solutions, the world leader in the production of electronic soldering and bonding materials, is pleased to announce it has recently launched a new search tool on its website that allows users to search for GHS Safety Data Sheets (SDS) on all ALPHA® Products that are commercially available world-wide.

The tool is accessible through AlphaAssembly.com located under "Site Tools" and can be utilized by entering either an ALPHA® Product Name or an ALPHA® Finished Goods Item Number (SKU). In addition, the tool can be filtered by Region and/or Language to further refine search results.

"The ability to locate a material safety data sheet quickly and with ease has become an important capability to our customers", said Tom Hunsinger, Vice President of Marketing at Alpha Assembly Solutions. "This new tool was developed with that in mind and has eliminated the task of customers having to request this information and then wait for it, and has instead given users the ability to find what they need with a simple query."

www.AlphaAssembly.com



Be BEST IN CLASS

with our solder bond family providing highest power density

Benefits

Thyristor/diode modules in solder bond technology from leading manufacturer of power semiconductors

- Cost and performance optimized
- One supplier for a broad range of bipolar modules
- Profit from over 20 years of expertise in IGBT soldering and bonding
- Fast and extensive technical support

Main Features

- Blocking voltage $V_{DRM} = V_{RRM} = 1{,}600\,V$
- Average current 55...330 A
- Surge current 1,500…9,500 A
- Available with thermal interface material TIM

www.infineon.com/solderbond-family

Infineon Technologies Bipolar