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Power Systems Design: Empowering Global Innovation

April 2013

Special Edition: Multi-Media (pg43)

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COVER STORY

The drive towards more energy-efficient motor control in compressors and pumps (pg 16)

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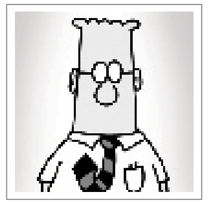

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Registration of copyright: January 2004
ISSN number: 1613-6365

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Volume 10, Issue 3

Power moves

One way to look at change is to see it as the unfolding path we take on our journey to the future version of normal. Every trip brings us encounters we did not plan to meet, challenges we had not anticipated, and barriers we had to overcome. How we take those challenges on is part of how we are defined, an example of our character, insight, and determination.

The power electronics is a mature industry challenged by the latest technical developments and how they are being applied to and by society. This challenge is one many industries have, and all industries will, face. Looking back on this year's Applied Power Electronics Conference (APEC) while looking forward to the upcoming Power Conversion and Intelligent Motion (PCIM) event, this industry is handling the challenges pretty well, considering what's going on in other disrupted industries.

The big winds blowing at APEC are coming from a few interesting directions, most notably from exotic materials and advanced packaging. The former has had more of the cool buzz, but the latter will have a greater overall impact on the industry. Older packages are too large, inefficient, and often have very poor thermal characteristics. The newest highly-integrated chip packages will impact the performance power systems in every application at every power level.

Considering materials, there was quite a buzz at APEC (and will undoubtedly also be at PCIM) around Silicon Carbide semiconductors, as well as Gallium Nitride on both Silicon Carbide and Silicon. This buzz is completely deserved, as they each have merits to offer the industry in performance and efficiency. There were around a dozen companies either talking enthusiastically or demonstrating amazingly about both GaN and SiC, and I would wager about half of them are hoping/expecting to be bought out by bigger players. It is interesting to note that TI has more drivers than devices in this space.

The packaging evolution is following the rest of the industry on the convergence trail. Highly-integrated packages addressed device complexity and system integration, while smaller and more efficient packaging tackled the problems with legacy casings like the TO-220. A very good example can be found in the Infineon DrBlade chip-embedded package technology, which integrates the DC/DC driver and MOSFET VR power stage. One day every sub-system will be in its own (possibly standardized) sub-package that will either bond to one another or to some yet-determined substrate/scaffold infrastructure to form a device.

APEC 2013 broke records for attendance, and considering the level of change going on in the industry, it would not be surprising to see PCIM do the same. The power electronics industry faces many challenges, from the board to the grid, but we will eventually get the future we seek if we apply ourselves to creating it.

Best Regards,

Alix Paultre

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Programmable 30A brushless DC motor controller serves robotics and automation apps

Targeting designers of Industrial Automation systems, mobile robots, mechatronics, or other medium-power motor control application, the SBL1360 intelligent controller from Roboteq is capable of directly driving a hall-sensor equipped brushless DC motor up to 30Amps at up to 60V. The controller accepts commands from analog pedal/joystick, standard R/C radio, USB, CAN or an RS232 interface. Using the serial port, the controller can be used to design fully or semi-autonomous robots by connecting it to single board computers, wireless modems or WiFi adapters. Using CAN bus, up to 127 controllers can be networked on a single twisted-pair network.

The SBL1360 incorporates a Basic Language Interpreter capable of executing over 50,000 Basic instructions per second. This feature can be used to write powerful scripts for adding custom functions, or for developing automated systems without the need for an external PLC or microcomputer.

The SBL1360 uses the motor's hall sensors to measure speed and travelled distance with high accuracy. The controller can operate the motors in open loop or in closed loop speed or position mode with a 1 kHz update rate. The SBL1360 features intelligent current sensing that will automatically limit the power output to 30A in all load conditions. The controller also includes protection against overheat, stall, and short circuits.

The controller includes up to 4 analog, 6 digital and 5 pulse inputs. Two 1.5A digital outputs are provided for activating brakes or other accessories. The controller's operation can be optimized using nearly 80 configurable parameters, such as programmable acceleration or deceleration, amps limits, operating voltage range, use of I/O, and more. A free PC utility is available for configuring, tuning and exercising the motor. The controller can be reprogrammed in the field with the latest features by downloading new operating firmware from Roboteq's web site.

The SBL1360 is built into a very compact 70mm x 70mm, board-level open frame design. The board comes equipped with an aluminum bottom plate that ensures sufficient heat dissipation for operation without a fan in most applications. Additional cooling can be achieved by mounting the board and its bottom plate directly against a metallic chassis. The SBL1360 is available now to customers worldwide at $225 in single quantities, complete with cable and PC-based configuration software.

www.roboteq.com

Who's managing your power management?

By: Bob Frostholm, JVD

A few dozen years ago, engineers fresh out of school were assigned to the power supply team; the most boring and least challenging aspect of the system and the one most forgiving of inexperience. Could it come to that again? Not likely. But you really should ask yourself, who is really managing your power management? Is it you or your suppliers? Who really understands your power management needs and more importantly, the solution you've implemented? Is your 7Amp 1.2V solution overkill for your 2.9Amp requirement? Could a lower cost LDO be used instead of that switcher?

Power Management is more than developing solutions that run cool and conserve power. It's also about managing cost.

Financial management is inextricably intertwined with power management. Often power management solutions transcend multiple product generations. It's the most logical place to drive cost out of a system for greater long term savings. Yet, for some reason, it's also the most overlooked. The following represents the power board for a typical consumer application . Depending on total volume, the Bill of Materials may range from $1.00-$1.50 at the low end, to perhaps as high as $2.00.

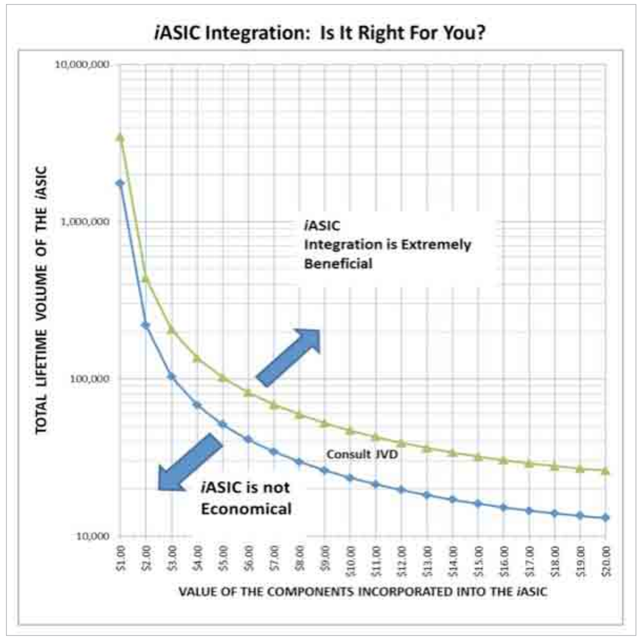

Figure 1: The economic benefits of integration

Integrating these seven chips into what is called and iASIC, or integrated ASIC, would yield a much lower cost single chip solution while retaining all the desired power saving functionality of the original designs. An iASIC (a chip integrating existing functions without the need to create new IP) is easy to accomplish and has a short Development time. The cost of the iASIC for the above set of requirements would be in the neighborhood of $0.60 each,

Power Management is as much about Power as it is about Finance. The maniacal focus on conservation of energy and power needs to be coordinated with the conservation of cash. The graph below clearly shows the financial benefits of integration using an iASIC. These numbers are typical and include amortization of all NRE and tooling costs to develop and put the iASIC into production. The vertical scale is the total estimated lifetime volume of the iASIC and the horizontal axis is the approximate cost of the components being integrated (**see Figure 1**). Where does your application fit on this graph?

www.jvdinc.com

Oil & Gas boom propels high power low voltage VSD sales

By: Rolando Campos, IMS Research

Sales of high power low voltage (<690V) variable speed drives rated above 500 kW have remained bound for nearly a decade with sales from 2007 to 2012 in the range of $950M and $1.4B. As demand for high-powered drives increases from different industries IMS Research predicts that global sales will break out of a range and increase to nearly $1.9B in 2016. The increase in global sales of high power drives started about six months to a year after the recession ended in 2010—increasing each year from $983M in 2010 to $1.4 billion in 2012, while unit sales increased from 89k to 123k (**see Figure 1**).

From 2011 through 2016, IMS Research predicts that high-powered drives will break out above $1.4B per year in sales. Increased sales will be driven by an increased willingness from end-users to purchase high-powered drives and higher demand from oil & gas, mining & extraction, metals, water & wastewater, and cement industries.

The return on investment for putting high power rated drives into oil projects is often high. These drives are often used in the application of artificial lifts and horizontal pumps that push saltwater and other fluids to bring oil to the surface. The drives used in such applications often have power ratings greater than 500 kW and usually higher than 300 kW. If there is not sufficient power coming into a set of wells, the oil company must choose which wells are active, whereas, with the installation of motor drives, more wells can run at the same time using the same electricity, saving money on electricity costs and utilizing existing infrastructure more effectively. Low voltage drives are particularly suited for remote drilling operations since electricity is often generated onsite since power lines physically inaccessible. With a limited supply of electricity, it becomes more critical for all machines to run efficiently.

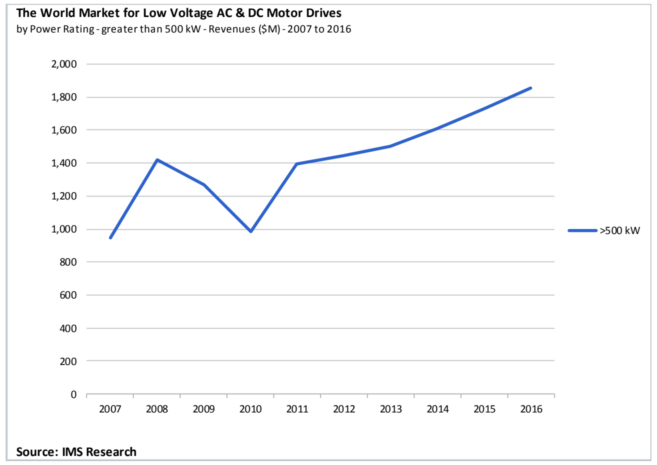

Figure 1

While global sales of high-powered motor drives are forecast to increase, the rate is expected to moderate. In 2013, IMS Research forecasts that the high growth rate in global sales of high power rated motor drives will only grow at 4% as the recent economic slowdown catches up with high-powered drives. Despite these near-term headwinds, the long-term picture for the sale of high power low voltage motor drives is robust with high power motor drives forecast to grow at a 5.3% CAGR from 2011 to 2016.

www.imsresearch.com

Flyback power supply development - part III

By: Dr. Ray Ridley, President, Ridley Engineering

This article is the third of a series in which Dr. Ridley shows the steps involved in designing and building an offline flyback converter. The input filter rectifier is simulated to find the design range of the converter, and the transformer design is completed and measured.

Input Voltage Range

The specifications for the power supply were as follows:

1. Input Voltage: 185 – 265 AC
2. Output 1: 15 VDC @ 1.1 A
3. Output 2: 15 VDC @ 50 mA nonisolated (bias and regulation supply)
4. Maximum power: 17.25 W (was 22 W)

Notice that between the first article of this series, and this third part, the load on the main output dropped from 1.4 A to 1.1 A. This is common during a power supply development; the end user is rarely finished with design and measurements before the power supply design starts. Being flexible in your design to accommodate changes both up and down in power is just a fact of life for power supply engineers. The first step in the design process is to determine the actual range of the dc input bus after the rectifier. There is no simple equation to calculate this, and the fastest way to determine the range is to run a simulation, using a constant power load on a capacitor and rectifier. As the design progresses, and input filter and protection circuits are added to the design, the simulation can be modified to accommodate the additional components. Filter inductors, surge resistors and fuses all reduce the actual input voltage to the converter. Trying to incorporate all of this in a calculation is probably not the best use of design time, and simulation is a powerful aid here. Just about any circuit simulator will be able to do this part of the circuit for you, but POWER 4-5-6 was used to generate the waveforms in **Figure 1** for maximum speed.

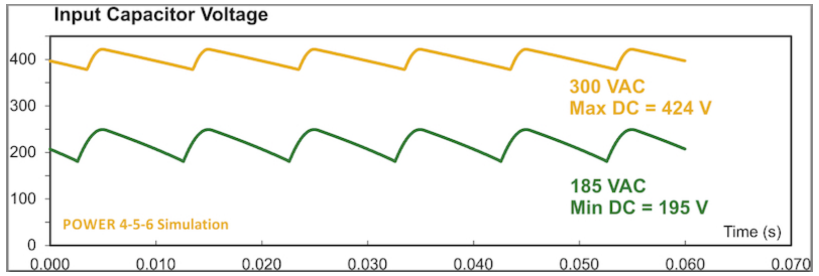

Figure 1: Input line voltage POWER 4-5-6 simulation, showing rectified voltage on a 10 µF input capacitor.

If you were to do true worst-case analysis design, it is necessary to introduce variation in the frequency range of the AC supply, and include the anticipated variations of the input capacitor with initial tolerance and aging effects, but that is beyond the scope of this article.

From this simulation, we see that the maximum voltage seen at the input of the power supply will be 424 V under surge conditions of 300 VAC input. The minimum voltage used to design the power stage is 195 V. For those new to power supply design, this range can be a surprise. Designing for a nominal 240 VAC input results in more than a 2:1 dc input range. This range is obtained using a full-wave input rectifier. If a half-wave rectifier were used, the range would be even larger.

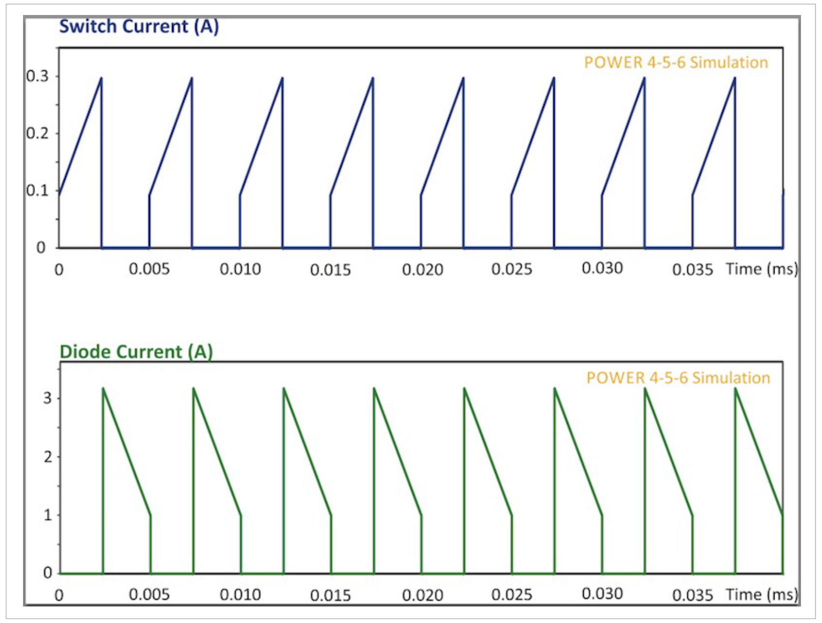

Figure 2: Main FET and diode currents with 2200 µH primary inductance and 11:1 turns ratio.

Magnetics Design – Turns Ratio

The first step in designing a flyback transformer is to determine the turns ratio required at low line to give the required output voltage without using an excessive duty cycle. Design approaches vary greatly in choosing the maximum duty cycle. At low power, it is quite common to operate with quite a small maximum duty cycle in order to minimize the stress of the primary power FET. At higher power levels, some wide-range designs may allow the duty cycle to be in excess of 50% to reduce stresses on the secondary parts and reduce the primary currents.

In this design, the maximum duty cycle was set at 47%. (That is the value that is obtained when selecting a controller than naturally has a maximum nominal value of 50% - a few percent are lost to the finite discharge time of the timing capacitor). With a minimum input voltage of 195 V, a turns ratio of 11:1 provides sufficient voltage to operate the converter over the full specified range with enough margin to control the converter properly.

Magnetics Design – Primary Inductance

While there is a fair amount of leeway in choosing the maximum duty cycle of the controller, and subsequently the turns ratio of the transformer, there is even more freedom of choice in choosing the primary inductor value. Some power designers will select a value to force the converter to operate in discontinuous-conduction mode at all lines and loads. This is the most popular approach for low power flyback designs at 10 W or less.

At higher power levels, this can result in high primary currents, and some designers will select a larger value of inductance to reduce the peak current stresses. The optimal design point is not obvious in most cases, and some experimentation with different designs is beneficial. If you can wind your own magnetics prototypes, this is fast and easy to do, and we teach this process in our design workshops [5].

For this design, the first transformer was chosen to have a primary inductance of 2200 µH. this value runs the converter in CCM at full load, yet it is small enough to make sure the converter is controllable. **Figure 2**

Power	17.25 W
Inductance	2200 µH
Core Type TDK	EPC 19
Core Area	0.2 cm^2
Current Limit	0.33 A
Primary Turns	120
Maximum Flux	0.305 T
Secondary Turns	11

Table 1

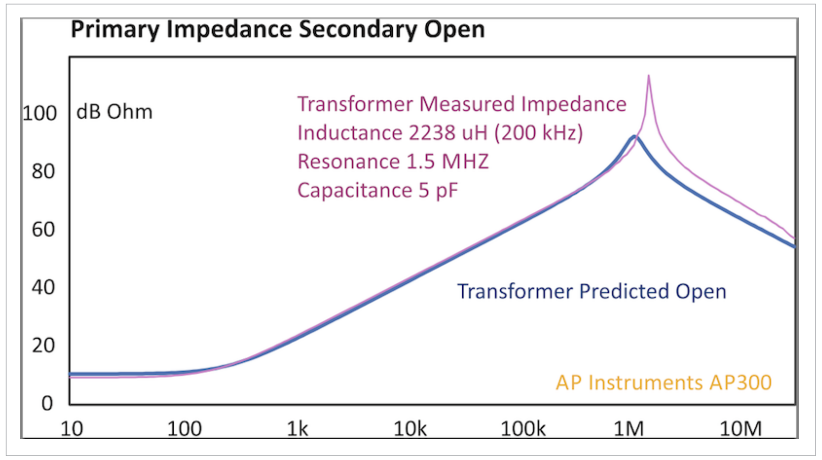

Figure 3: Transformer winding layout. Secondary winding uses triple-insulated VIP kapton wire.

shows the primary switch current and main secondary diode current that result from this choice of inductor value. Notice the peak diode current on the secondary is in excess of 3 A, almost three times the average value of the output current.

The primary switch current was just below 0.3 A. The current limiting of the converter was set at 0.334 A, just above the maximum required primary current. **Table 1** shows the calculations used for the transformer design using a TDK EPC19 core. 120 primary turns were needed to support the maximum current at 2200 μH without saturation. 11 turns on the secondary gave the required turns ratio.

The required isolation in the transformer was achieved with the use of kapton-wrapped wire from VIP wire [4]. This gives full triple insulation rating with a minimal thickness of insulation. The primary was wound in two layers of three segments to minimize winding capacitance and keep the primary impedance as high as possible. More details of this are given in [1]. The winding layout is shown in **Figure 3**.

Whenever you build or purchase magnetic components, it is important to do a frequency response characterization before inserting them in the power circuit. This allows you to verify proper design construction, and calculate circuit snubbers quickly from measured transformer parameters. The frequency response is best done on an instrument designed for the job, such as an AP300 frequency response analyzer [2]. It can also be done manually as described in [3].

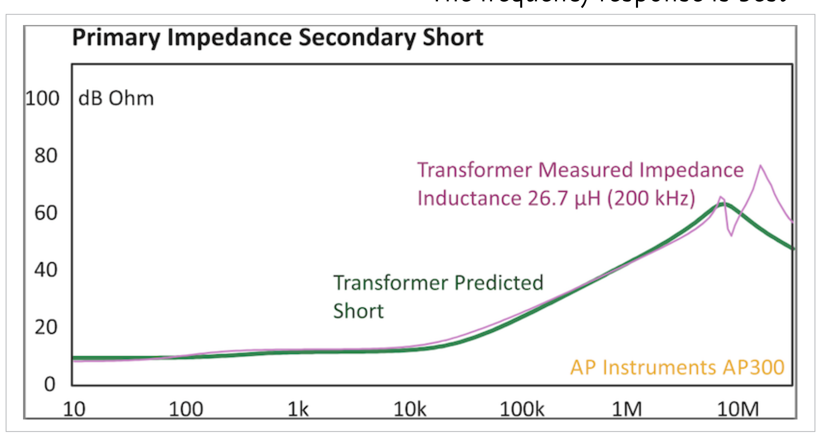

Figure 4: Flyback transformer primary winding impedance with secondaries open.

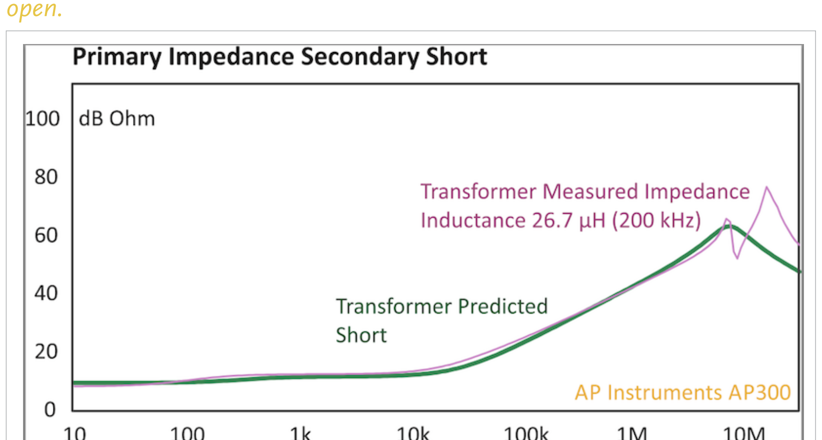

Figure 5: Flyback transformer primary impedance measurement with secondaries short-circuited.

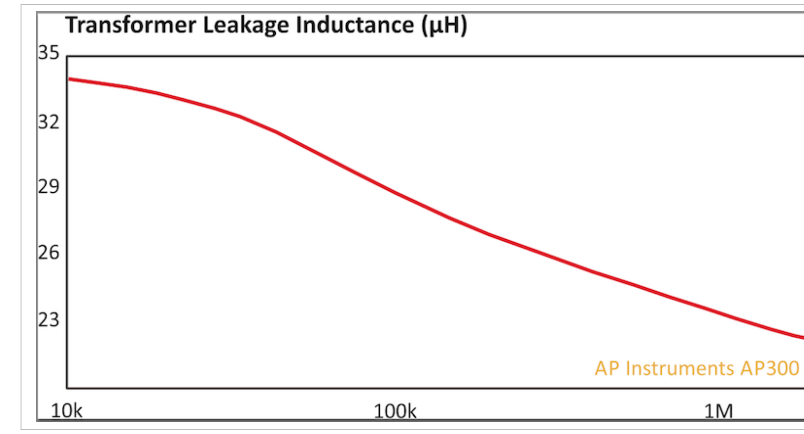

Figure 6: Flyback transformer leakage inductance measurement versus frequency.

Figure 4 shows the primary impedance of the flyback transformer measured with the secondaries open. This measurement gives the value of the magnetizing inductance at 2234 μH, calculated at 200 kHz. The resonant frequency was at 1.5 MHz which is produced by an equivalent capacitance of about 5 pF. This capacitance was very low due to the segmented winding structure of the primary.

Figure 5 shows the measurement of the transformer primary impedance with the secondaries shorted. The rise in impedance between about 20 kHz and 10 MHz is due to the primary leakage inductance. It can be seen from the curve of the predicted impedance that the slope of the measurement is not quite as steep as 20 dB per decade. This is usually the case for high frequency transformers, and it is caused by proximity effects in the windings. The varying distribution of currents in the winding affects the primary to secondary leakage inductance, and this value is plotted in Figure 6 versus frequency.

Figure 6 also shows that the leakage inductance changes with frequency and it exhibits a significant change from 10 kHz to 1 MHz. It is very important when you specify a custom transformer that the leakage inductance be specified at a given frequency if you want to get repeatable designs and measurements. At 200 kHz, the leakage inductance was measured to be 26.7 μH.

With the transformer qualified, it is ready to be inserted into the power circuit for testing to continue.

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Summary

The third part of this series has described the simulation of the input voltage rectifier, main current waveforms, and the construction of the power transformer. Frequency response measurements of the transformer provided the value of the magnetizing inductance, leakage inductance and resonant frequency. With this data complete, the power testing can proceed.

www.ridleyengineering.com

The drive towards more energy-efficient motor control in compressors and pumps

New energy efficiency standards and regulations put pressure on designers

By: Alberto Guerra and Diego Raffo, International Rectifier

Considering that almost 60 percent of total electric energy produced worldwide is used to run motors of every size, shape and efficiency, the adoption of variable speed drives can save as much as 70 percent of energy costs by controlling the speed of the load. New energy efficiency standards for compressors and pumps require the adoption of electronic controlled motors and present further challenges to electronic designers.

A high-voltage multichip solution based on standard QFN packaging technology such as IR's µIPM™ product family has taken the same industry standard approach of VRM modules utilized in the computing industry into the industrial and motor-drives industry. By using PCB copper traces to dissipate heat from the module, a device of this kind delivers cost savings through a smaller package design, and in specific applications through eliminating the use of an external heat sink.

The implications of the ERP Directive

In Europe the key legislation that is driving the move to increasingly efficient fan and pump applications is Directive 2009/125/EC, or the European Energy Related Products (ERP) Directive. Designed to minimize energy consumption and support lower carbon emissions by improving energy efficiency, this legislation replaces the Energy Using Products (EUP) Directive and provides a framework for establishing minimum eco-design requirements for energy-using and energy-related products.

The Directive is implemented in the form of product-specific regulations that cover items ranging from finished units to sub-assembly elements of a finished unit, such as fans and circulator pumps. The Directive is being implemented in various stages, with the key dates for fans and circulator pumps being January 1st 2013 and January 1st 2015, as defined in regulations EU 327/2011 and EC 641/2009 respectively.

The impact of this new legislation should not be under-estimated. It has been estimated that between 30% and 50% of all fan and compressors currently in the market will not be compliant with the ERP requirements. By including the water pump circulators employed in heating and air conditioning systems, some expert has estimated that over 90% of those products currently on the market will soon be prohibited for sale. As a result, OEMs will have to replace their products with more energy-efficient systems if they are to achieve the all-important CE mark.

Facing this new demanding and challenging requirements, it is imperative for the power semiconductor industry to offer a simple and economical way to address the requests of designers for easy to use system in package solutions. These solutions must be also characterized by scalability in voltage and current range so to simplify standardization of assembly and portability of design.

Devices like the µIPM product family are intended to provide designers with an economical, flexible and scalable solution that it is easy to use across a fairly large range power level.

Features such as an open-source topology for leg-shunt current sensing help to further simplify motor control designs (common source options are also available) while optimized dV/dt characteristics minimize losses and the need for EMI trade-offs. The 3-phase µIPMs (**see Figure 1**) also incorporate propagation delay matching circuitry, ensuring that the response at the output to a signal at the input requires approximately the same time turn-on and turn-off time durations for both the low-side and the high-side channels.

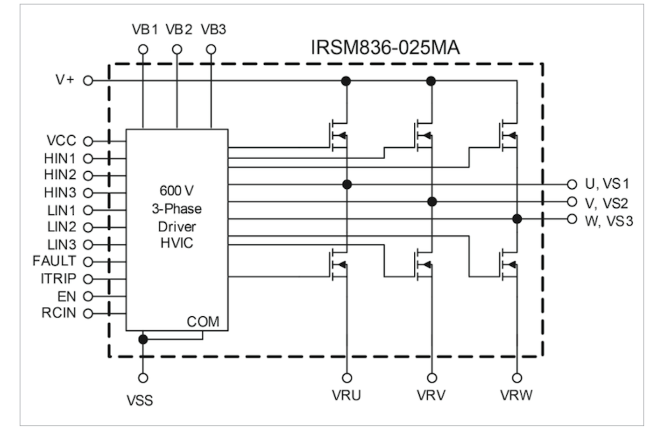


Figure 1: µIPM 3-Phase Inverter Internal Schematics

Despite their current and voltage ratings and high levels of integrated functionality, each of the new devices is supplied in a miniature 'QFN-like' package, which until now has been more commonly associated with low-voltage DC-DC controllers or voltage regulators. Indeed, with dimensions of just 12mm x 12mm x 0.9mm, the 3-Phase µIPM devices are believed to be the smallest IPMs currently on the market and can help designers to achieve space savings of up to 60% compared to alternative devices. This is without compromising isolation safety requirements, as the µIPMs meet the creepage distance requirements of the UL standards.

Among the factors that have led to these significant space savings is the approach taken to device cooling. In particular, unlike the poor die-to-PCB heat dissipation characteristics of gull-wing lead and DIP packages, the µIPMs achieve high die-to-PCB heat dissipation, allowing them to actively use the PCB as a heatsink. This is a similar approach that point-of-load (PoL) or VRM QFN-based packages use. The power semiconductors (500V FredFETs) and the HVIC die are bonded to the lead-frame, which is exposed and then soldered to the PCB.

In order to address higher power

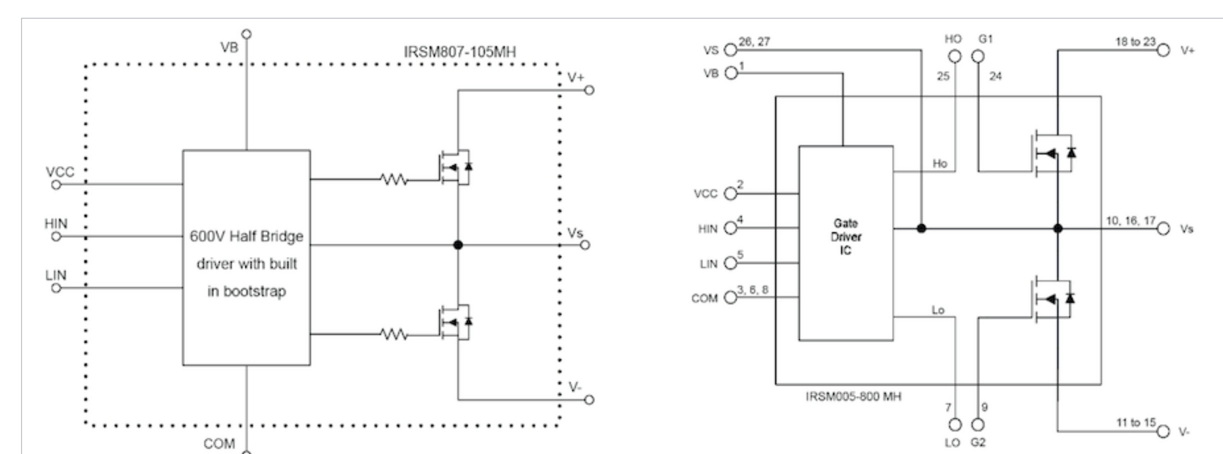


Figure 2. µIPM Half-Bridge Schematic and Pin-out versions

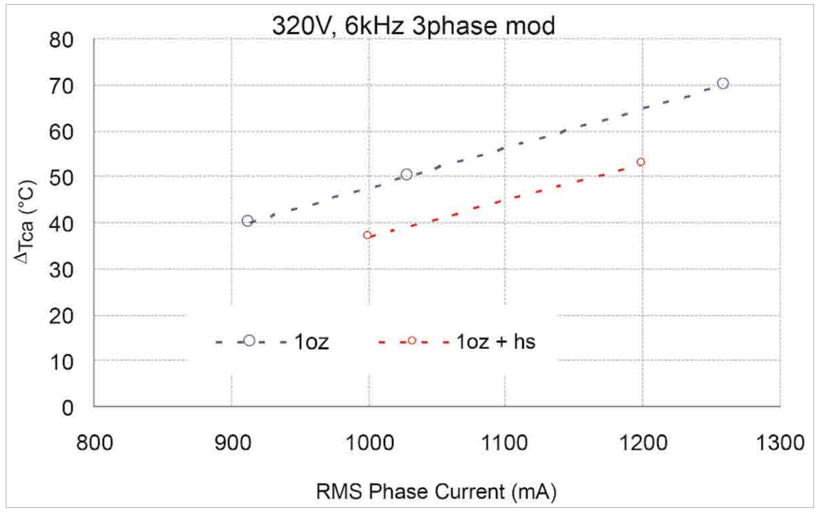


Figure 3 µIPM 3xHalf-Bridge Inverter Phase Current vs. ΔTCA

level applications, the µIPM family has expanded with new 7mm x 8mm x 0.9mm and 8mm x 9mm x 0.9mm modules in Half Bridge configuration (**see Figure 2**) with voltage ratings including 40V and current rating capability increased to 10A for the 500V version and up to 30A for the 40V version.

By splitting the integrated 3-phase inverter in 3 individual half-bridges, several benefits can be obtained. First and most importantly, this approach enables to spread the module power

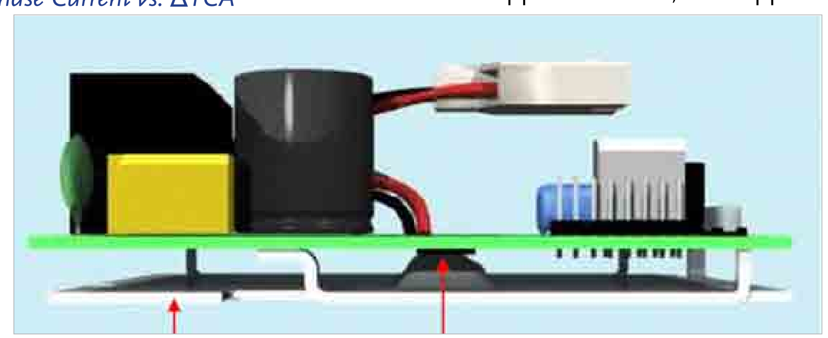


Figure.5 Compressor Drive Prototype

dissipation on a bigger printed circuit board area, improving the overall thermal performance.

In general, IPM current capability depends on the DC bus voltage, the ambient temperature, the switching frequency, and for all these elements, the higher they are, the higher the losses are), the modulation scheme (i.e. 3Phase vs. 2Phase), dV/dt of phase voltage and, of course, the FET characteristics (R_{DSON}, I_{REC} etc.)

In the case of a surface-mounted solution like the one offered by the µIPM™ family, the current capability also depends on the PCB design and specifically to the copper thickness, the copper pad areas, the number of layers and ultimately by the maximum allowable PCB temperature.
In other words, the maximum junction temperature of the power semiconductors is, in fact, less of a concern than the maximum PCB temperature.

By increasing the PCB copper thickness the overall thermal resistance Junction to Ambient, is lowered and consequently, the PCB temperature. Lowering the temperature enables higher current capability. The following graphs (**see Figure 3-5**) illustrate the direct impact of the increased PCB copper and additional heath-spreader to the current

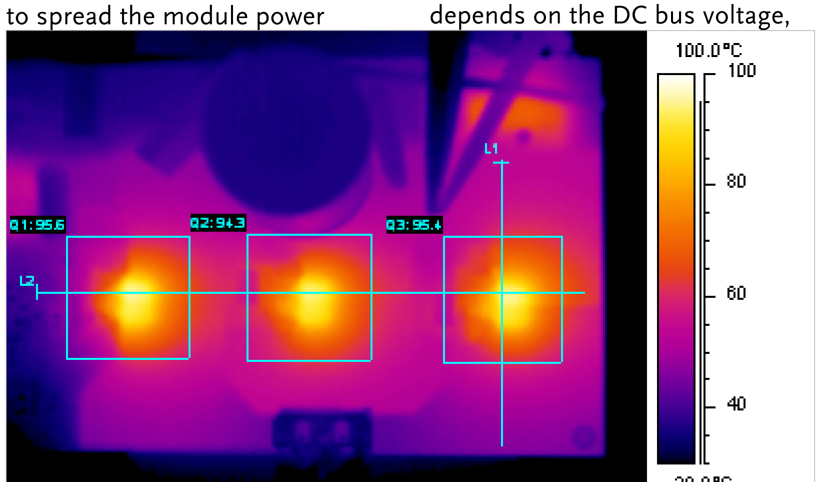


Figure 4 µIPM (HB) Thermal Image at Full Load

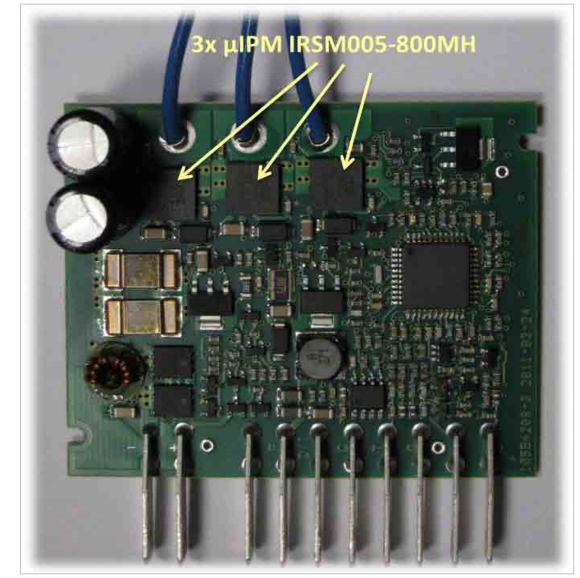


Figure 6 : µIPM Half-Bridge 40V-20A Inverter board

capabilities of a 300W nominal compressor drive with the inverter stage based on 3 half-bridge modules IRSM807-105MH.

Output current capability increases with higher ΔT_{CA} and also increases when a 2 phase modulation versus a 3 Phase modulation scheme is used. Similarly by lowering the switching frequency, lower switching losses enable higher output current. Additional top-mounted heat-spreader further reduces the temperature for even cooler operation. By using a set of µIPMs Half-Bridge modules, the overall compressor driver dimensions were also reduced to by 40% to a board 10cm x 7.7cm size.

The µIPM family scalability come handy when higher current but lower operating voltages are required to address specific application. 40V-20A µIPM Half bridges been used to address high efficiency application on battery operated inverters for automotive applications. In this type of application, size and weight are paramount and the efficiency is a must. By using three Half-bridge µIPMs (**see Figure 6**) a complete 200W compressor operating at 5.5Khz with DC bus voltage range 10-32V has been realized is a minuscule heat-sink less 7cm x 6cm board. Efficiency up to 98% for the inverter was recorded at 4000 RPMs with maximum case temperature well below 85°C at the highest load profile (**see Figure 7**).

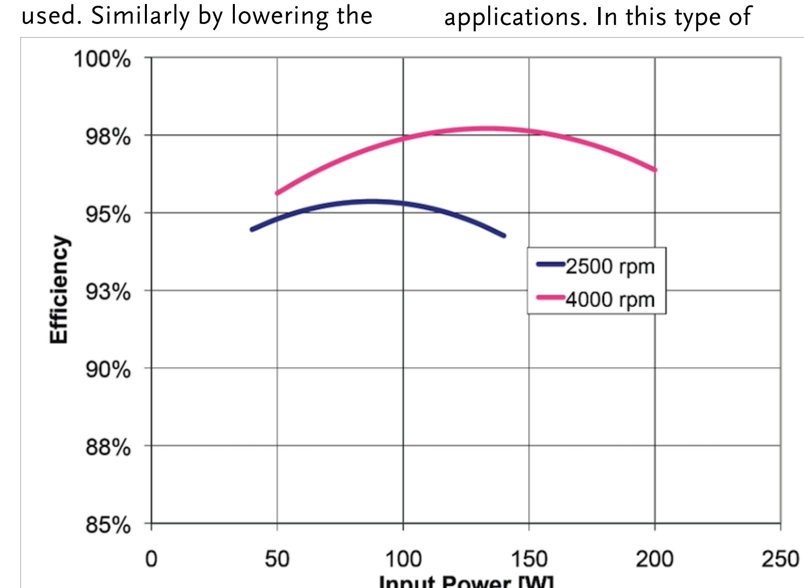


Figure 7 : µIPM Inverter Efficiency Curve

Technology Trends

As much as a package platform is advanced, like the QFN based µIPM is, its thermal balance hence its current capability is ultimately defined by the power dissipation of the semiconductors used. Clearly all topologies based on Silicon switches have intrinsically limited improvement opportunities in term of power losses reduction and only by migrating to more advanced material it will be possible to achieve higher power density levels. Also based on state-of-the-art active components and passive components, constrained integration opportunities pose a limit to the technology evolution. For future integrated modules, GaN based switches have a better potential figure of merit than other power components based on Si or SiC material. The potential improvement achievable from GaN technology is significant based on the material limits.

To improve overall conversion

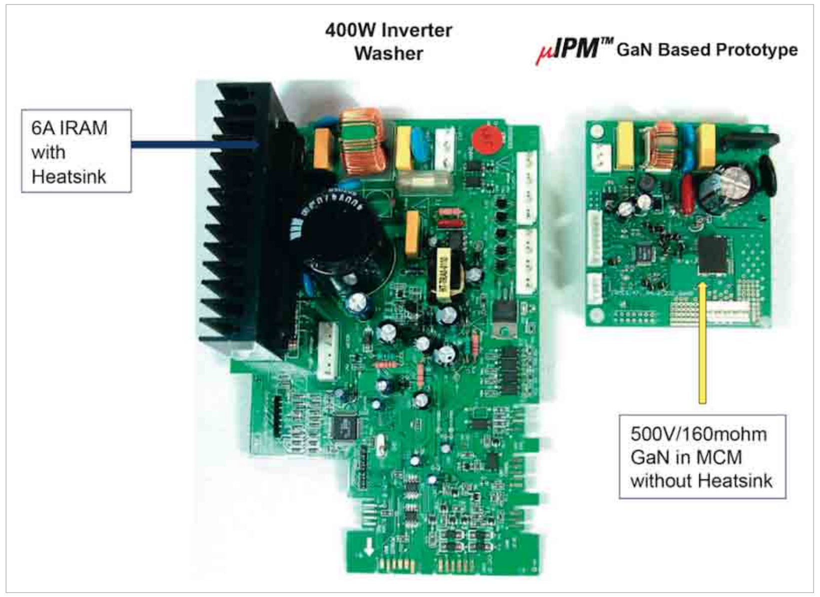


Figure 8 Inverter boards comparison

switches driven by a regular 3-Phase gate driver IC. The prototype µIPM Gan module with an IRMCK Digital control chip were the core of the small inverter board used for the power loss comparison. (**see Figure 8**). A standard home appliance inverter board using an IRAM IPM module was used as reference.

By loading both inverter boards with the same motor and loading profile (set by a dynamometer) the total power losses were compared (**see Figure 9**). GaN based µIPM module shown 6x

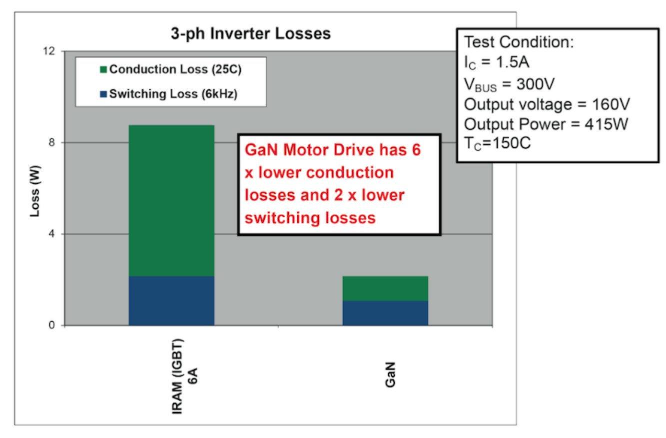


Figure 9a

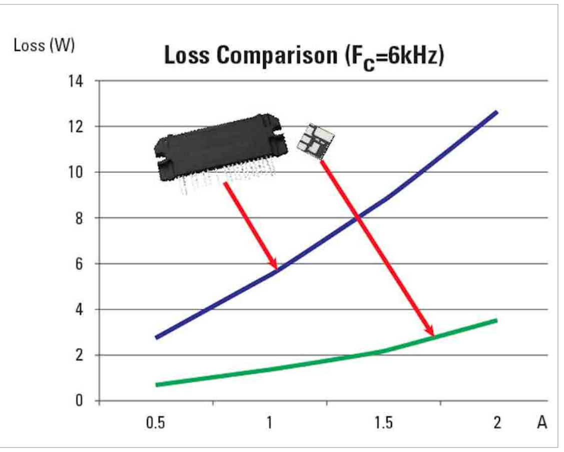


Figure 9b

Figure 9a-b GaN µIPM prototype losses vs. IGBT based module

efficiency, all inverter topologies require the power switch with the lowest possible specific RON*ETS Figure of Merit where RON is the specific On Resistance and ETS is the specific total energy per pulse loss. GaN-based MOSFETs show great potential in FOM improvement over the coming years.

The first generation of GaN based switch prototypes have 20x Lower Qrr compared to an IGBT Copak and more than 200x less than that of Super Junction body diode. Eoff (off switching loss) of these GaN Switches has been measured 72% less than for IGBT and 30% lower than HV Super Junction.

To prove in a real application all the above FOM improvements, a complete µIPM inverter stage, 12x15mm was built using prototypes of IR 500V Gan lower conduction losses and 2x lower switching losses than the IGBT based module enabling the small inverter board to operate heat-sink less. Considering the overall power loss versus motor current, the Gan based µIPM has up to 4x total power loss reduction which translate to a 10x power density increase (module to module comparison).

www.internationalrectifier.com

Improving appliance safety: designing for protection

Implementing safety measures is a significant concern in design

By: Cristian Ionescu and Ceyda Akbay, NXP Semiconductors

When it comes to home appliances, the overwhelming focus tends to be on advanced features and functionality. Nevertheless, design choices that enhance user safety and overcome possible malfunctions should play an even more important role.

In the UK alone, in 2010/11, 6,000 appliances were officially reported as "catching fire" with many non-official reports of "smoking" appliances. In US, according to Consumer Reports, more than 15 million appliances have been recalled during the last 6 years for defects that could cause a fire. Even if there is no person danger or harm caused, the cost of failure and brand damage are significant.

Implementing safety measures starts already from concept design. Engineers make detailed evaluations of possible thermal conditions and electric situations which could generate short circuits or overheating, eventually leading to component damage or even, in extreme cases, fires or explosions. In these cases, external protection is required to overcome dangerous situations.

Integration of protection in the triac

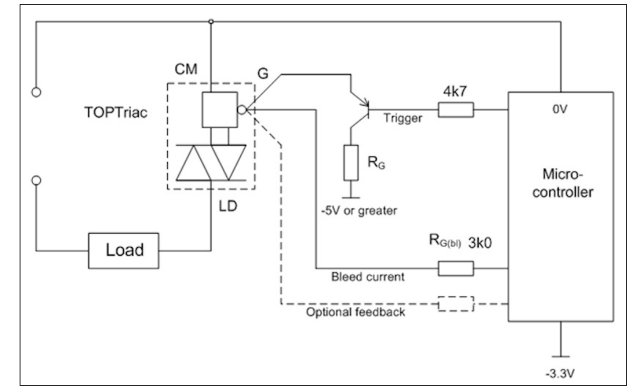
Over-temperature events can cause loss of switching control and over-current conditions for sustained periods of time in the load. This can not only result in the over-heating of the power switching control component (generally a triac), but also potentially the load. Some examples here are the motors in washing machines, dishwashers or vacuum cleaners, but also compressors in fridges. Over-temperature events of this type can damage the triac itself, damage the appliance, and affect the number of appliance failures occurring in the field.

In order to address these challenges, NXP has introduced a temperature and over-load protected triac (TOPTriac™) created specifically to protect itself and the appliance loads from damage during over-temperature and over-load events. TOPTriac is a two quadrant, high commutation, AC power switch which includes several unique characteristics beyond standard triac features, including:

- Over-temperature self protection
- Over-load self protection
- Exclusive negative gate triggering
- Smart functions like control capability and over-load status monitoring

The TOPTriac works like a standard triac when the chip temperature is lower than the normal operating Tj(max) (e.g. <125°C). When the temperature rises above the maximum normal operating temperature, Tj(max), the gate conditioning circuitry functions and the TOPTriac will turn-off automatically at a temperature Ttrip , protecting the device and load. When the chip temperature cools below Tj(max) (125°C), the gate trigger current can be reset and the triac will function normally again.

The TOPTriac is only triggered with negative gate current and



TOPTriac NXP diagram

can be controlled with a modified discrete phase control circuit or with a microcontroller. The Gate of the TOPTriac acts as the triggering input, but for control purposes, it can also act as a feedback output since it provides voltage signatures that indicate the status of the triac. These voltage signatures enable a microcontroller to monitor this feedback from the Gate and act upon it, according to the needs of the application.

In addition to the safety advantages it brings to the application, the TOPTriac helps reducing the overall system cost. In the case of a standard AC switch without integrated protection, the design might need to ove- specify the heatsink to make sure the application can deal with faults and overloads situations.

In the case of TOPTriac, heatsinks can be reduced in size and specified for normal operation only, since the smart triac's self-protection takes care of over-load conditions. In general, with the appropriate triggering and reset signals, TOPTriac could be useful for any application that may experience over-loading, over-current or over-temperature events.

Safer integration of the control unit

Another area that requires close attention when it comes to safety measures is the control unit for appliance operation. For example, in major home appliances, the IEC60370 safety norms will define a set of hardware and software guidelines the MCU should comply with. According to these norms, the MCU should be able to run various internal checks (memory or registers) and assure proper reaction even in the case of internal malfunctions, such as unexpected loss of internal clock.

In order to enable these requirements, NXP has embedded a set of safety-relevant features into a very cost-effective MCU implementation around the ARM® Cortex™-M0 processor. The NXP LPC1100 MCU family is very suitable for control operation in the home appliance industry, in both major and small appliances.

The LPC1100 family features from 4 KB up to 64KB flash, a very flexible clocking system including 1% internal RC oscillator, up to 8-channel ADC, and high current output drive capability. The family also offers a range of standard communication peripherals such as UART or I2C for connection to the other system boards. The packages start from 20 pins up to 48 pins.

For Safety compliance, the integrated windowed WD with independent WD oscillator helps the application identify any clock malfunction and assures proper reaction. The flash CRP (Code Read Protection) allows the user to define different application security levels and avoid unwanted access to the flash memory, for example. In addition, the parts are certified for Class B software compliance.

As the appliance environment is also a significant source for electro-magnetic disturbances generated by motors, valves or power line, designing components like MCUs requires a good understanding of how the MCU pins behave under these conditions. In order to provide accurate insight into pin behavior, NXP provides the EFT Immunity Tests results according to IEC 61967 requirements. The test report evaluates the immunity levels for signal and power pins and helps with proper, safer integration of the MCU into the system.

As part of its commitment to the appliance industry, NXP continues to research and work together with its partners to find and implement new features aimed at increasing the functionality and safety levels of appliance designs.

www.nxp.com

Power interface module selection

Power module choice impacts system board space and time-to-market

By: Patrick Le Fèvre, Ericsson Power Modules

A comparison of alternative on-board power solutions is rarely at the top of the agenda for a board designer. Often designers will use a previous solution because all available resources and time must be spent on the functionality of the system design. However, time spent on the power solution will affect the cost, procurement and sourcing, and will reduce the technical risks and redesign cost. Most importantly it will also have a huge impact and pay-off in terms of reduced time-to-market and increased system packaging density. The main alternatives are standard power modules and discrete power components. Decisions are often based only upon the hardware cost, neglecting many of the other cost elements.

A standard power module is a component-like device produced in large quantities, 100% tested and guaranteed to meet the specification in the datasheet. A discrete power circuit consists of many components mounted on the printed circuit board (PCB) together with the main system electronics. There is no testing other than on the finished assembled board. A recent addition to the power module offerings on the market is the PIM (Power Interface Module). An example PIM is shown in **Figure 1**.

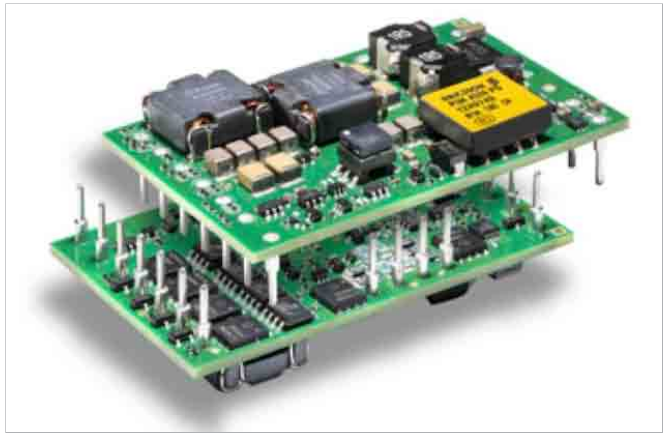


Figure 1

A PIM typically contains input filtering and transient suppression, inrush current protection and hot swap functionality, hold-up and under voltage shutdown, dual power feeds, monitoring, alarm and power management based on PMBus or I²C. The first release of a PIM was tailored for ATCA (Advanced Telecommunications Computing Architecture) standard based open platforms to reduce time-to-market and save valuable board space; but the PIM concept and functionality are actually a suitable fit for most boards in information and communications technology (ICT) equipment. Today this functionality is often provided by discrete solutions, but this situation may change due to the shift from proprietary platforms to more flexible and standard-based open platforms.

There are a large variety of board-input power interface solutions. Some of them are very simple and contain just a fuse and EMI filtering. Others are more complex and sophisticated, while also including inrush current protection and hot swap functionality, hold-up and under voltage shutdown, dual power feeds, monitoring, alarm, and power management.

The power interface circuitry built with discrete components on the board is often a proprietary solution that is adapted for different power system distribution architectures from ICT equipment manufacturers. There are standardization initiatives going on, such as the ATCA, but proprietary solutions are the most common.

There are several significant benefits of using a PIM instead of a discrete circuit solution, including reduction of design time and cost, reduction procurement and sourcing cost, reduction of time-to market and reduced board space for the power interface functionality.

Circuit and System Design Cost
This cost applies only to the discrete power interface circuit; as clearly internal circuit design is not required for the user of standard power modules. The circuit design cost consists of the following items:

- Circuit design and layout
- Determine component ratings
- Specify component part numbers and alternates
- Build and test prototypes, including thermal and EMC
- Modify circuits as required
- Documentation

The time and cost will of course differ depending on whether a basic design is already available, or there is a requirement for a completely new design. Design hours spent and hardware cost is a function of the number of components and complexity of the discrete power interface circuit. The result is also dependant on the skill of the electrical designer. In fact, a skilled power design engineer is required to design a robust and cost-effective power interface circuit.

However, there will be a power system design cost for both the discrete power interface circuit and for the standard PIM solution. The power system design cost consists of the resources needed and costs for the design of:

- DC distribution and decoupling
- Thermal analysis and cooling
- Safety and fusing
- Controls and diagnostics

The power system design will be significantly simpler and faster when using the standard PIM alternative, as there are much more advanced built-in functions and support literature available.

Procurement and Sourcing Cost
This is the resources and direct cost for procuring all of the components required for either solution, including vendor selection and qualification, price negotiation, quality assurance, inventory control, etc. For the standard PIM alternative, there is usually only one component to source, the power interface module. Also, in this case the hours spent and direct cost is a function of the number of components and complexity of the discrete power interface circuit.

The discrete power components, as with any other power components, are typically not part of the system board manufacturers' system-functionality electronics bill-of-materials (BOM), and therefore require specific skills and engineers to evaluate, qualify and approve the components and the solution in the specific application.

Time-To-Market Cost
This extremely important item addresses the technical risk and the fact that the first design is not always the final one. Engineering changes and redesigns are sometimes needed when the solution does not perform as expected. New microprocessors and ASICs are often developed in parallel with the board design with some uncertainty about the final circuit power and supply voltage requirement for the overall system. As the focus is on the performance and functionality of the primary application electronics, the final board power design cannot be finalized until testing and verification of the main system circuitry. This means that there is an apparent risk that the board power and interface circuitry must be re-designed very late in the project, multiplying the design cost and time, causing unexpected delays in the launch and delivery of the new system board. Obviously, there is a larger risk for severe delays when using a discrete power interface

Figure 2

solution, as the design is not as well defined or proven and there are dependencies upon several components and vendors.
Using a standard PIM solution can make the power system available earlier and thus capture additional sales.

The time-to-market cost accounts for the lost revenue (and profit) due to the loss of early product sales if the product introduction is delayed, impacted by the development schedule for the power solution. Not only it is a loss on the number of sold product – but also being early or even better the first on the market may account for a large part of the total revenue and profit as there is less competition and thus a significant higher market price. The time-to-market cost can be a very appreciable number compared with some of the other costs under consideration. With the very short product lifecycles today, this could very well be the determining factor for making a profit or not.

PCB Cost
The cost of the area on the circuit board occupied by the PIM or the discrete power interface circuit consists of:

- Material cost for the PCB itself
- Value of the PCB area to the system designer

The value to the system board designer will be quite variable. For some systems, with less crowded boards, this cost could be relatively low. For high-density systems with very tight packaging, the system designer may want to minimize the amount of area occupied by power and power interface functions to include additional system application circuitry.
In this case, the system board designer and the system manufacturer can assign a higher number to this value, which will serve to impose a cost penalty to the power solutions that have a lower area density.

In practice this has become one of the biggest challenges for ICT system manufacturers and system providers. Available space is very limited in all locations and come at a very high cost. Indoor and outdoor applications require minimal floor space and smallest possible equipment dimensions. Another constraint is that modern high-speed electronics require very small distances to minimize distortion by lead inductance and board capacitance. Certain functionality must therefore be built into the same PCB.

PCBs are manufactured in certain standardized sizes and the equipment cabinet and shelves are designed for specific board sizes. It is therefore not possible to increase the board size in a given system or equipment building practice. The only solution is to minimize the size and number of components on the PCB. This drives higher integration and smaller and smaller device packages, but at the same time higher functionality requirements result in higher pin count on each microprocessor or ASIC package. The result is very expensive board assemblies, not only because of expensive system electronics, but also due to the extremely high number of board layers required for the functionality. It is not unusual to find up to 30-40 layers in advanced ICT boards.

All together this means that board space is very expensive in modern ICT equipment and everything that is not part of the main system electronics needed for the required functionality

Figure 3

must be limited to an absolute minimum in terms of board space.

Application Examples
The first example is a board with conventional power interface circuitry (**see Figure 2**).

The power interface was designed a long time ago and has been used on many different boards for many years because it works, and besides there is no skilled power design engineer available to improve it. Components are old and costly, and the circuitry occupies a rather large area on the board. There are also increased demands on system availability and requirements for hot-swap and the power interface must therefore be redesigned and include alarm and power management. A PIM will solve all these issues at lower cost and significantly reduced board space.

The second example (**see Figure 3**) illustrates the board space that can be saved using the newly designed sixteenth-brick-format PIM4006 micro-power-interface-module (**see Figure 4**), which in addition to conventional input circuitry includes an I2C interface.

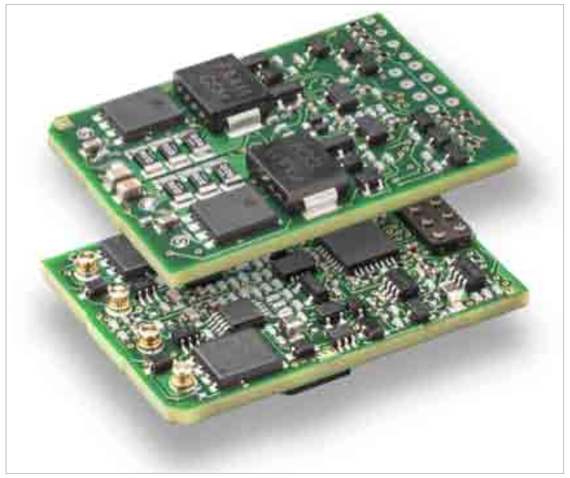


Figure 4

This module has been developed to meet the highest demands in system availability and robustness and also includes a digital communication interface for system architects to monitor the status of the application via software. The use of the latest technology to increase the amount of filtering has resulted in significant board-space saving (on both sides of the board). This space can be used for additional system processing capability while also simplifying power management and shortening time-to-market.

Also in this case, a PIM can save valuable board space and cost. This is possible due to an optimized design made by skilled and experienced power design engineers. The PIM utilizes smaller component packaging and advanced solutions, but still with a reduced bill-of-materials. Power management and internal communication makes it possible to reduce the hold-up time requirement and thereby minimize the required amount of capacitance. The result is a PIM that occupies only one-third maximum of the area taken by the discrete design.

Standardization in power distribution for ICT equipment will continue to meet demands from telecom and datacom operators for second sourcing and decreased cost. New PIMs are being developed for different power distribution standards and power levels, as well as proprietary solutions, making them a viable choice in most applications.

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What's shrinking AC-DC power supplies?

Smaller components, enhanced thermal performance, and DSPs enable smaller units with the same power rating.

By: : Don Knowles, Director of Engineering, N2Power

Power supply design trends are clear and dramatic: additional features, improved efficiency, and smaller size for the same power ratings, for both battery-powered portable units as well as larger, line-powered ones. For the AC-DC supplies, these changes are due to multiple factors combining to yield these more-compact designs. Some of the factors are obvious, but others are not.

Start with the most apparent change, which is the use of smaller passive components, as described in **Figure 1**. Vendors are shifting the basic resistor and capacitor footprint from 0805 (2.0 mm x 1.25 mm, 0.08" x 0.05") size, to 0603 (1.5 mm x 0.8 mm; 0.06" x 0.03") and to an even-smaller 0402 (1.0 mm x 0.5 mm; 0.04" in x 0.020") size. Diodes, as well, are also available in smaller packages than they previously were.

The use of larger parts was a holdover habit from previous generations of supplies. It made a lot of sense for vendors to continue using parts that were fully known and characterized in their supply chain and inventory, and all of the same size. The pressure to reduce supply size, along with the electronic industry's growing use of smaller parts in consumer products, has made them the body size of choice. The result is a significant reduction in required PC board space: the change from 0805 to 0402 cuts a component's immediate footprint to just 20% of its previous value—and there are many such devices on a supply's PC board.

Changes in the supply magnetics (inductors and transformers) are also helping squeeze the size down. Traditionally, these components have actually been the most complex 'simple' passive ones in the supply's implementation, often custom-designed by the OEM to get precisely the desired and often subtle combination of primary- and secondary-tier parameter values (including inductance, DC resistance, size, form factor, winding type, insulation, orientation, volume and cost). In addition, supply designers are also making better use of the available inductor volume. For example, they are re-orienting the inductor to take advantage of the supply's available height-dimension headroom, in return for a smaller footprint.

Actual and relative sizes of chip capacitors

Case size	Length (mm)	Width (mm)	Area (mm²)
0402	1.00 (0.039in)	0.50 (0.020in)	0.50
0603	1.60 (0.063in)	0.80 (0.031in)	1.28
0805	2.00 (0.079in)	1.25 (0.049in)	2.50

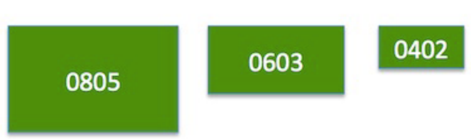

Figure 1

Figure 2a

Figure 2b

On the active component side, the packaging of the power semiconductors has also shrunk, primarily for the critical MOSFETs of the output. Chip-scale power MOSFETs such as the DirectFET from International Rectifier (where the metal enclosure which covers the bare die is also the drain terminal) provide significantly more power capability, but in a much-smaller package. This has had a major impact on supply size, since the DirectFET has a 30% larger MOSFET die but with a 60% reduction in PC board footprint compared to the widely used D2Pak package. Compared to the D-Pak package, the DirectFET die can be 33% larger than the D-Pak package yet its footprint is 54% smaller.

Of course, power supply size also involves the necessary concerns for thermal loads. To address this issue, engineers at N2Power are making extensive use of thermal gap pads for more efficient heat transfer. Since this thermal material can be a significant part of the bill of materials (BOM) cost, the company redesigned the heat-sink structure to use less of the gap-pad material, thus cutting both cost and size.

Finally, by increasing the internal operating frequency for these switching supplies, designers have been able to decrease overall size or, alternatively, pack a higher power rating into the same size unit. For example, the 125W XL125 supply from N2Power has a power factor correction (PFC) circuit operating at 87 kHz and a half-bridge output at 43 kHz. By moving both to 125 kHz in the 160W XL160 design, the volume of the associated magnetics was reduced by one third, thus allowing this 160W unit to fit in the same 3"x5" 1U footprint as the 125W supply, and with a height of just 1.25".

As another dramatic example of the benefits of higher frequency, consider the XL375 from N2Power, **Figure 2a**, versus the XL275, **Figure 2b**; despite being rated 36% higher in output, the 3.3"x5.0"x1.5" (1U form factor) 375W unit (power density of 15W/in³) is just 0.3" longer than the 1.25"x3.00"x5.00" 275W supply (12W/in³).

What about "smarter" supplies?

Active components also are playing a major role in the shrinking of supplies in several ways. IC vendors are developing better analog components for power management, especially helpful for complex functions such as PFC. The result is better accuracy and performance at both high and low line voltages. Early-generation PFC circuits could achieve power factor up to 0.99 (nearly a perfect unity value) at lower AC-line voltage of 90/110VAC, but the correction dropped to as low as 0.75 at 240VAC. Using the latest analog ICs, designs can now maintain high PFC across the full voltage range, leading to the need for fewer corrective components and thus smaller supply size.

The most dramatic change for supplies architecture is the incorporation of digital control circuitry in the inner workings of the supply. In recent years, processors have been used in the secondary side of the supply to monitor key points and performance, to establish some operating parameters and to manage a communications interface port. But the primary-side control loop still remained analog.

With the availability of high-performance, low-cost digital signal processors (DSPs), digital control now extends to the primary loop. This brings additional flexibility in control and operating points, of course, including on-the-fly adaptive control and dynamic operating changes. It also impacts size, by putting more of the control functions in less space, due to fewer needed ICs and passive components to implement the hardware control-loop strategy. For example, a supply using DSP control can do three-phase AC line control with about the same footprint as a single-phase unit. The DSP can also provide the required PFC with no further footprint penalty.

Conclusion

For switching AC/DC supplies, no single factor is responsible for shrinking physical size. An additive combination of the switch to smaller passives, smaller power MOSFETs and increased availability of customized magnetic components is the starting point. Add the enhancements which analog power IC vendors are offering, plus the radical architecture shift which DSP-based control brings and the result is that users are seeing shrinking supply size, but without penalties in performance or cost.

Figure 1: The reduction in needed PC board real estate resulting from using components with smaller linear dimensions is dramatic, as seen by this comparison of 0805, 0603, and 0402 bodies. A 0402 capacitor takes just one-fifth of the space required by a 0805 chip.

Figures 2a and 2b: by adopting a higher switching frequency, N2Power achieved a 25% improvement in power density for the 375W AC/DC unit on the right, compared with the company's 275W power supply on the left.

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Increasing efficiency in LED street light power supplies

New LLC converter simplifies design of high efficiency PSUs

By: Peter Rogerson, Power Integrations

Solid-state exterior lighting requires a regulated AC to DC power supply to drive LED loads, which can vary in size from 1 W to over 500 W. To ensure a good return on investment, these power converters must offer very high efficiency (to compliment the increased efficacy of the light source) and a long lifetime (due to cost and often remote/inaccessible mounting locations). The LLC converter, which runs in conjunction with a high-efficiency PFC boost conversion stage, offers the best efficiency above 100 W, but also presents some unique challenges before a reliable design can be achieved.

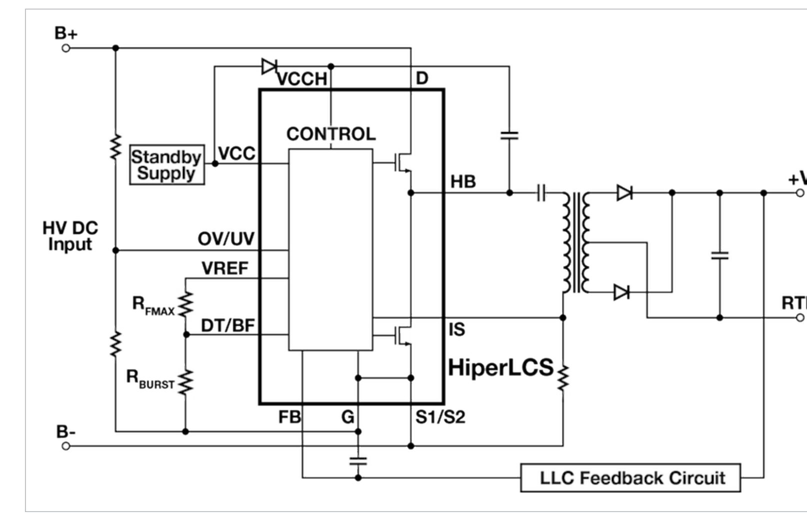

Figure 2: HiperLCS typical application circuit

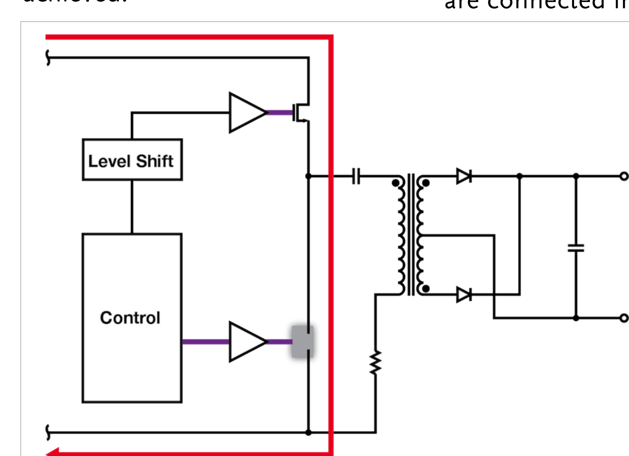

Figure 1: Shoot-through due to drive-signal timing mismatch

An LLC is a resonant switching converter which employs a half-bridge switch in series with a resonant circuit. In an LLC converter, high- and low-side drivers are connected in a half-bridge configuration to a transformer via a series capacitor. The transformer's inductance and the capacitor comprise the resonant load while the two driver transistors of the half-bridge conduct alternately, leaving dead time in between each conduction phase.

Variations in the drive parameters and parasitic components on the gates of the half-bridge MOSFETs can result in timing mismatches and possibly cause shoot-through and catastrophic failure of the MOSFETs, as illustrated in **Figure 1**. The risk of shoot-through is the primary constraint on the switching frequency of LLC designs.

Power Integrations (PI) has now addressed these issues with a new product family called HiperLCS™. HiperLCS

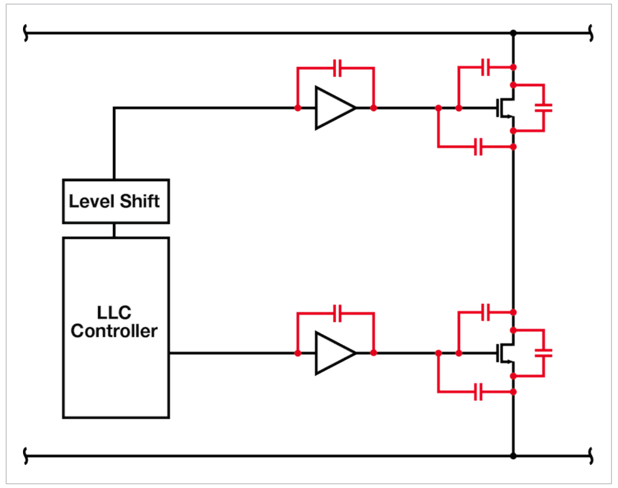

Figure 3: Closely coupled driver stages and MOSFETs in HiperLCS control parasitics.

ICs incorporate all the essential features and protection circuitry required for an LLC converter into a single monolithic IC family capable of up to 440 W output1. Devices include two 530 V power MOSFETs, high- and low-side drivers, an LLC controller, UV and OV shutdown and brown-in/brown-out protection. (**Figure 2**)

In HiperLCS ICs, the output high-voltage MOSFETs, together with the drivers, level shift and controller, are closely coupled on a single silicon die. This enables accurate control of variations in the entire drive system, allowing compensation of all parasitic elements. In addition, the dead time and duty cycle matching are trimmed device by device during manufacturing, with duty cycle balanced to within ±1 percent. (**Figure 3**)

The accurate control of drive timing enables HiperLCS ICs to maintain nominal steady-state operation at a switching frequency of 500 kHz and a maximum operating frequency of 1 MHz. This high switching frequency is important because it enables the use of low-cost SMD ceramic capacitors in the output loop instead of bulky electrolytic capacitors. Ceramic capacitors are also preferred in long-lifetime applications such as area lighting, because they do not suffer from parameter drift or premature failure – unlike electrolytic capacitors which often fail at elevated temperatures.

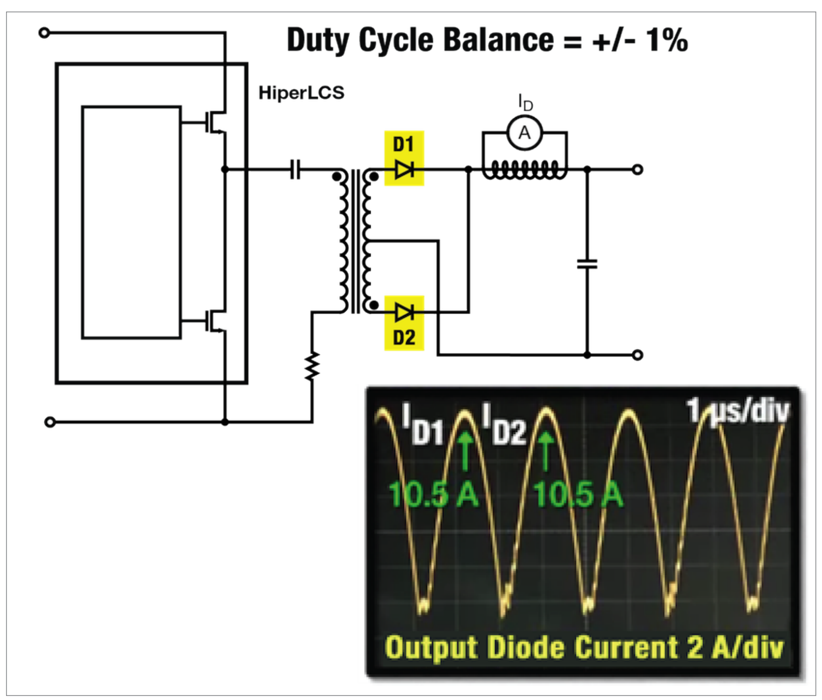

Figure 4: Output duty cycle balancing

A further advantage of using a high-switching frequency is that significantly smaller transformers and output inductors are required, enabling production of low profile designs with only 11 mm headroom.

Precise duty-cycle trimming ensures accurate duty-cycle sharing between the two output diodes and between each half of the transformer's secondary winding. Therefore it is not necessary to oversize the output diodes to accommodate current imbalances. (**Figure 4**)

If the duty cycle becomes imbalanced, it will be necessary to specify the output diodes to accommodate the worst-case peak current. The transformer would also have to be designed to deliver the higher current. Clearly, efficiency would suffer because of the I^2R losses resulting from the higher peak currents. (**Figure 5**)

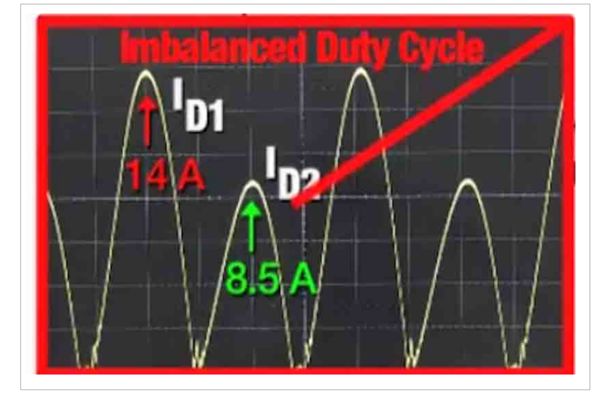

Figure 5: Effect of imbalanced duty cycle

Figure 6 includes the essential elements of a complete power supply with HiperLCS device output. At the AC supply input, a CAPZero™ X-capacitor discharge IC saves energy by preventing continuous current drain through discharge protection resistors. A HiperPFS™ IC, a high efficiency power factor correction front-end, delivers 380 VDC to the HiperLCS device output stage. Devices in the TOPSwitch™-JX family provide a very low-consumption standby supply that serves two functions: first, it enables functions such as remote-on/off of the main supply; and second, it delivers a 12 VDC supply to HiperPFS and HiperLCS devices while the main supply is in standby.

Efficiency

HiperLCS ICs have two modes of use. For high-efficiency design, their resonant control circuitry provides very low power loss, enabling designs that are greater than 97 percent efficient at a nominal 66 kHz switching frequency. If cost and size are the determining design criteria, then a high-switching frequency is required. In this case, efficiency still remains high – for example, 96 percent at 250 kHz, the frequency where maximum power is achieved.

When coupled with a HiperPFS power factor correcting front-end, as in **Figure 6**, the design achieves overall efficiency levels of over 89 percent at full load.

Modeling

HiperLCS ICs allow the designer to optimize the design by setting parameters such as the maximum and minimum switching frequencies and dead time to match power train requirements. The frequency at which the supply enters burst mode can also be

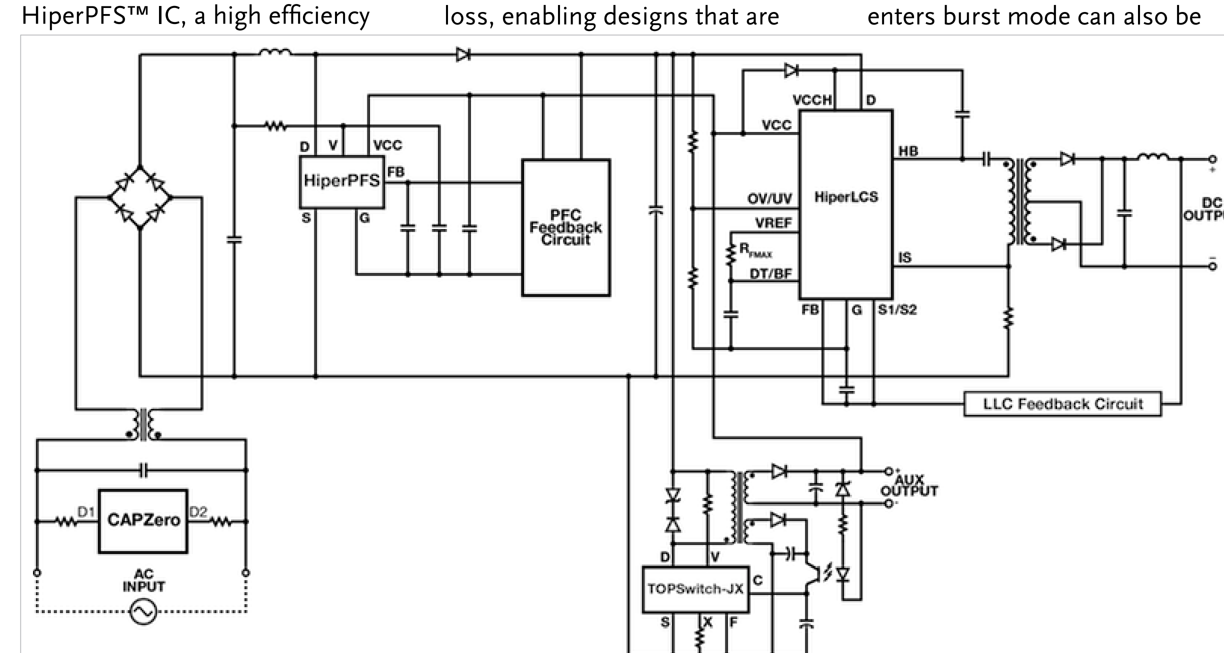

Figure 6: A complete power supply using the HiperLCS device

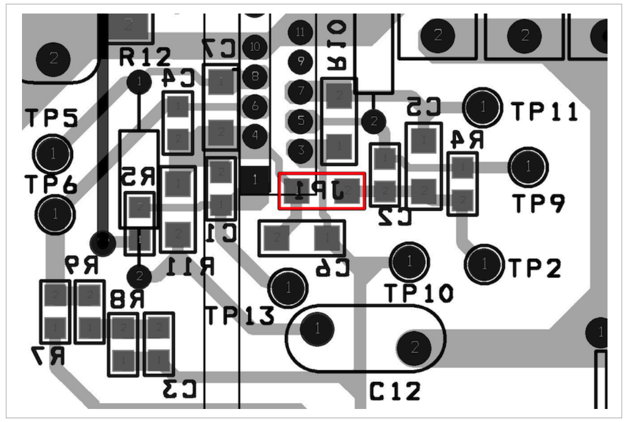

Figure 7: Alternate Layout for LCS Footprint using Round Pads with Jumper Connecting Two Grounds Highlighted.

adjusted. This allows the power train to be optimised for maximum efficiency while still maintaining regulation at zero load during input voltage swells.

With all these options available to the designer, it is essential to use an accurate modeling tool to simulate the circuit's behavior and automate the design of the transformer and inductors. Power Integrations' XIs Expert Suite Version 8, a real-time design and modelling tool, fully supports HiperLCS designs. The software provides a complete first-pass design capability for both the transformer and resonant power train. The unique switching model within XIs is accurate to within 3 percent. This is a great improvement on most simplified AC models which are only accurate to 15 percent. The enhanced accuracy significantly shortens the design cycle by eliminating the prototyping of repeated iterations. Application Note AN-55, published by Power Integrations, contains a step-by-step procedure for using XIs to design a HiperPFS application[2].

Tight layout

With high currents switching at frequencies of 500 kHz, it must be understood that the placement of components and wiring traces requires careful attention in order to achieve maximum performance. Certain pins of the HiperLCS IC, such as the FEEDBACK pin or DEAD-TIME/BURST FREQUENCY pin are sensitive to noise and therefore require decoupling. The transformer is a source of both high di/dt signals and dv/dt noise. Di/dt signals can couple magnetically to sensitive circuitry, while dv/dt signals can inject noise via electrostatic coupling. Electrostatic noise coupling can be reduced by grounding the transformer core, but it is not economically feasible to reduce the stray magnetic field around the transformer without drastically reducing its efficiency. Sensitive traces and components (such as the optocoupler) should be located away from the transformer to avoid noise pick-up.

The HiperLCS datasheet contains further detailed information of how to address component placement and trace layout issues. **Figure 7** gives an example.

Power Integrations' Reference Design Report RDR-239 describes a complete HiperLCS design appropriate for exterior lighting applications. The converter produces a 6.25 A output at 24 V with >95 percent efficiency at full load[3]. The Reference Design Kit RDK-239 includes a working power supply, sample devices, unpopulated PCB, data sheet, comprehensive engineering report, PI Expert design software and other related documentation.

With HiperLCS, Power Integrations has made designing high efficiency LLC power converters simpler and faster. The integrated device itself deals with the matching of timing and the control of parasitics, and ready-made evaluation examples give the designer a head start. HiperLCS technology is a new resource for the roll-out of LED street and area lighting, using higher efficiency converters to provide ever greater savings in energy consumption.

References

1. LCS700-708 HiperLCS™ Family Integrated LLC Controller, High-Voltage Power MOSFETs and Drivers. June 2011.
2. Application Note AN-55 HiperLCS Family Design Guide. June 2011.
3. Reference Design Report for a 150 W LLC High-Voltage DC-DC Resonant Converter Using HiperLCSTM LCS702HG. September 13, 2011.

www.powerint.com

Elegant step-down conversion for 24V industrial applications

supply voltage and current monitoring is crucial to conserving power and guaranteeing reliability

By: Frederik Dostal, Analog Devices

Industrial power supplies need to have very high efficiency today and often times need to be highly compact. In combination with the typical 24V rail available, many solutions utilize a switching regulator rated for 36V Vin max. Unfortunately most solutions available are non-synchronous switching regulators with an external Schottky diode. New synchronous solutions integrating the high side as well as the low side MOSFETs in one chip offer small solution size, high efficiency and especially low switching noise. This article will introduce and discuss a typical 24V down to 5V converter solution with the ADP2441 industrial buck regulator IC.

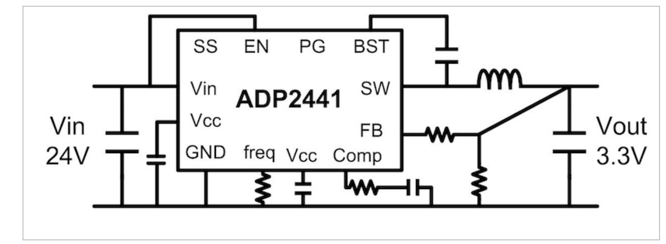

Figure 1. Circuit diagram of the ADP2441 step-down switching regulator in a 24V nominal to 3.3V conversion

Figure 1 shows the circuit diagram of a 24V to 3.3V step down conversion for industrial applications. In such applications, 24V nominal input voltage usually means that the actual input voltage will me much higher. Typically, plus or minus 20% is quite a common tolerance. Combined with possible input voltage spikes, very often applications demand 36V Vin max. Usually the higher the input voltage capability of a given DC/DC converter the better. Very often, the 24V supply rail is distributed across large factory floors with many different loads attached. Any cable and connector parasitic inductance as well as different loads turning on and off will generate a quite noisy and voltage spike prone environment.

Low EMI, easy board layout

It is very elegant not having to worry about an external Schottky diode. After all it is one less component to worry about. Also a low EMI, optimized board layout becomes very simple. **Figure 2 A and B** shows the current flow in a buck regulator during the on-time and current flow during the off-time of a synchronous buck regulator. **Figure 2 C** shows the AC-current flow. These are the traces which have to be kept very short and tight to avoid large loops with excessive parasitic inductance which will generate noise. Using a synchronous switching regulator with the high side and the low side switch integrated, the trace between the high side and low side switch stays all

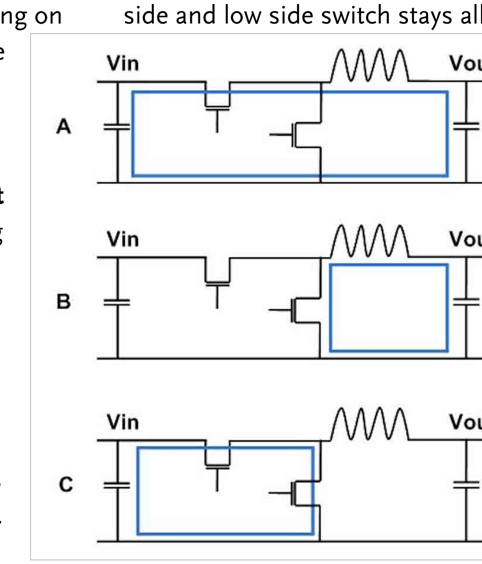

Figure 2. Current flow of a synchronous buck regulator during the on-time (A), the off-time (B) and the traces with AC current flow (C)

internal on the die. This AC trace will not need to go through bonding wires, IC package pins and board traces with quite high parasitic inductance. This AC trace is kept local with low parasitic inductance and thus very low EMI.

The only trace the design engineer needs to worry about is the connection traces of the input capacitor. It needs to be places as close as possible to the Vin and ground pins of the IC. This is a simple task and thus board layout is very easy. Very good EMI behavior can be achieved this way.

High efficiency

Synchronous switching regulators (two active switches instead of one active switch and one diode) are usually more efficient than non-synchronous regulators. This efficiency advantage becomes significant as the output voltage becomes lower and lower in newer applications. The voltage drop across a diode of about 0.6V versus the voltage drop across a fully turned on MOSFET (0.2V as an example) is higher. When looking at an output voltage of 12V, this voltage drop difference is not so significant.

When dealing with output voltages of 2.5V or 1.8V however, the voltage drop across the low side switching element becomes quite important for the overall efficiency. Five years ago, most industrial applications powered off a 24V bus, required a 5V system voltage for some function. Today, we see applications where the highest system voltage is 3.3V or even 2.5V. For these systems, the efficiency advantage of using a synchronous switching regulator becomes greater.

High switching frequencies

Designing a power supply with high switching frequencies increases switching losses and thus decreases the overall efficiency in most cases. However, some applications call for low solution cost as well as small solution size. These demands yield the utilization of a high switching frequency in order to save space and cost of the inductor and capacitors used. The ADP2441 has an adjustable switching frequency of up to 1MHz. The ADP2442 is very similar to the ADP2441 but the switching frequency can also be synchronized to a clock frequency of up to 1MHz. While 1MHz is not so unusual for a switching regulator, there is an important limitation which many available devices on the maket have. It is the minimum on-time. This is a time period that the switching regulator keeps the high side switch turned on before it can turn it back off. While at low frequencies, the minimum on-time does not matter much, at higher switching frequencies this is a very important specification. At 1MHz switching frequency, there is 1000ns in one cycle. When stepping down 24V to 2.5V, the duty-cycle would need to be roughly 10%. So the switching regulator needs to turn on the high side switch for 100ns.

If the nominal 24V happens to be a bit higher for a certain amount if time, the on-time will reduce to periods shorter than 100ns. Many 36V switching regulators on the market have a minimum on-time of higher than 150ns and in many cases the minimum on-time is not even specified. Circuit designers then notice that the regulator is skipping switching cycles and that the switching frequency is not fixed at 1MHz anymore. The ADP2441 was designed for high switching frequencies at large step-down ratios. It has a specified minimum on-time at 50ns typical and 65ns is guaranteed as a worst case value. This allows the design of step-down switching converters at 1MHz from a high input voltage to very low output voltages.

Circuit example and design tools

Figure 3 shows a circuit stepping 24V industrial bus voltage down to 5V. It is operating at 500kHz

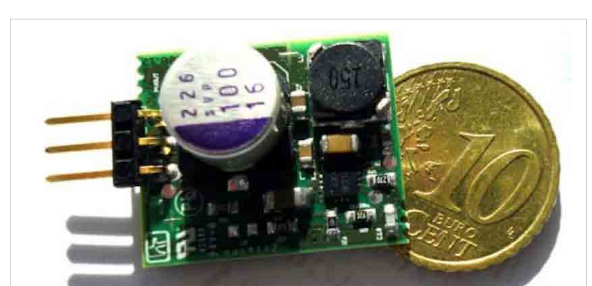

Figure 3. Small size evaluation board 24V to 5V as linear regulator replacement (photo: Semitron)

Screenshot of design tool

which is a good compromise between high efficiency small solution size and low component cost. The board was designed by the franchised German Distributor Semitron (www.semitron.de) to be used as a replacement for 24V to 5V TO-220 packaged linear regulators which are still in place in many low current industrial applications today.

For design engineers there is a circuit design tool available which can help to select external components and circuit parameters such as switching frequency very quickly. The tool is able to select the right external components from a passive components database to suit complex operating conditions. The user can enter a certain expected load change on the output and the amount of output voltage overshoot or undershoot which is acceptable. Then the tool will select the right type of output filter to accommodate these requirements. Stability considerations can be evaluated with the integrated Bode plot section. The tool can be downloaded free of charge from the product folder of the ADP2441 on the Analog Devices website.

www.analogdevices.com

Current-mode controllers can provide benefits over voltage-mode counterparts

The ability to sense a very low ramp voltage maintains excellent stability

By: Bruce Haug, Linear Technology

As Microprocessors and Digital Signal Processors demand progressively higher current at lower operating voltages, it becomes more critical to minimize power supply conduc-tion losses by making the resistance of the current sense element as low as possible. However, a low resistance current sensing element produces a lower ramp voltage, which is not generally conducive for stable operation when using a current mode control-ler. A low ramp voltage causes a current mode controlled switching power supply to have significant jitter and can become unstable in most applications. Accordingly, a voltage mode controller is normally used for these applications even though it has deficiencies and potential reliability issues.

A current mode controlled switching power supply has several advantages over a volt-age mode switching power supply, these are:

1. Higher reliability with fast, cycle-by-cycle current sensing for output short circuit and overload protection. A voltage mode controlled power supply is slower to re-act to an over current condition which can result in a failure in some applications.
2. Simple and reliable feedback loop compensation allowing the power supply to be stable with all ceramic output capacitors making for a smaller solution size.
3. Easy and accurate current sharing in high current multiphase designs.

However, for high current outputs of typically greater than 20A a low DCR inductor will not produce enough of a voltage ramp signal for a current mode controller to be stable under all operating conditions and so a voltage mode controller has had to be used. This is about to change. Linear Technology has recently released the LTC3866, a current mode controller that has the ability to sense a very low ramp voltage and maintain excellent stability. The LTC3866 is the first true current mode controller that breaks through the minimum 1mΩ required DC resistance inductor and still maintains stability.

The LTC3866 is a peak current mode synchronous step-down DC/DC controller that al-lows the use of very low DC resistance power inductor using a novel DCR sensing archi-tecture that enhances the signal-to-noise ratio of the current sense signal. A power in-ductor DC resistance of as low as 0.17 milliohms can be used to maximize converter ef-ficiency and increase power density. Furthermore, this new DCR sensing technique dramatically reduces the switching jitter normally associated with low DCR resistance applications. DCR temperature compensation maintains a constant and accurate current limit threshold over a broad temperature range.

This device operates from a 4.5V to 38V input voltage range that encompasses a wide range of applications. Strong onboard N-channel MOSFET gate drivers allow the use of high power external MOSFETs, DrMOS devices or power blocks for an output current of up to 40A, with output voltages ranging from 0.6V to 3.5V when using the onboard re-mote sense Diff Amp and 0.6V to 5V when not using remote sense. The LTC3866 can easily be paralleled by tying the ITH pins together of multiple devices for even higher power multiphase applications. A low current sense threshold from 10mV to 30mV can be selected. The fixed operating frequency is adjustable from 250kHz to 770kHz or can be synchronized to an external clock. Additional features include an internal bias voltage regulator, soft start or tracking, overvoltage protection, soft short-circuit recovery, current limit foldback, thermal shutdown and external V_{CC} control. The LTC3866 is available in thermally enhanced 4mm x 4mm QFN-24 and TSSOP-24E packages.

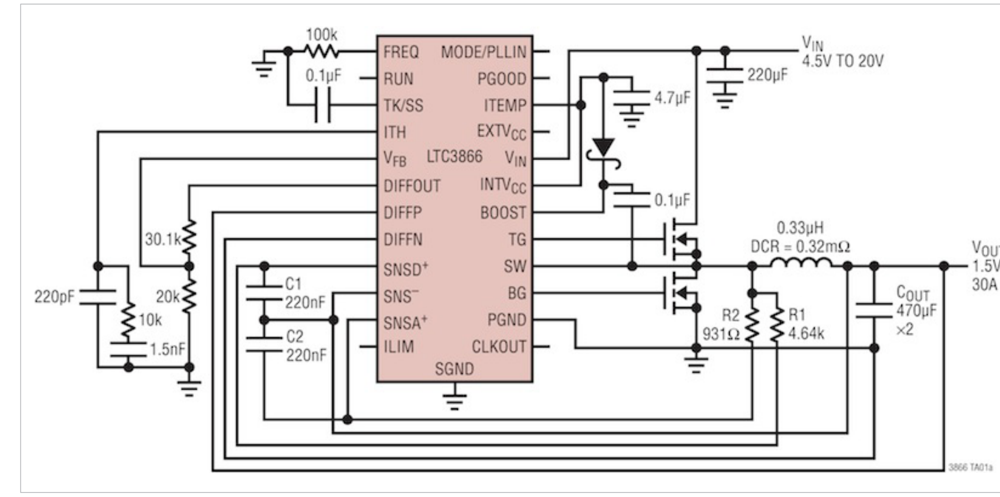

Figure 1: Typical LTC3866 Applications Schematic for 12V_{IN} to 1.5V_{OUT} at 30A

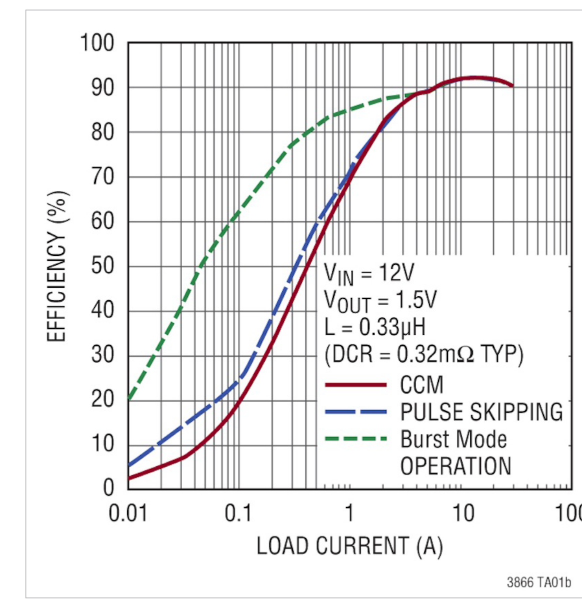

Figure 2: Efficiency Curve of Figure 1 Schematic, Show-ing Efficiencies >90% Are Possible

Typical Application

The LTC3866 can work with very low DCR inductors due to its ability to operate with only a small peak-to-peak sense voltage. **Figure 1** below shows a LTC3866 schematic circuit design that operates from a nominal 12V input and produces a 1.5V output at up to 30A. An induc¬tor with DCR = 0.32mΩ is used to maximize efficiency at greater than 90% as shown in **Figure 2**.

Features

The LTC3866 comprises two positive sense pins, SNSD+ and SNSA+, to acquire the ramp signal and process it in-ternally to provide a 14dB signal-to-noise ratio improvement in response to low voltage sense sig-nals. The current limit threshold is still a function of the inductor peak current and its DCR value, and can be accurately set from 10mV to 30mV in a 5mV steps. The part-to-part current limit error is only about 1mV over the full temperature range assuring good accuracy.

In addition, since the LTC3866 uses constant frequency peak current mode control archi-tecture, it guarantees cycle-by-cycle peak current limit and current sharing between dif-ferent power supplies. It is especially well suited to low voltage, high current supplies be-cause of a unique architecture that enhances the signal-to-noise

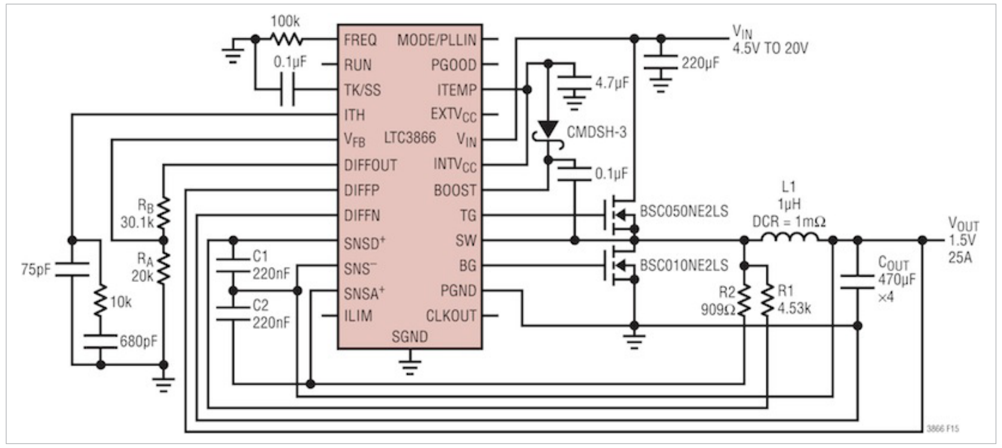

Figure 3: High Efficiency, 1.5V/25A Step-Down Converter with Very Low Output Ripple

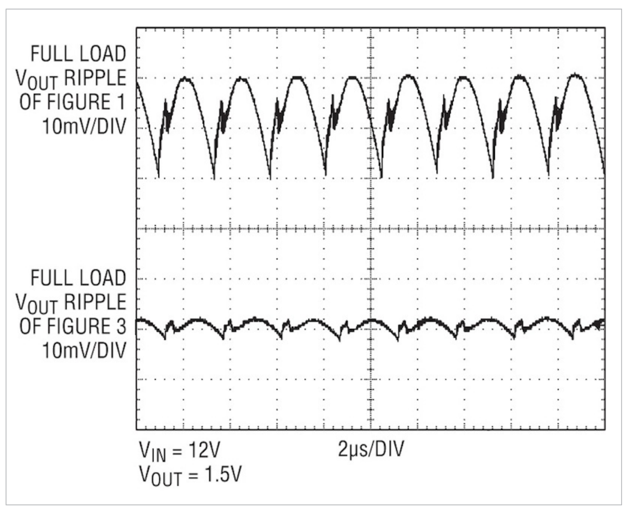

Figure 4: Low Output Ripple Curve of LTC3866 Figure 3 Schematic

ratio of the current sense circuit. The improved signal to noise ratio minimizes jitter due to switching noise, which could corrupt the signal. The worst case switching jitter is reduced by 60% when com-pared to a standard current mode controller.

Low Output Ripple Application

Because the LTC3866 only requires a ramp signal about a quarter of the sense signal of the next best current mode converters, output ripple can be drastically reduced by in-creasing the inductance and capacitance of the output filter. **Figure 3** shows a high effi-ciency converter with the benefit of low output ripple voltage. The much lower output voltage ripple of less than 10 mV, as shown in **figure 4** is critical for extremely noise sen-sitive applications such as test/measurement systems and audio devices.

Alternatively, the LTC3866 can be used with power blocks and DrMOS devices for a more compact and very high output current. **Figure 5** shows a dual-phase, high efficien-cy, 1.8V/80A power supply based on two LTC3866 controllers driving power blocks in parallel. The current share between phases is within +/-5% due to the current mode con-trol of the LTC3866. If two voltage mode controllers were used in place of the LTC3866, accurate current sharing would not be possible due to there being no means of control-ling the phase current.

In applications where a higher value DCR inductor or sense resistor is used, the LTC3866 can be configured like any typical current mode controller by disabling the SNSD+ pin by shorting it to ground. An RC filter can be used to sense the output induc-tor signal. If the RC filter is used, its time constant, R • C, is set equal to L/DCR of the output inductor. In these applica¬tions, the current limit is normally five times larger for the specified current sense.

Conclusion

The LTC3866 allows the use of an ultralow DCR current sensing element to increase the efficiency in high current applications. Its current mode control provides the benefits over the alternative voltage mode controller of high reliability with fast, cycle-by-cycle current sensing, simple feedback loop compensation and the ability to use all ceramic capacitors for the smallest solution size. The LTC3866 is a good fit for low volt-age, high current step-down converter applications needing high efficiency and high reliability. Tracking, strong on-chip drivers, mul-tichip operation and exter-nal sync capability fill out its menu of features. The LTC3866 is ideal for point-of-load computer and tele-com sys-tems, industrial and medical instruments, and DC power distribution systems. Finally, a power supply designer can have a controller that incorporates the best of both current and voltage mode control schemes.

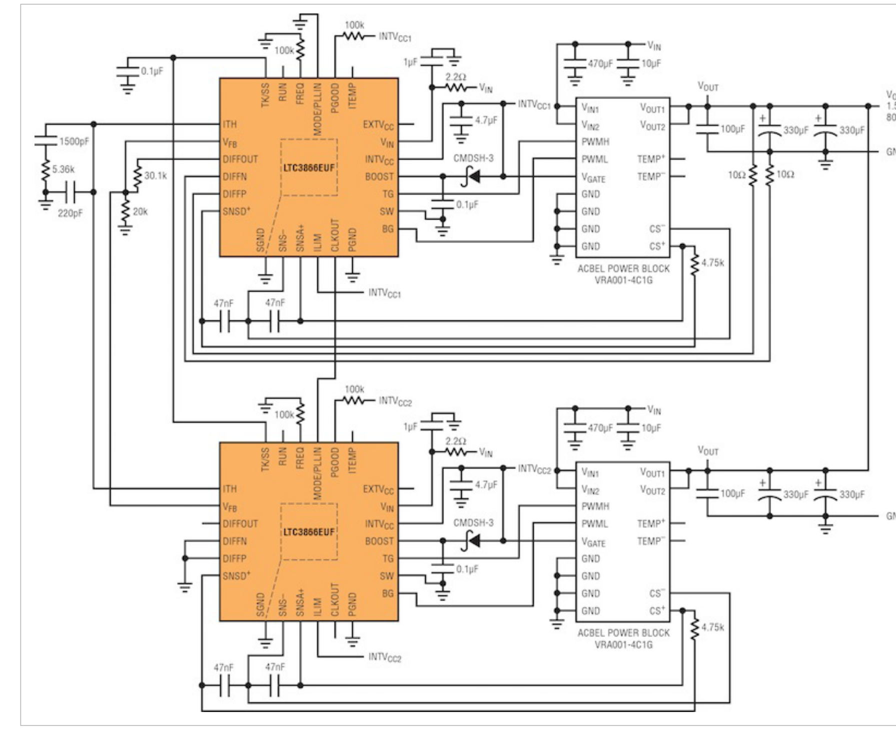

Figure 5: 1.5V/80A Power with Two LTC3866's Paralleled, Each Using Power Blocks

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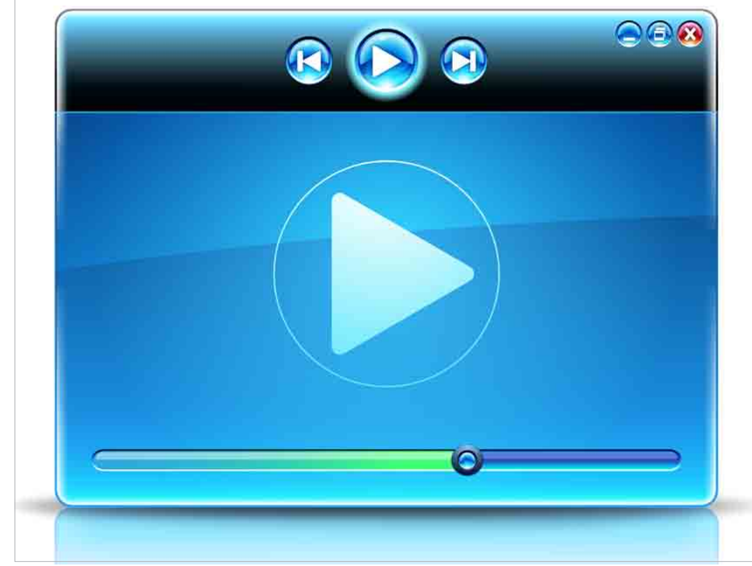


Inside:

APEC 2013 video roundup

Highlight videos from the APEC exhibition floor

By: Alix Paultre, Editorial Director, PSD

This year's APEC was a great show, with lots of things going on in advanced materials, packaging, and technologies. Here are some highlighted videos from the exhibit floor of the event.

Teledyne LeCroy

Steve Murphy of Teledyne LeCroy demonstrates power analysis for efficiency

Steve Murphy of Teledyne LeCroy demonstrates several of the company's latest devices for Power Systems Design and how they aid designers in power analysis for efficiency gains. Understanding phenomena like switching losses, conduction losses, and other power-robbing issues are critical to designing an efficient system. http://tinyurl.com/PSD-Teledyne-LeCroy

GaN Systems

GaN Systems goes over their GaN product development

Geoff Haynes, the VP of Business Development for GaN Systems, explains the development of the company's GaN technology over the recent years at their booth. GaN devices offer exceptionally low on-resistance and negligible charge storage, and can enable switching efficiencies well in excess of current silicon based solutions http://tinyurl.com/PSD-GaN-Systems

Micrel

Micrel motor control IC reference design demonstration

Miguel Mendoza of Micrel demonstrates a couple of reference designs, including a motor control system using Micrel ICs. The presentation also includes an explanation of the various drivers and the software used in the system presentation. ttp://tinyurl.com/PSD-Micrel

NXP Semiconductors

NXP shows their GreenChip power conversion technology

Erving Seinen of NXP demonstrates a power supply created using GreenChip technology, which lies at the heart of NXP's power and lighting ICs. GreenChip products are suitable for any device that draws AC power and offer benefits from minimal standby power (as low as 10 mW) to CFL-dimming capability. http://tinyurl.com/PSD-NXP

Xitron

Xitron power test analyzer demo

Allan Armstrong of XiTRON Technologies, precision power testing and measurement equipment for industrial manufacturing and consumer electronics, talks about their power quality analyzer product line, demonstrating their latest portable tester. http://tinyurl.com/PSD-Xitron

Intersil

Intersil describes their latest digital power converters

Chance Dunlap, Senior Marketing Manager at Intersil's Zilker Labs, explains their latest digital power devices. He talks about Intersil's digital point-of-load module and how their new DC/DC converter module can deliver up to 17 amps. Chance also gives a sneak peek of Intersil's upcoming power management GUI.
http://tinyurl.com/PSD-Intersil

CUI

CUI demonstrates their Novum digital power management system

Mark Adams, SVP of CUI, demonstrates their Novum Advanced Power product line for Power Systems Design. The Novum series has been developed to specifically address the growing complexities in today's advanced designs. Incorporating high-density intermediate bus converters with intelligent firmware, coupled with digital point-of-load dc-dc modules. http://tinyurl.com/PSD-CUI

International Rectifier

International Rectifier explains their latest SupIRBuck integrated DC/DC converters

Ramesh Balasubramaniam of International Rectifier describes their latest SupIRBuck integrated DC/DC converters at APEC 2013, touting their newer smaller form factor. One of their latest devices, a 25-Amp dc/dc converter is highly integrated to occupy a footprint of 12mm x 14mm. along with all necessary peripheral devices. http://tinyurl.com/PSD-International-Rectifier

Microsemi

Microsemi demonstrates their digitally-controlled power devices

Mark Smith of Microsemi demonstrates the performance aspects of their digitally-controlled device portfolio, including the LX7165, a digitally-controlled step-down regulator IC with an integrated 30mohm high-side P-channel MOSFET and a 10mohm low-side N-channel MOSFET. http://tinyurl.com/PSD-Microsemi

Methode

Methode demonstrates their SmartPower Stack embedded power technology

SmartPower Stack™ is presented as the industry's first fully integrated, deployment-ready commercial embedded system for high volume solar, photovoltaic, wind, hybrid electric and electric vehicles, as well as high capacity uninterruptible power supply and efficient motor drive applications.
http://tinyurl.com/PSD-Methode

Renesas

Renesas displays their latest miniPOL devices

Tad Keeley from Renesas describes Renesas' latest miniPOL devices for Power Systems Design at APEC 2013. Claiming to have highest level of miniaturisation and power density available, the devices can achieve a size reduction of up to 75% compared to earlier products, perform high efficiency power conversion during normal load (typically 90% of the time), and execute the frequent transitions to low power mode quickly.
http://tinyurl.com/PSD-Renesas

Paultre on Power podcast highlights

By: Alix Paultre, Editorial Director, PSD

Paultre on Power is PSD's audio podcast series on power systems and design engineering. Hosted by editorial director Alix Paultre, each podcast is a conversational interview with guests from across the power industry, from the power grid to the circuit board, and everything in between.

Cree

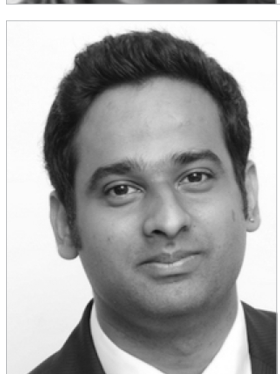
Talking to Paul Scheidt of Cree on solid state lighting

Steve Murphy of Teledyne LeCroy demonstrates several of the company's latest devices for Power Systems Design and how they aid designers in power analysis for efficiency gains. Understanding phenomena like switching losses, conduction losses, and other power-robbing issues are critical to designing an efficient system.
http://tinyurl.com/PSD-Teledyne-LeCroy

SBE

A talk with Mike Brubaker of SBE on capacitors

In this podcast we talk to Mike Brubaker, the CTO of SBE, a leading developer and manufacturer of film capacitors and their related systems. We talk about current industry challenges, and how capacitor technology is rising to meet them with new technologies and products.
http://tinyurl.com/PSD-SBE-interview



Yokogawa

Hafeez Najumudeen of Yokogawa on Power Measurement

In this podcast we talk to Hafeez Najumudeen, Yokogawa's Product Marketing Manager for Power Meters and Analyzers about power measurement and its importance to the design engineer. We discuss issues like precision vs. accuracy, the importance of establishing a device's energy consumption as a means to address improved product efficiency, and the company's latest tools to aid engineers in their tasks.
http://tinyurl.com/PSD-Yokogawa-interview

Microchip

A talk with Steve Stella of Microchip on the migration to digital power

In this podcast, we talk to Steve Stella, a power electronics, digital power, and alternative energy professional with Microchip, a leading developer of embedded solutions. Many engineers are facing issues with the migration to digital, and this discussion covers ways to address digital power, communications and management.
http://tinyurl.com/PSD-Microchip-interview

Efficient Power Conversion

A chat with Alex Lidow of Efficient Power Conversion on GaN devices

In this podcast, we talk to Alex Lidow of Efficient Power Conversion (EPC) about GaN devices and their impact on the power industry. EPC is a leader in enhancement-mode Gallium Nitride based power management devices. EPC was the first to introduce enhancement-mode Gallium-Nitride-on-Silicon (eGaN®) FETs as power MOSFET replacements. http://tinyurl.com/PSD-EPC-interview

iWatt

Talking with Scott Brown of iWatt about solid-state lighting drivers

In this podcast we talk to Scott Brown, SVP of marketing for iWatt, manufacturer of innovative Power Management ICs, about solid-state lighting, lighting drivers, and the quest for an inexpensive LED light bulb. http://tinyurl.com/PSD-iWatt-interview

Transphorm

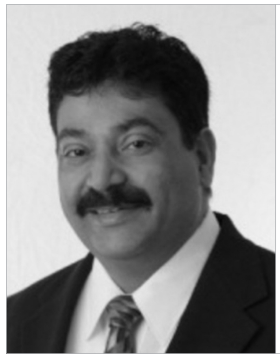
Transphorm's Umesh Mishra talks GaN at APEC

In this podcast, Alix talks to Umesh Mishra, Chairman and CEO of Transphorm, a leader in GaN power devices. the discussion covers their newest developments, some of the latest news from the company at APEC, and the products they currently have available.
http://tinyurl.com/PSD-Transphorm-interview

EEMBC

Markus Levy of EEMBC on microprocessor benchmarking and its impact on design

In this podcast we talk with Markus Levy, founder and president of the Embedded Microprocessor Benchmark Consortium (EEMBC). Markus is also president of the Multicore Association, and chairman of the Multicore Developer's Conference. http://tinyurl.com/PSD-EEMBC-Interview



AMS

Sajol Ghoshal of ams on sensor-driven systems

In this podcast we talk to Sajol Ghoshal, the director of sensor-driven lighting for ams, a developer and manufacturer of high-performance analog semiconductors such as sensors, sensor interfaces, power management ICs and wireless ICs. Sensor-driven systems are key to increased operating efficiency and proper energy management, among other things. http://tinyurl.com/PSD-ams-Interview

Ikon

Conor McAuliffe of Ikon on solid-state lighting development

In this podcast we talk to Conor McAuliffe, Founder and CEO of Ikon Semiconductor, about solid-state lighting and its development in the marketplace. The discussion ranges from the pursuit of an Edison-socket solution to the importance of cost, size, and reliability in a solid-state lighting product. http://tinyurl.com/PSD-Ikon-Interview

Anagear

Talking to Guus Dhaeze of Anagear about low-power system design issues

In this podcast Alix talks to Guus Dhaeze of Anagear, a privately held, mixed-signal semiconductor company with innovative integrated solutions for systems where ultra-low power consumption is vital. http://tinyurl.com/PSD-Anagear-interview

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Solving the smart-grid puzzle

By: Alix Paultre, Editorial Director, PSD

Many of us talk about the smart grid without really thinking about what we are really talking about. Most people are referring to functionality sets instead of the systems that furnish them, and in that lies a problem for those who must define the development of the systems involved. It is easy to say that solar panels and wind turbines will be part of the picture, but usually it is only the engineer that thinks about what systems will be required to achieve those lofty goals.

Even in cases where there is an understanding of the technologies required for a desired functionality, there are often multiple potential solutions. Let's look at grid stability and energy storage for managing the varying power output of solar & wind systems and for peak/off-peak power management. There are multiple solutions that range from lead-acid battery stacks to fuel cells and ultracapacitor stacks, and each has their own particular operational parameters, weaknesses, and strengths.

With multiple technologies available to draw solutions from, and mixed (and occasionally conflicting) requirements from users and providers, the design industry must not only work towards a solution for their immediate application, but since that solution is being implemented in a developing infrastructure environment it behooves the engineer to not only address their application, but also be clairvoyant enough to see far enough into the future to be able to prepare their system for integration into any future technical infrastructure and regulatory environment.

Engineers do not like to think about politics (at least in a professional sense), but the regulatory environment that is developing to guide and establish parameters for smart-grid infrastructures (often framed as functionality requirements or restrictions) should be a very important concern to the engineering community. Any legislation or regulation on grid-level energy management will now directly impact the development of the systems designed to operate in that infrastructure in the new paradigm of the internet of things.

Going forward, eventually every powered device will have some communications responsibility to cloud-based systems, which also means that almost every powered device will have to have all the communication and security protocols of any other web-based software-driven system, from consumer, to industry, to military, and everywhere in-between. Your white goods will have firewalls, and your car will have an IP address.

What that means for the development of the smart grid is that the industry should at least develop a common system of standards for power infrastructure that created an intelligent structured environment for system development, or the piecemeal efforts going on right now across the country will never properly develop into a reliable and rugged power grid to serve America into the next century.

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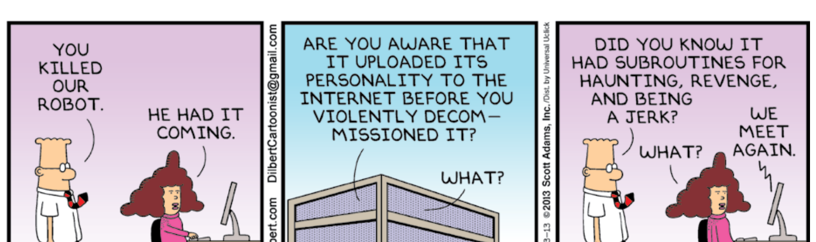

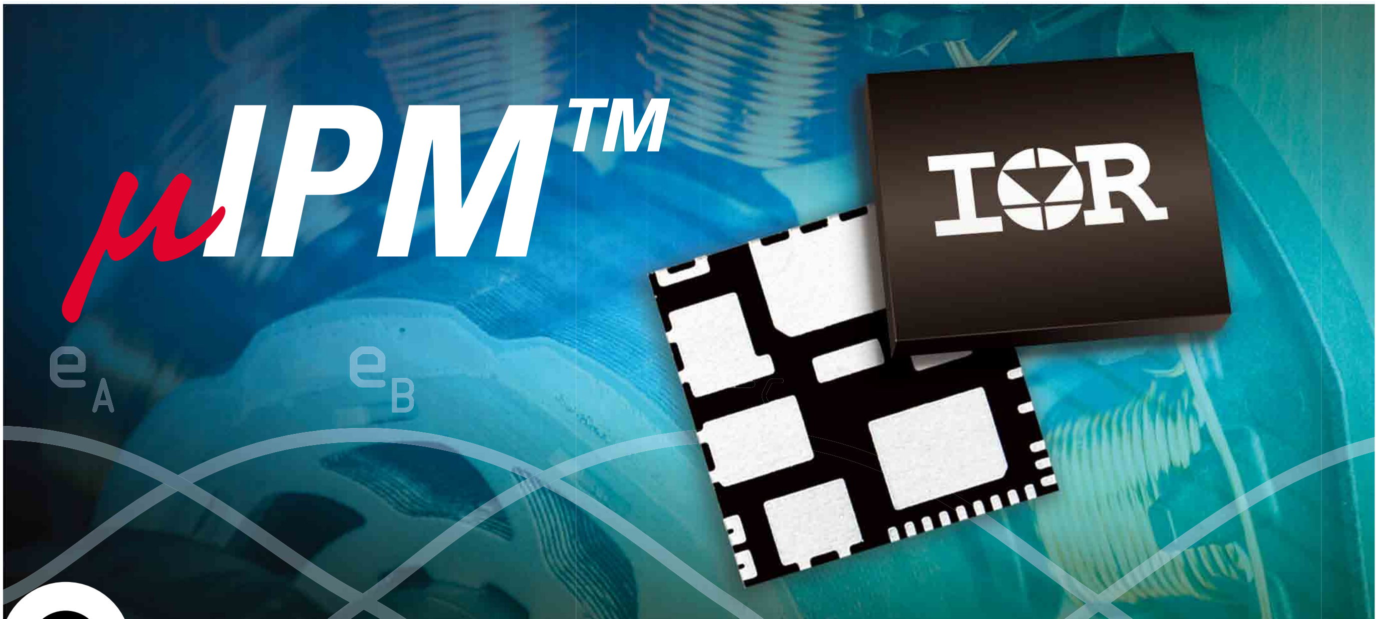

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IRSM836-025MA	12x12	500V	2A	360mA	440mA	93W/114W	3P Open Source
IRSM836-035MB	12x12	500V	3A	420mA	510mA	108W/135W	3P Common Source
IRSM836-035MA	12x12	500V	3A	420mA	510mA	100W/130W	3P Open Source
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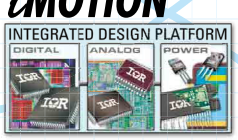

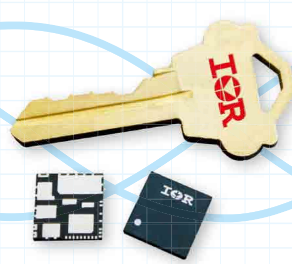

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