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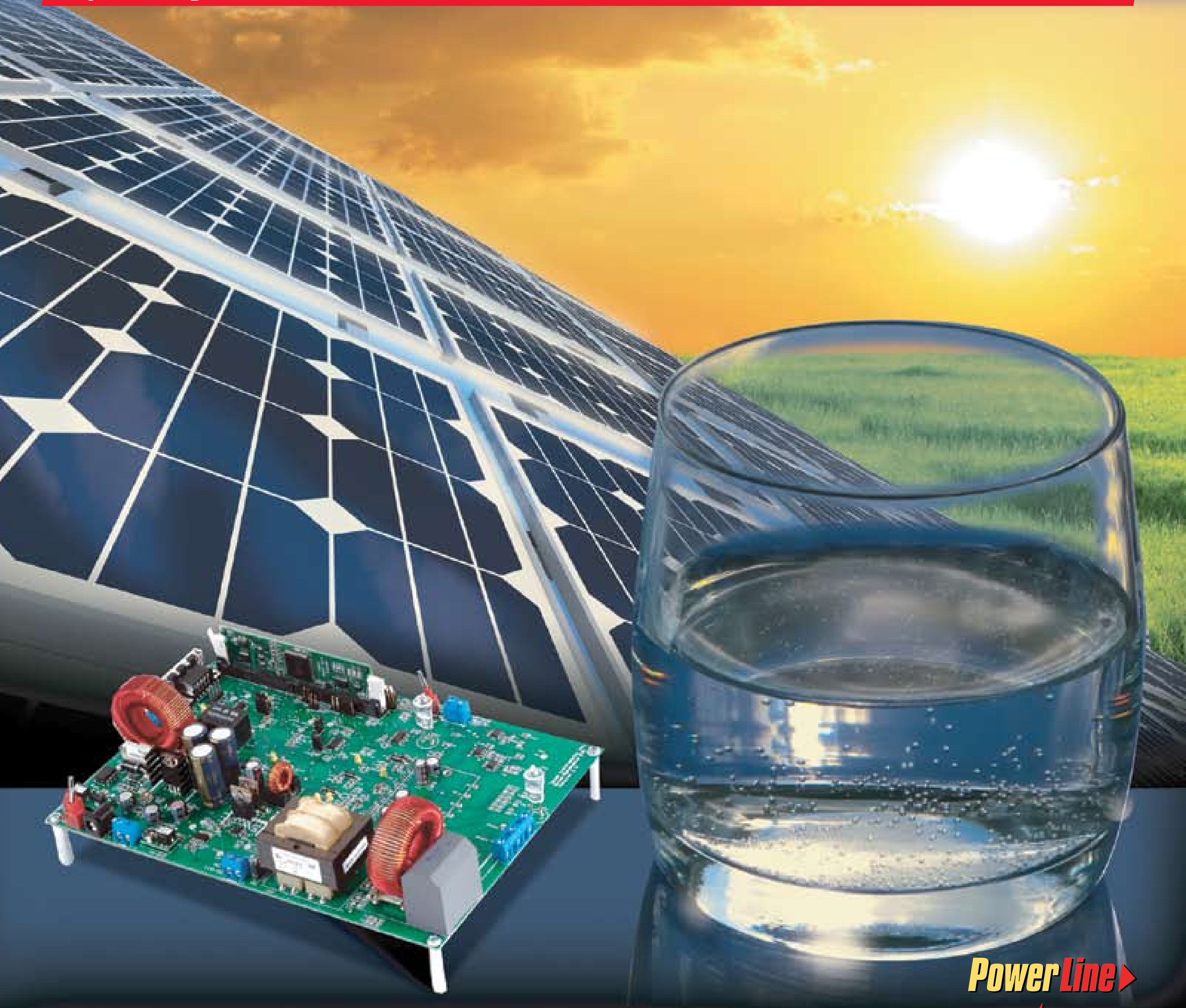
NORTH AMERICA

Empowering Global Innovation

November/December 2009



PowerLine

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PSDNA Green Power
ENERGY EFFICIENCY

Special Report - Renewable Energy

ISSN: Pending

Power Systems Design NORTH AMERICA

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Registration of copyright: January 2004
ISSN number: Pending

Send address changes to:
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Volume 1, Issue 6

Let's Look Forward

Welcome to the December issue of PSD North America. It's been a tough year, challenging some might say. I believe I'm not alone in saying that we, in this industry as well as many others, have all suffered a full repertoire of difficulties from short-time working as well as the ever present threat of job losses. Hopefully next year will see a continuation of the much-publicized resurgence in industry confidence and a timely return to investment and an improvement in real business.

In this issue we have another great crop of articles, news features and interviews as well as further reading in our increasingly popular online magazine. Also, look out for our new regular news bulletin, PowerSurge, which delivers timely industry and product news direct to your inbox.

A report from IMS Research says the use of inverter-based variable speed drives (VSD) in home appliances is forecast to double over the next five years. Currently, appliances with VSD account for just one in eight new appliances - mainly room air conditioners and washing machines, however, times are changing quickly. At the heart of the uptake of VSD is a government labeling scheme to promote more energy efficient appliances. Just last month, the US Environmental Protection Agency announced it would be taking control over the popular Energy Star program and would introduce a new top-tier classification called 'Super Star' to create a more rigorous set of criteria for top performing appliances.

Heartening news is now coming in: Although global semiconductor revenue is set to decline in 2009 for the second consecutive year, quarterly year-over-year growth is expected to finally return to the market in this fourth quarter, signaling the start of the industry recovery, according to iSuppli Corp. Revenue is expected to rise by 10.6% in the fourth quarter of 2009 compared to the same period in 2008. The fourth quarter will mark the first quarter in 2009 that revenue has risen compared to the same period a year earlier.

Meanwhile, semiconductor inventories returned to more normal levels in the third quarter after chip suppliers shed stockpiles by slashing costs dramatically in order to reduce unsold inventory carried since the beginning of 2009.

But while the electronics market is visibility improving, considerable uncertainty lingers regarding the market outlook in the first half of 2010. Most suppliers are likely to continue to hold off on significant capacity increases until their outlook improves.

So with this overall positive news coming in - coupled with our collective industry optimism, we should experience a better year in 2010 than we did in 2009. I still firmly believe that the power industry is the place to be and that we will see continued advances, and a return to investment and stability.

I hope you enjoy the issue, keep the feedback coming and check out our fun-site, Dilbert, at the back of the magazine.

All the best!

Cliff Keys

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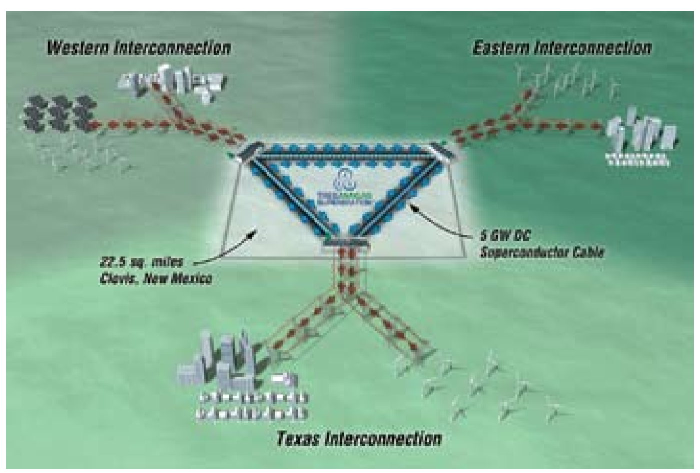
Superconductor Electricity Pipelines for America's First Renewable Energy Market Hub

American Superconductor Corporation, a global energy technologies company, has announced that Superconductor Electricity Pipelines have been chosen for The Tres Amigas Project, the nation's first renewable energy market hub. Superconductor Electricity Pipelines comprise transmission-level direct current (DC) superconductor power cables powered by AMSC high temperature superconductor (HTS) wire and high-powered voltage-source AC/DC power converters. The Tres Amigas Project focuses on uniting America's three power grids for the first time to enable faster adoption of renewable energy and increase the reliability of the U.S. grid.

Tres Amigas will utilize the latest in power grid technologies. It requires gigawatt-scale underground cables and power conversion systems that can serve as access points for each of America's Interconnections, making Superconductor Electricity Pipelines a logical fit for the Tres Amigas SuperStation. The same can be said for American Superconductor. With its power grid experience, expertise in transmission planning, and global leadership in superconductor technology, AMSC is well equipped to help make the vision of Tres Amigas a reality.



Tres Amigas will be the first system to interconnect all three of America's power grids (Eastern Interconnection, Western Interconnection and Texas Interconnection. The Tres Amigas SuperStation will utilize Superconductor Electricity Pipelines to enable gigawatts of electricity to be bought and sold between the three Interconnections, creating the first power market hub in the U.S.

Following the project's approval, AMSC is expected to provide transmission planning services, superconductor wire and the superconductor cable system for the project. AMSC intends to partner with some of the industry's leading superconductor power cable and system component companies to manufacture the cable system to AMSC's specification.

AMSC has acquired a minority equity interest in Tres Amigas, LLC for $1.75 million in cash and AMSC stock. AMSC will hold one of four seats on the Board of Directors of Tres Amigas, LLC. Terry Winter, executive vice president of power grid projects for AMSC, will be AMSC's representative on the Board. Winter was formerly the chief executive officer of the California Independent System Operator (CAISO), the transmission balancing authority for California.

The Tres Amigas renewable energy market hub will be a multi-mile, triangular electricity pathway of Superconductor Electricity Pipelines capable of transferring and balancing many gigawatts of renewable power between the three Interconnections. Similar to highway rotaries used for traffic flow control, multiple power transmission lines from each of the Interconnections will feed power into and out of the Tres Amigas SuperStation through multiple AC/DC converters, each connected by DC superconductor cables. Tres Amigas, which will be a balancing authority, will help ensure the efficient and reliable flow of power from multiple renewable generation sources in all three power grids to customers across a wide area of the U.S., Canada and Mexico.

The Tres Amigas hub will be constructed in Clovis, New Mexico, a location that has easy access to all three of the nation's power grids.

www.amsc.com

Telecom Power Drives Innovation

By Patrick Le Fèvre, Marketing Director, Ericsson Power Modules

From its early beginnings up to the present, the telecommunication industry has been innovative in terms of powering systems and applications, and an originator of several major technical evolutions - if not revolutions - such as distributed power architecture, high efficiency – high power density bricks, digital power control and management, and new ways to power sites while constantly reducing the level of CO_2 emissions.

For most of us telecommunications are part of daily life. However, this is not the case for a large percentage of the earth's population. Making it possible for them to access such technology will contribute to local development and reduce the digital divide, but simultaneously, it presents a real challenge to power engineers to secure sustainable sources of energy where, very often, they are simply not available.

Powering telecom for all - everywhere

How to power radio base stations in the middle of deserts, on top of mountains, in the middle of the rain forest or at any remote place where the power grid doesn't exist? How to charge mobile phones there and how to make it possible for a child living in those places to receive the same school programs as those living in towns? These are some of the challenges that the telecom industry has to address and generating sustainable sources of energy that will guarantee systems operate is a technical challenge indeed.

Alternative sources of energy such as solar, wind, bio-fuel, local hydroelectric generator and others have to be adjusted to their environment and optimized to deliver the highest available energy at any time of the operation whatever weather conditions and traffic demand.

For example a radio base station in the middle of Mongolia will benefit from combined sun and wind power when in India, bio-fuel generated from Jatropha oil can be used in diesel generators and in high sun ratio conditions, power generated from solar panels might be the most relevant technology.

Optimizing local sources of energy to power telecommunication in remote areas has driven innovations. The recent launch of a trial project by Ericsson and Telecom Italia of a radio base station with integrated solar panel (Eco Smart) is an interesting example of innovation to power remote telecom systems. The project perfectly illustrates the innovative aspect of powering telecom sites. In a novel approach, flexible solar panels are wrapped in a three-quarter circles around the tower, capturing the highest possible level of photons while located in a secure place preventing 'ground damage'. This type of development will immediately benefit other sites, reflecting the high level of research that the telecom industry invests in renewable energies.

Managing Energy for sustainability

Once power is generated and supplied from the local grid, the job for the power engineer is not finished, and how such energy is used within a telecom system is the next step on the 'Do List'. The telecommunications industry has always improved the usage of energy to give longer battery lifetime, lower power consumption - with the direct effect of reducing the level of CO_2 emissions per user, higher systems' reliability and many other benefits.

The range of possibilities ranges from the simple shutdown of a function on a single board to extended energy management including dynamic bus voltage (the bus voltage adjusted to reduce power losses to the lowest extend) and many other applications to other parts of the systems such as power amplifiers.

Powering telecommunications for all has been driven by power innovations and despite huge progress made over the last 50 years I would like to propose that we are at the early beginnings of a new power era, reducing CO_2 emissions while contributing to create a sustainable environment for future generations. To close, I refer to a sentence often used by Antoine de Saint-Exupery (1900 -1944), who said: "We have not inherited the earth from our ancestors; we borrow it from our children."

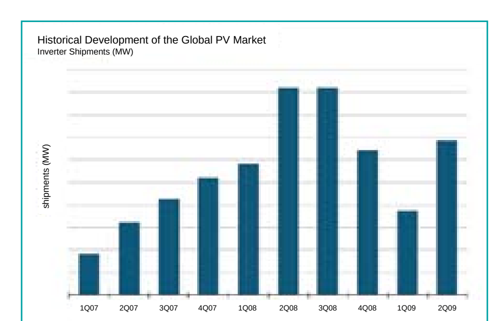
www.ericsson.com
www.ericsson.mobi

Solar Market Suffers but Outlook Still Bright

By Ash Sharma, Research Director, Power & Energy Group, IMS Research

The final quarter of the year always seems to bring huge uncertainty in the solar power market, and this year things are no different. Last year, following the explosive growth in the Spanish PV market, the main concern was what would happen once this market was capped. Where would all those extra PV modules go and which markets would drive growth? This year, the uncertainty concerns different issues: how much further will module prices fall? Will Q4's strong demand counteract the slide in revenues seen in the first half of the year? And looking further ahead, what will happen after 2010, once incentives are inevitably cut in Germany and Italy?

IMS Research estimates that the PV market declined year-on-year by 30% in the first half of 2009. This is based on inverter shipments and it also showed that dollar revenues fell by even more – some 38%. This was mainly caused by the collapse of the Spanish market which eliminated nearly 2GW of demand, but also by the lack of access to financing, and speculation over future module price decreases.



Strong incentives remain in place in many countries. Others, including China and the US, have announced major plans for renewables, including PV, yet these markets have been relatively slow to develop.

Discussions at the recent PVSEC conference revealed that invariably, PV companies were expecting a huge fourth quarter in 2009. The second half of the year is typically much stronger than the first, with companies rushing to get projects constructed and connected to the grid before annual reductions to the FIT occur in certain countries. This year, the 4Q rush looks set to be compounded by existing pent-up demand and easing credit conditions, which may lead to a massive fourth quarter.

Strongest growth (in absolute MW terms) is anticipated to come from Germany and Italy, whilst emerging markets such as Bulgaria, Czech Republic and Belgium also show promise. Similarly, much greater demand is anticipated in the US and China, and also in Canada, now that a feed-in tariff has been approved in Ontario.

One interesting development that has been attracting significant media attention is distributed PV systems using micro-inverters, AC modules and other distributed maximum power point (MPP) solutions. Some companies, such as Petra Solar have seen good initial success by promoting their product's ability to distribute PV generation with intelligence and communications throughout the grid to improve grid reliability.

Other companies, such as SolarEdge and National, are marketing their new products and apparently seeing good success, on the basis that they can help to improve yields by distributing MPP tracking across the entire array to counteract the negative effects of shading and module mis-match.

Despite the current uncertainty surrounding the industry, IMS Research predicts that shipments will reach 5GW in 2009, around 15-20% down on 2008. Despite this fall, more than 7GW of new PV systems are anticipated to be installed in 2010, resuming the industry's strong double-digit growth.

www.imsresearch.com

Frequency Response of Switching Power Supplies – Part 6

Loop gain assessment

In this article, Dr. Ridley continues the topic of frequency response measurements for switching power supplies. This fifth article shows how the injected signal size can impact the quality of the measured results, and demonstrates how to optimize the level of injection.

By Dr. Ray Ridley, Ridley Engineering

Introduction

In this article, Dr. Ridley continues the topic of frequency response measurements for switching power supplies. This sixth article discusses the measures of relative stability that can be obtained from a loop gain of a power supply.

Phase Margin of a Control Loop

The previous articles in this series have shown how to make successful frequency response measurements on power supplies, including loop gain. Figure 1 shows the standard loop gain measurement test setup described in the previous articles of this series [1].

Figure 2 shows a typical measured loop gain with the gain monotonically decreasing with frequency. For this case, definitions of stability are quite clear. At the crossover frequency, where the gain crosses 0 dB, we measure how many degrees the phase is above -180 degrees. This measurement is defined as the phase margin.

(Notice that when you measure

the loop with the circuit of Figure 1, the measurement will give the phase margin directly, without having to measure it from -180 degrees. That is because the measurement test setup includes an extra inversion that was not part of Bode's original theory for loop gains.)

The phase margin for the loop gain of Figure 2 is approximately 70 degrees. This amount of phase margin is relatively easy to achieve for a current-mode controlled converter with a conservative crossover frequency.

Designers in different industries have different standards for phase margin requirements. For rugged military or aerospace supplies, they look for a worst-case phase margin of 60 to 90 degrees. For many practical supplies, a worst-case phase margin of 50 degrees is the standard that I use in commercial design. The power supply will exhibit a small amount of damped ringing with this phase margin, but with very wide line and load ranges, it is often impossible to do much better than 50 degrees under all conditions of line, load, and temperature, without seriously compromising transient performance. Less than 45 degrees gives serious cause for concern.

Many companies today have forgotten the point of measuring loops and having a good phase margin. It is not unheard of to see designs with less than 30 degrees phase margin. While a single unit designed like this may be nominally stable, the whole point of a good phase margin is to ensure

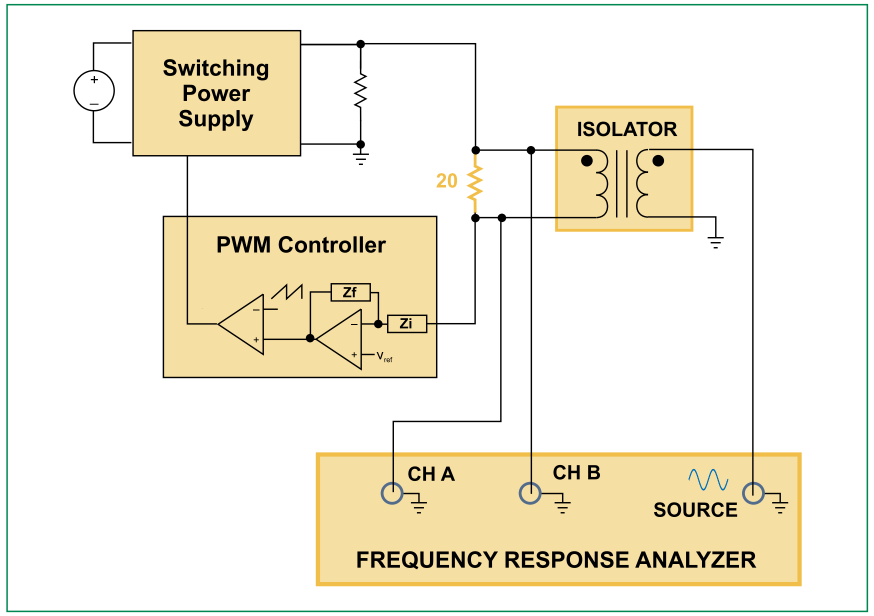


Figure 1: Open Loop Gain Measurement with the Loop Electronically Broken.

that power supplies produced in large quantities will all be stable, and remain that way throughout their lifetime.

Optimizing the loop for good phase margin takes time, and incurs some engineering costs. Perhaps 5 man-days of work are required for a conscientious design. This is a very small price to pay when compared to the cost of a product recall caused by oscillation.

Gain Margin of a Control Loop

There is more to stability assessment than just the phase margin. The phase margin only addresses one frequency, the crossover point. It does not give information about other frequencies that may cause trouble with variations of parameters in the feedback system. Beyond the crossover of loop, it is important to look at the gain margin. This is defined as the amount the gain is below 0 dB when the phase hits -180 degrees. A gain margin of 10 dB is reasonable. This allows parameter changes which could cause the loop gain to change by a factor of approximately 3 before the system becomes unstable.

The gain margin for the loop gain of Figure 2 is approximately 17 dB, a good value for a rugged and conservatively-designed control system.

Point-of-load converters often push the crossover frequency of a power supply very high in order to minimize the amount of capacitance on the output. In doing so, they often end up with a loop with very small gain margin, and the system may be on the verge of instability even though the phase margin under nominal conditions is reasonable. This is not good design practice.

Conditionally Stable Systems

It is quite common in power supply design to encounter loops which are conditionally stable. An example of such a loop is shown in Figure 3. A conditionally stable system is one in which the phase delay of the loop exceeds -180 degrees while there is still gain in the loop. This is a common occurrence with voltage-mode control where the phase dips abruptly around the resonant frequency, then recovers with the effect of real zeros added in the compensation. It also is common in the feedback loop of power factor correction circuits, and is often impossible to avoid.

In the loop of Figure 3, there is between 20 and 40 dB of gain, shown in red, when the phase drops below -180 degrees. There is no problem with such a system. As long as there is plenty of gain margin and phase margin, the control will be rugged.

In Figure 3, the phase margin is about 50 degrees, and the gain margin above the crossover frequency is about 15 dB.

We must also be concerned with the phase margin to the left of the crossover. This is a measure of how much the gain would need to be reduced due to parameter variations before the system would become unstable. It can be seen that this example has no problem since it has more than 20 dB gain margin at several kHz.

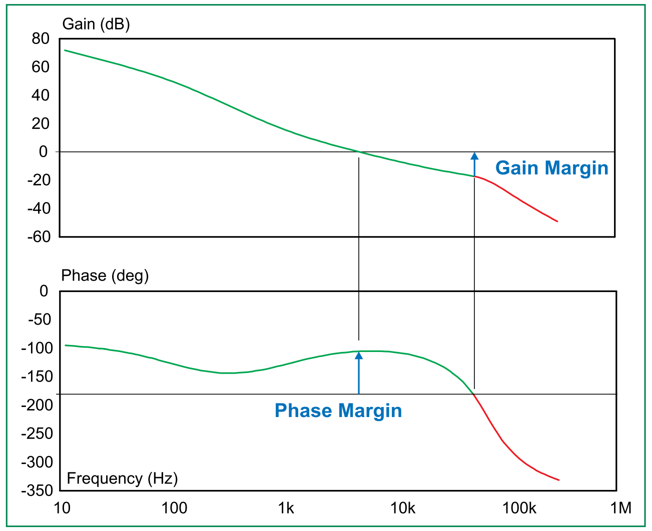


Figure 2: Well-behaved loop gain with monotonic decrease of gain with frequency.

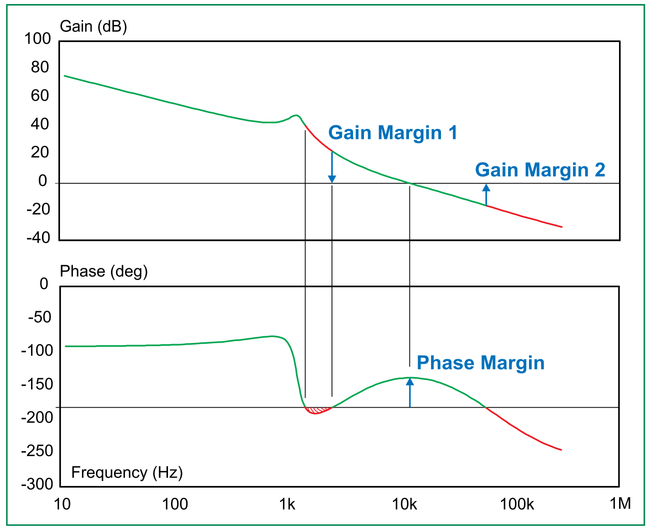


Figure 3: Loop gain with more than 180 degrees phase delay at low frequencies. The system is still stable.

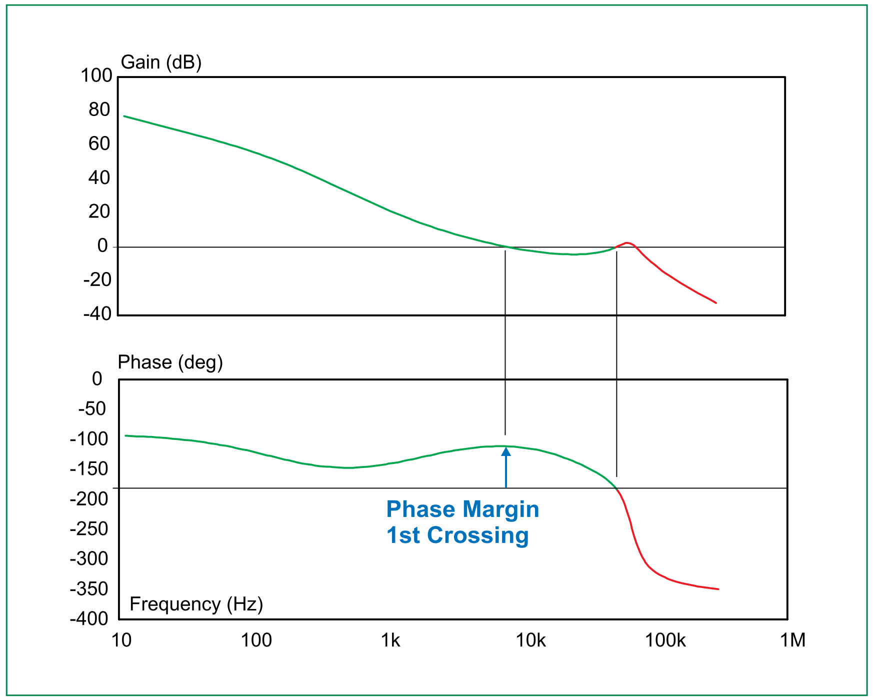


Figure 4: Loop gain measurement with multiple crossing frequencies.

Loop Gains with Multiple Crossover Frequencies

It is common in power design to encounter loops with more than one crossover frequency, as shown in Figure 4. If the loop crosses over multiple times, it is the final crossover (the one at highest frequency) that determines stability.

In Figure 4, the phase margin at the first crossover frequency (about 9 kHz) is very good, approximately 65 degrees. However, the loop crosses over two more times, each time with more than 180 degrees phase delay, so this system will be unstable.

There are numerous systems that might have multiple crossings. Three common examples are:

1. Current-mode control systems where the subharmonic oscillation is not properly damped with sufficient compensating ramp.

2. Converters which have RHP zeros in their control transfer function, causing the gain to flatten out.

3. Converters with improperly damped input filters in front of them.

For the loop gain of Figure 4, either the shape of the compensation must be changed to prevent the increase in gain at high frequencies, or the crossover frequency must be significantly reduced to avoid instability.

Summary

Every power supply has a unique control loop which can change significantly with line, load, temperature, and component variations. It is important to measure the loop and ensure that the gain and phase margins are properly designed for a rugged power supply. The entire loop gain must be studied, not just the crossover region, to ensure that the system will always be stable.

Unusual loop gains are relatively common in power supply design, resulting in conditionally stable systems, and loops with multiple crossings.

References

1. "Frequency Response of Switching Power Supplies, Parts 1-5", Power Systems Design Magazine, Design Tips Archive. http://www.powersystemsdesign.com

2. "AP Instruments AP300 User Manual", http://www.apinstruments.com/files/Model300.pdf

www.ridleyengineering.com

Linear Lights Up

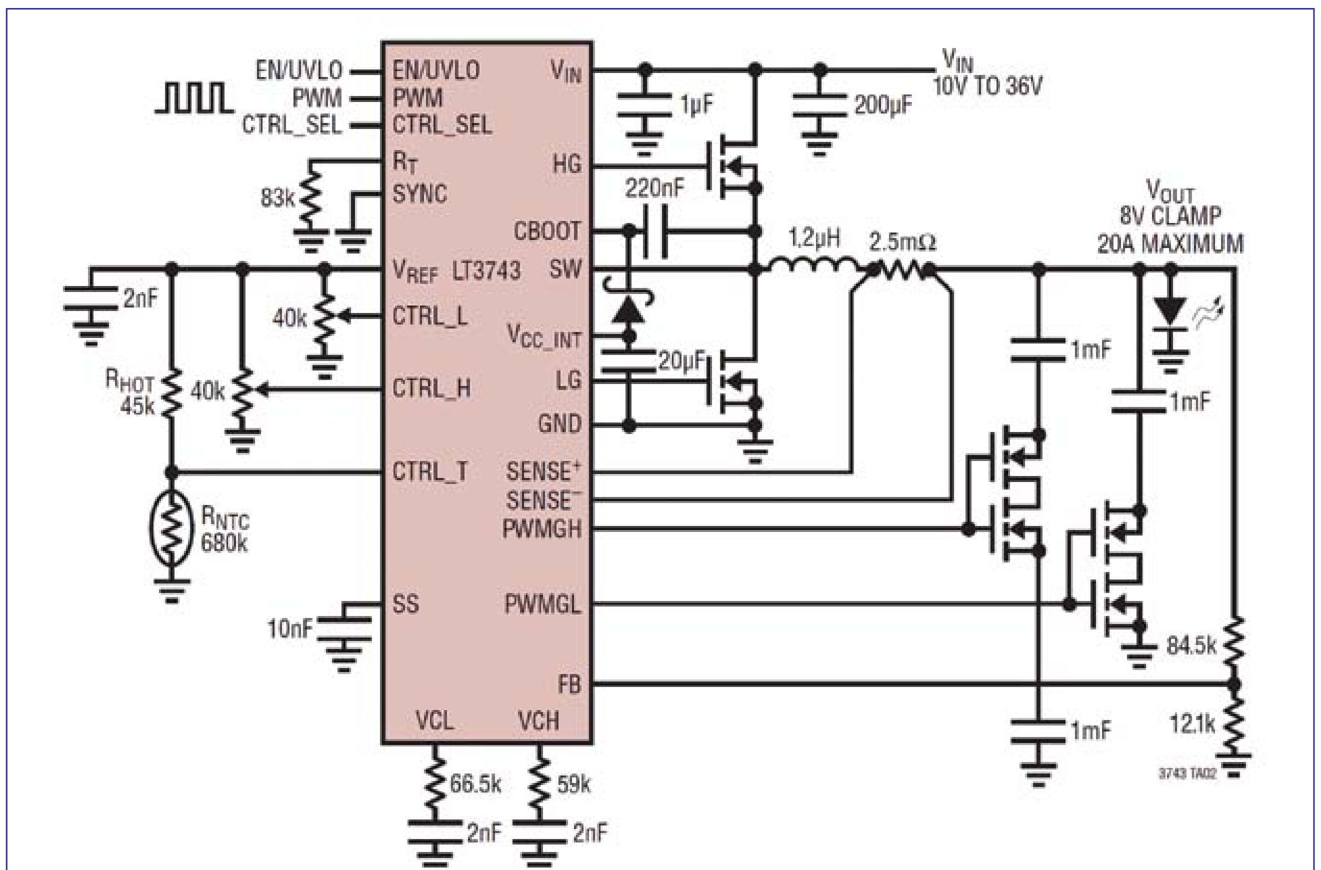
Over 20A continuous LED current from new driver

I talked with Tony Armstrong, Director of Product Management and Bryan Legates, Design Manager at Linear about the company's new synchronous step-down LED driver that delivers over 20A continuous LED current suitable for but certainly not limited to, industrial applications, professional DLP projection and architectural lighting.

Reported by Cliff Keys, Editor-in-Chief, PSDNA

Linear Technology recently launched the LT3743, a synchronous step-down DC/DC converter which designed to deliver constant current to drive high current LEDs. The device's 5.5V to 36V input voltage range makes it ideal for an increasingly wide variety of applications.

The LT3743 provides up to 20A of continuous LED current from a nominal 12V input, delivering in excess of 80 Watts. In pulsed LED applications, it can deliver up to 40A of LED current or 160 Watts from a 12V input. Efficiencies as high as 95% eliminate any need for external heat sinking and significantly simplify the thermal design. A frequency adjust pin enables the user to program the frequency between 100kHz and 1MHz so designers can optimize efficiency while minimizing external component size. Combined with a 4mm x 5mm QFN or thermally enhanced TSSOP-28 package, the LT3743 offers an extremely compact high-power LED driver solution.



Full-featured LED controller delivers over 80W of LED Power.

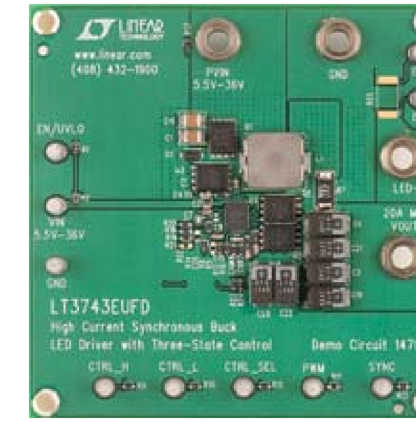
The LT3743 offers both PWM and CTRL_SELECT dimming, offering 3,000:1 dimming capability at three LED current levels, making it ideal for color mixing applications such as those required in DLP projectors.

The LT3743's unique topology enables it to transition between two regulated LED current lenses in less than 2µsec, enabling more accurate color mixing in RGB applications. LED current accuracy of +5% is maintained in order to ensure the most accurate luminosity of light from the LED. Additional features include output voltage regulation, open-LED protection, overcurrent protection and a thermal derating circuit.

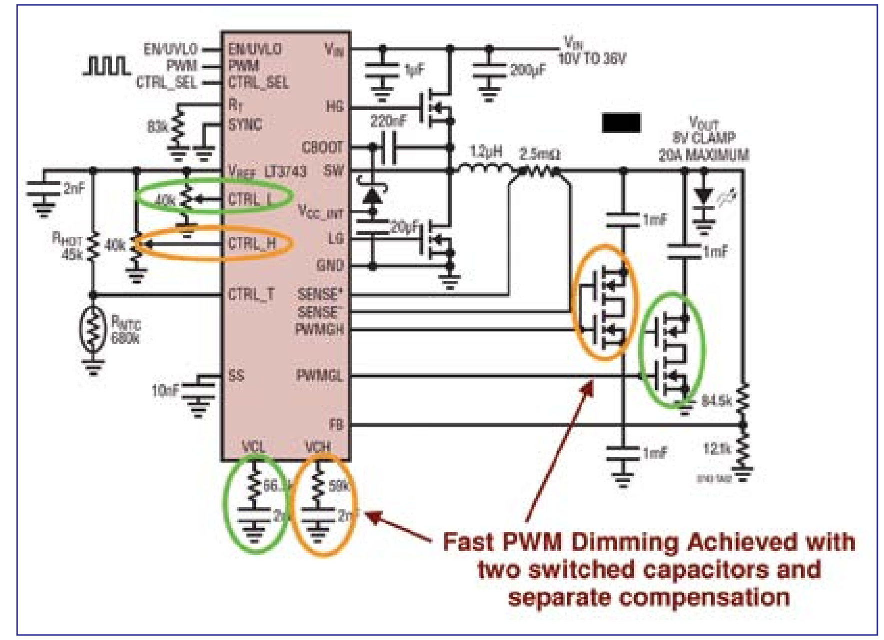
The debut of this device will for sure open up new and diverse applications other than lighting and projection. Interest is reported in driving laser diodes, used extensively in industry for precise and clean cutting of metal or fabrication.

The LT3743EUFD is available in a 28-pin 4mm x 5mm QFN package, whereas the LT3743EFE is available in a thermally enhanced TSSOP-28. Pricing starts at $4.80 and $4.95 each, respectively in 1,000-piece quantities. Extended temperature versions, or "I" grades, namely the LT3743IUFD and LT3743IFE are also available. Pricing starts at $5.65 and $5.82 each respectively in 1,000-piece quantities. All versions are available from stock.

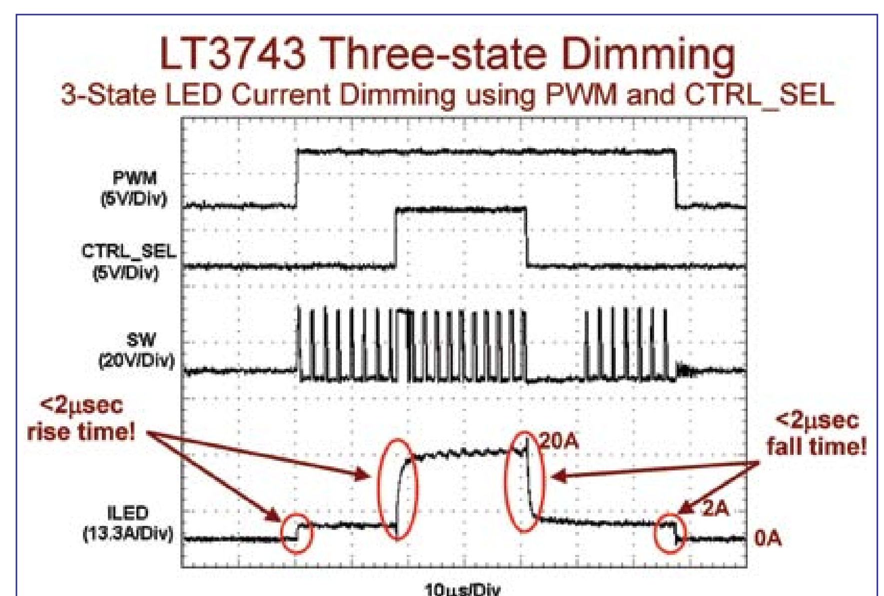
www.linear.com



LT3743 Demo-board.



LED dimming is achieved through analog dimming on the CTRL_L, CTRL_H and CTRL_T pins and with PWM dimming on the PWM and CTRL_SEL pins. Through the use of externally switched load capacitors, the LT3743 is capable of changing regulated LED current levels within several µs, providing accurate, high speed PWM dimming between two current levels. The switching frequency is programmable from 200kHz to 1MHz through an external resistor on the RT pin.



COVER STORY

Solar Perspective

Is the solar energy glass half full?

The question of whether the glass is "half full" or "half empty" is often answered based on whether you are optimistic or pessimistic. Solar energy critics generally come from the economics of solar energy installation. Once the installation is completed, the fuel cost is nearly zero. We will discuss the difference between considering $/W and $/W-h, and how module electronics can help optimize the system's total energy.

By Dave Freeman, TI Fellow and Engineering Manager; Nagarajan Sridhar, Technologist at TI's Solar Lab and Chris Thornton, Power Systems Designer, Texas Instruments.

Recently, another Moore's Law-like prediction was cited by Bill Sweet (Photovoltaic Grid Parity, November 2009, IEEE Spectrum Energy Wise News): The cost of solar installation comes down about 20 percent for every doubling of installed capacity. Because this is not happening yet, the glass appears to be half empty.

The solar industry admits it needs help to reduce installation cost. However, they want the comparison based on $/kW h. The website www.solarbuzz.com tracks prices and trends. They draw a distinction between residential and industrial solar energy. Residential cost is about $0.35/kW h, whereas industrial is closer to $0.20/kW h. These numbers still indicate "the glass is not half full," but getting close.

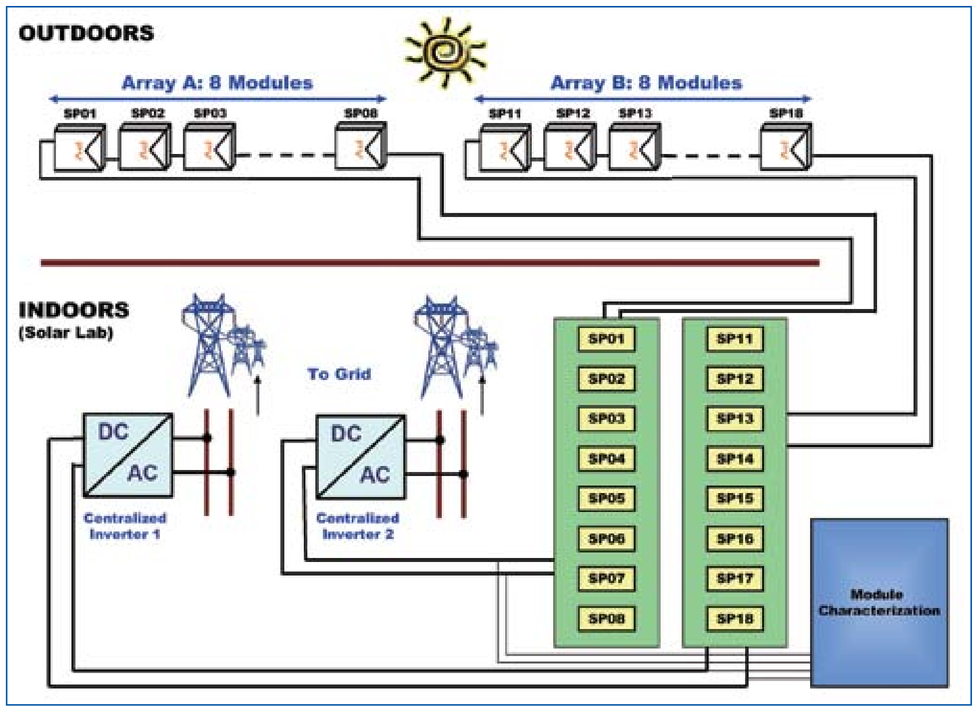


Figure 1: PV array and testing block diagram.

Rather than compare solar energy costs to other sources, shouldn't the question be: "Do you want to live in a house powered by solar energy only?" This question was pondered by the Solar Decathlon, a competition in which 20 teams of college and university students competed to design, build, and operate the most attractive, effective, and energy-efficient solar-powered house. Each participant constructs a livable house and is judged on everything from market appeal, day-to-day home activity, and engineering solution. Talking to the various student competitors, they think the glass is half full. They believe powering a house with solar energy makes more sense when energy-efficient appliances are used. Consider the desirability of a completely solar-powered house and corresponding efficient appliances, then indeed solar may be considered half full. Let's look at the solar energy system and consider what can be done to improve performance.

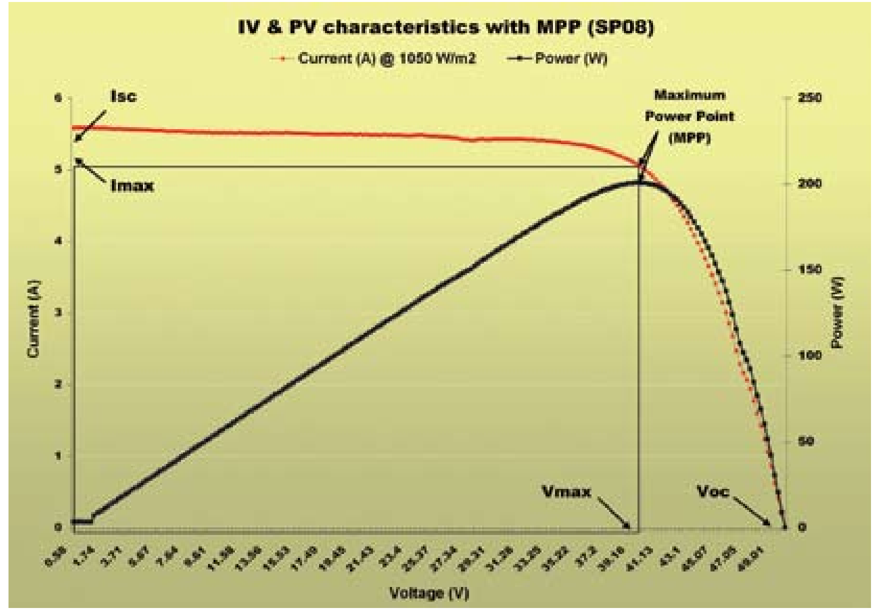


Figure 2: IV and PV curve for a PV module shows maximum power delivered for that condition.

Behavior of photovoltaic modules

Solar cells, when connected together in series or parallel, comprise to form a photovoltaic (PV) module. In a typical residential or grid-tied application, the PV system has one or more PV modules connected in series to form a string to increase the overall system voltage. Each string is connected in parallel to form a PV array and increase the system current. The goal of this system or array is to deliver maximum power to the load. Since power delivered by a solar cell/module/array is the product of the current and voltage under DC conditions, it is critical to ensure that power delivery occurs at the point of the IV curve where the IV product is maximized. This is the maximum power point (MPP).

Assuming one MPP for a string may be incorrect due to mismatches and varying irradiance from module shading. Module electronics can address this performance mismatch. To design and build the module electronics optimally, it is important to characterize and understand the behavior of PV module parameters under different irradiance and ambient conditions.

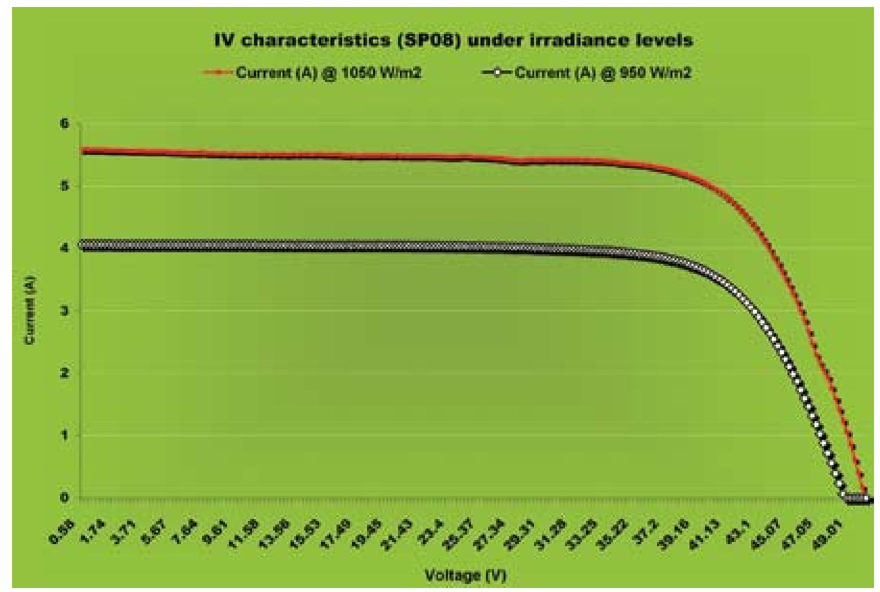


Figure 3: IV curve under different irradiance conditions.

Photovoltaic array configuration

Before understanding the behavior of the module parameters, one must understand the PV array configuration (see Figure 1).

Eight modules (SP01–SP08) are connected in series that are connected to a string inverter 1. Similarly, another eight modules are connected to a string inverter 2. All sixteen modules are made of mono-crystalline silicon solar cells from the same manufacturer, and rated at 215W at standard operating conditions of 1000 W/m^2 and 25°C. AC power from the inverters is sent back to the local grid. The behavior of each module can be individually monitored for MPP operation.

Module IV and PV Characteristics

Figure 2 shows an IV (current voltage) curve and a PV (power voltage) curve generated from one of the modules (SP08) for an irradiance condition of 1050 W/m^2. The MPP is located close to the knee of the IV curve where the current and voltage product is maximized.

Changing the irradiance condition reduces the ISC and, to a lesser extent, the VOC (see Figure 3).

Most commercial IV units take two to three seconds to sweep using a quick diagnostic tool. This prevents any false peaks and valleys in the curve that could occur from any moving cloud condition.

Module-to-module mismatch

Figure 4 shows the mismatch for all modules for a given irradiance condition. The mismatch varies from –0.9% to +1.25%. A static or passing cloud or any other realistic condition could increase the mismatch. This is where module electronics can pay off.

Under no mismatch condition, total maximum power from an array (eight modules connected in a string) is equal to the sum of the individual module power. Without module MPP and mismatch condition, the total maximum power delivered by the array is always less than the sum of the individual module's maximum power because some modules are operating below their maximum power point. Under irradiance condition of 1015 W/m^2, taking the array connecting modules SP01–SP08, the percentage mismatch is 2.4 percent, or a loss of 37W.

Module electronics advantages

Many small and some large companies use module electronics to improve energy performance and monitor / manage the solar module. Module electronics fall into two categories: micro-inverters (dc/ac), or micro-converters (dc/dc). A micro-inverter converts the power so it can be applied directly to the ac-line to connect to the utility grid. Alternatively, a micro-converter converts the variable current from the PV module to match the common output current shared with other modules in a series string connection. The combined string output is used by a larger string or central inverter to deliver ac-line power to the grid. For either a micro-inverter or a larger central inverter, an operating grid offers infinite demand. Irrespective of the module electronics type, the principle is the same: operate each individual solar module at an IV point that delivers maximum electrical power for a given level of solar irradiation.

PV modules produce a relatively constant output voltage for a given temperature. However, their output current varies with irradiation. When connected in a typical series string configuration, the string current is constant for each module. This is not a problem, if all the modules have the exact same IV output characteristic and are exposed to the same level of solar irradiation.

Nevertheless, if PV modules' are different, or current generated by one or more of the modules differs due to shade, the whole string output is impacted because the modules have limited compliance to accommodate any differences between the common string current and their own individual output current. This causes the output voltage from a shaded module to be significantly reduced or even reversed. Protective diodes are placed across the PV modules to prevent this. As a result, the total amount of power produced by the string drops significantly for even one module under partial shade.

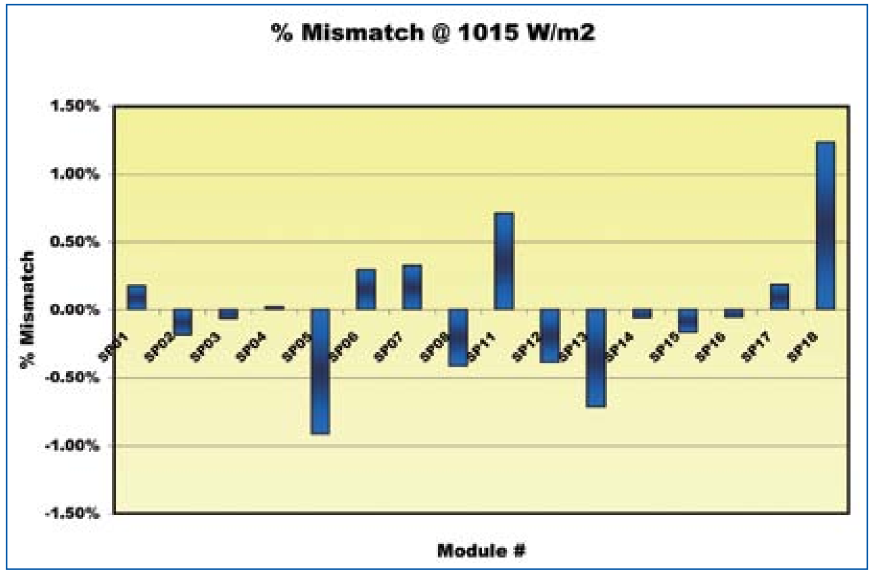


Figure 4: Mismatch at 1015 W/m^2.

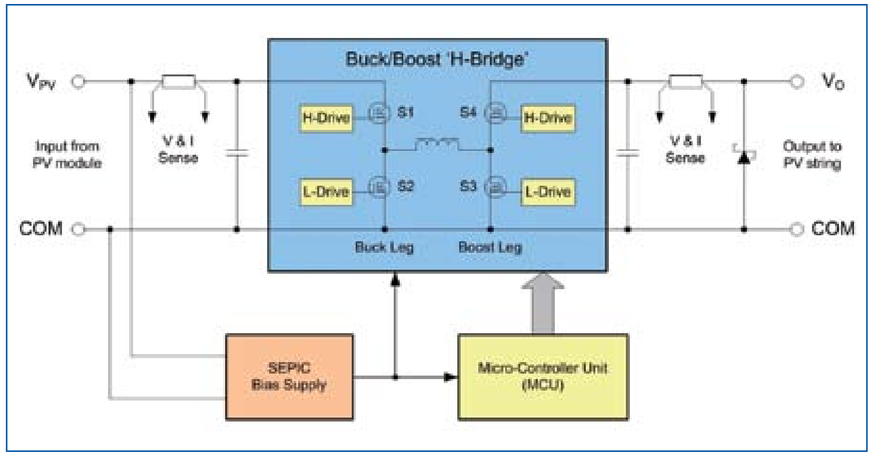


Figure 5: Solar micro-converter block diagram.

Adding a micro-converter to PV modules provides two benefits:

1) It continually operates each module at maximum power point (MPP) by increasing or decreasing its module current so the product of module current and voltage remains at maximum value.

2) It converts the module's variable power produced to a variable output voltage, accommodating whatever current is flowing in the series string. This allows the MPP of each PV module to be reflected through the voltage it contributes to the string, irrespective of its IV characteristic or solar irradiance level.

Figure 5 shows a typical micro-converter block diagram that attaches to a single solar PV module. Three principal elements are: H-bridge power circuit, micro controller, and bias supply. The H-bridge power circuit provides a micro-converter the flexibility to operate in both buck (voltage step-down) and boost (voltage step-up) switching conversion modes. The buck leg is formed by the synchronous switch pair, S1–S2, and the boost leg by S3–S4. When $V_{PV} \geq V_O$, the buck leg is active. When $V_O \geq V_{PV}$, the boost leg is active. Whichever leg is active, the opposite side is idle with its top switch permanently turned on.

Controlling the H-bridge is complex. It has to provide a seamless transition between buck and boost conversion modes, each of which has its own distinct control compensation. It must continually monitor the voltage and current at both the input and output terminals. This determines the operating mode, as well as the IV condition that correlates to the module's MPP. Performing maximum power point tracking (MPPT) makes this an appropriate application for embedded digital control. A micro-controller unit (MCU) is in Figure 5. The power conversion must be done at a very high efficiency.

Several methods are used to identify the MPP for a PV module. Techniques include simple constant voltage operation, perturb & observe (P&O), and methods that calculate the MPP using additional module temperature and solar irradiance measurements.

The two most popular methods provide good accuracy using just the VPV and IPV module measurements during normal operation: the optimized P&O and incremental conductance.

Optimized P&O averages several

module power samples, while perturbing the module current. It uses this information to identify the operating point and dynamically adjust the perturbation magnitude and direction. This method provides the best performance versus cost.

The incremental conductance method compares the instantaneous conductance (I_{PV}/V_{PV}) to the incremental conductance (dI_{PV}/dV_{PV}). When the $I_{PV}/V_{PV} = -dI_{PV}/dV_{PV}$, the PV module is operating at its MPP. Basically, the system increments and decrements the module current to find the point where there's a proportionate change in the module voltage. This method offers the best performance at high irradiance levels, and has a fast response to rapidly changing conditions. However, it is not as accurate as the optimized P&O at low-irradiance conditions (<30 percent).

The economic benefit of module electronic assemblies can be analyzed only in terms of recovered electricity cost. Energy recovered for the entire string as a result of one mismatched or shaded module can be significant. A micro-converter can recover as much as 50 percent of the power from a partially shaded module whose voltage contribution might otherwise be reduced to zero. While a shade condition might exist for a couple hours during the day, mismatched modules are a permanent condition. Once you estimate the amount of energy recovered, savings can be calculated in dollars. Equation 1 calculates the annual savings G ($), from ESAVED or the energy recovered per day (kW h), and RATE or the local electrical tariff ($/kW h):

$$G(\$) = 365 \times E_{SAVED} \times RATE$$

Electrical savings must be offset by annualized cost of the module electronic assembly. The loan installment to purchase the assembly, A ($), assuming it is paid off over its useful life is calculated using the capital recovery factor (CRF) in Equation 2:

$$A(\$) = PE(\$) \times \frac{i \cdot (1+i)^n}{(1+i)^n - 1}$$

Where, PE ($)=initial cost of assembly
i = interest rate (APR% ÷ 100)
n= loan term or useful life in years

In the final analysis the economic justification requires that A ($) ≤ G ($).

Example: Assuming energy recovered per day is 0.06 kWh, Equation 3 shows the break-even cost for a micro-converter assuming fixed 12¢/kW h local retail tariff, and a loan interest of seven percent APR over a 25-year lifetime? (See Equation 3)

$$PE(\$) \le 365 \times E_{SAVED} \times RATE \times \left[\frac{(1+i)^n - 1}{i \cdot (1+i)^n}\right]$$

Answer: PE($) ≤ $30.63

This evaluation is the benefit provided by just one module electronic assembly fitted to one PV module in the string. Figure 4 reflects the typical benefit a micro-converter provides in a good installation and after accounting for power conversion efficiency. It is equivalent to three-to-seven percent of the module's total energy generated. The amount recovered is higher in the string for adversely mismatched modules or those periodically in partial shade.

Safety, monitoring and management benefits

Once module electronics are added, they can provide other functions beyond power conversion and MPPT such as safety, monitoring and management. In a traditional string installation the individual string series elements can not be disconnected in the event of a fire. The local fire department knows to disconnect the grid, but this only turns off the string inverter output. Many cities have inspection requirements for proper installation, but disconnects are not currently required. At some point as system numbers increase awareness kicks in and insurance companies get involved. MCU-controlled systems can accommodate these regulations.

Monitoring and management are desirable functions. Module problems like fouling the module surface or encroaching shadows from trees and new construction can be detected and service can be requested.

Conclusion

Is the solar energy glass half full? It depends on your perspective. If you only look at the cost per watt, it does not compete well and likely will not get there soon. However, if you consider the smart grid and the ability to manage many distributed power sources of intermittent performance, then solar energy may be the answer. Installing a 4kW solar system on your house or business is certainly more attractive than installing a 4kW pulverized coal plant. Solar when combined with energy efficient use can be even more attractive. Solar energy is not new, but the attention it is getting is. Previously, installation focused on cost with little concern for management at a module level. When the integrated module electronics is brought down to a cost of about $30, then solar module management will become accepted. We think the glass is half full and well on its way to adding more in the glass.

For more information about solar energy, visit: http://www.ti.com/solar-ca

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Powering the New Mobile Computing Era

Dedicated power management ICs boost performance

The netbook PC has evolved significantly since its relatively recent inception. What started off just two years ago as a small PC intended primarily for the 'One Laptop per Child' project with limited capabilities is now emerging as an important and popular business tool. Effective power management techniques can further improve efficiency and shrink the required board space in the new generation of ultra-portable lightweight computers.

By Michael Maurer, Technical Marketing Manager, Dialog Semiconductor

Crucially, the small size, low weight and, more recently, integrated 3G-connectivity of netbooks make these devices an ideal way to maintain contact with the office via the internet when travelling. As a result, netbooks and similar small format portable computing devices need to deliver the functionality of larger business PCs. In particular, they must keep users in touch, entertained, and productive while on the move.

However, delivering this means silicon architects are posed with substantial challenges. Designers must find ways of supplying sufficient computing power to run sophisticated operating systems and application software from battery power sources whilst delivering a rewarding user experience with acceptable run times even when devices are connected to 3G mobile broadband for several hours at a time.

And, as the netbook market becomes more and more crowded it is becoming increasingly difficult to deliver differentiated products. But, accurate power management and a shift from discrete solutions will allow designers to take the next step.

A quick history of the portable PC processor

Traditionally, the architecture of choice for devices that wished to exploit the massive base of Windows or Linux software was the IA-32 instruction set that Intel introduced for its first 32-bit processor in 1986. This is now changing and a growing number of chips are being created to meet the processing needs of the standard netbooks, the ultra-portable sub-netbooks and the plethora of devices in between. These demonstrate several new approaches to portable computing and provide designers with a hardware platform that's architecturally similar to previous PCs at instruction-set level, but with order-of-magnitude reductions in power consumption and circuit-board real estate. As a result, it's now possible to construct pocket-sized mobile internet devices (MIDs) that run familiar applications and embody additional functionality such as GPS mapping.

Qualcomm recently demonstrated an ASUS Eee PC that used its Snapdragon processor. This features integrated 3G broadband and GPS connectivity and Google's Android operating system was used for the demonstration. The Snapdragon is a relative newcomer to the market. However, the leading family of such chips in systems sold today is still Intel's Atom processor. It was used in the original Asus Eee and is now in similar devices from numerous manufacturers including Acer, Fujitsu, HP and Samsung. For this reason, the following technical data discusses power management with respect to the Intel Atom Z5xx. The following principles can also be applied to similar processors.

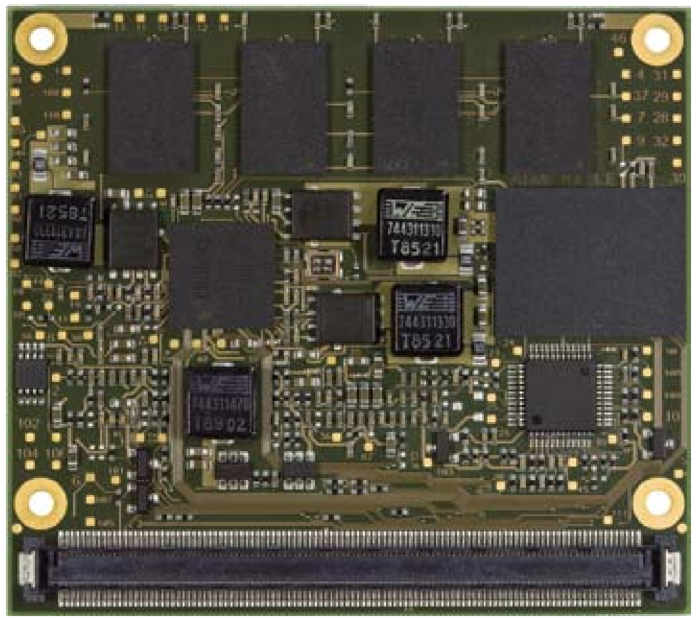
Power down by 90%, area by 80%

The Atom Z5xx series uses a 45nm CMOS process technology to fabricate around 47 million transistors on $25mm^2$ of silicon. Designers are provided with seven options that span 800MHz to 2GHz operation with 400 or 533MHz front-bus interfaces. Two thermally-enhanced packages are also available to handle nominal power dissipation levels that range from 0.65W to 2.64W.

However, it's the IC's power efficiency that's arguably the greatest achievement of both the Atom and Snapdragon designs.

Power management hardware can take this further and, if precisely controlled, a top-speed netbook processor will consume just 2.5W. Compared with the 35W that the mobile Core 2 Duo processors typically consume, this is a power saving of more than 90 percent.

Another major achievement is the reduction in circuit-board area that this new generation of processors enable. Looking once more at the Atom; the processor is intended to work alongside a system controller hub (SCH) chip that integrates memory and I/O controllers together with Intel's Graphics Media Accelerator 500. It is estimated that using the Atom shrinks circuit-board area from $3,592mm^2$ to just $666mm^2$, a saving of more than 80 per cent. And, to build a complete system, you only need add your choice of peripherals, a flash memory to hold EFI (extensible firmware interface) BIOS code, some DDR2 RAM, a clock source that meets the clock synthesiser specifications and power management hardware to manage the platform's multiple power domains and control supply sequencing. However, these latter requirements are not trivial.



Precisely tailored PMICs simplify power management in portable devices.

A cutting-edge discrete power management solution will require at least 200 active and passive components.

A tailored solution

The first companion PMIC for the Intel Atom, the DA6001, was announced earlier this year. Here we look at the development of the DA6001 with respect to the Atom and determine the key steps required in the development of a tailored power management solution.

The Atom's low power states operate at two levels. At thread level, on-chip logic implements what loosely equates to ACPI (advanced configuration and power interface) protocols for processor power states. Because a change in the core's power configuration only occurs when both threads request it one thread can sleep while the other operates normally. Two software interfaces are available to control these features. The first mechanism exploits extensions to the processor's MWAIT instructions while the second consists of reads to the chip's ACPI registers in I/O space that the processor internally maps into a set of equivalent MWAIT codes. This second mechanism does not directly result in any I/O accesses on the front-side bus.

By contrast, a package level change requires external intervention. Again, the results generally map to processor states from C0 (active execution) through the C1 (one thread halted) and C2 states (one or both threads halted but still performing bus snoops to maintain cache coherency) to the C4, C5, and C6 sleep modes. These sleep modes have multiple layers that lower the processor core power supply to its minimum value. In the C6 mode an on-chip SRAM powered from the I/O supply holds the processor's state until a break event triggers a sequence that returns the processor to normal operation.

The system controller hub IC also has several sleep modes and therefore state transitions and handshake terminations to be controlled with supply domains that require switching off/on. The S3 'suspend to RAM' state writes the current state of the machine and the operating system to DDR2 RAM that is automatically refreshed by the memory controller. Most system components are powered down in this state, leaving a suspend power domain active to allow the GPIO, PCI Express, and USB interfaces to wake up the system. The S4 state is a hibernate or 'suspend to disk' state, which saves the machine and operating system states to disk, enabling the system to be essentially powered down. The very similar 'soft-off' S5 state does not save the operating system's context.

Software can configure the processor to run at different frequencies and voltages to yield the greatest efficiency in a given scenario. Changing frequency requires the reprogramming of the processor's PLL (phase-locked-loop), whereupon the processor automatically adjusts the core voltage to a suitable level and the PLL locks in. Furthermore, an enhancement to the thermal monitor mode can automatically cause the processor to move to a lower-voltage and lower-frequency mode if the die temperature becomes too high. This feature is configurable in software by setting appropriate values within the processor's MSR (model-specific register).

The processor changes core voltage by writing new values to its seven VID (voltage identification) pins to request VCC levels from 0.3V to 1.2V in 12.5mV increments. To ensure glitch-free transitions, the processor ramps the voltage that an IMVP (Intel mobile voltage positioning) compliant regulator supplies. Actual maximum and minimum VCC voltages for high and low frequency operation differ slightly between Atom variants, with most operating between 0.75V and 1.10V at maximum currents of 2 to 4A. The 0.3V core-voltage level applies during the C6 sleep state and must not fall below this value.

The VCCP plane that powers the processor's I/O tracks the main core voltage. Optionally, you can create a split VTT plane that makes it possible to disconnect power during C6 from all I/O pins except those that are necessary to wake the processor. This is accomplished by the system controller hub asserting a signal which gates an external MOSFET; this process reduces leakage currents by about 30 per cent. And during all power states the companion VCCP6 plane must be held at 1.05V.

The front-side bus employs a hybrid CMOS/GTL (Gunning transistor logic) interface to minimise power dissipation for most signals while maximising signal integrity for strobe lines, this requires the motherboard to supply reference voltages for the respective transceivers. In addition, the PLL requires a clean 1.50V supply that's permanently present.

More circuits, more power supplies

Other platform elements complicate the power supply and management requirements. For instance, the Intel system controller hub, SCH US15W, uses the same core and front side bus voltages for its host processor interface, but requires additional supplies for its DDR2 memory controller, graphics display system and numerous I/O interfaces. These additional levels include 1.5V, 1.8V, 3.3V, and 5V, several of which are dedicated to functions such as the display PLL, the LVDS (low-voltage differential signalling) interface, the PCI Express interface, and the USB system. And of course, the DDR2 and EFI memories require power sources and control that closely couples with the processor and its system controller hub.

Powering multiple power planes with quite different current requirements in consumer-volume devices demands a holistic approach that takes maximum advantage of the available silicon area at the lowest possible cost. For instance, existing power-management ICs (PMICs) that target the ARM-dominated world of baseband processors and RF-interface platforms that lie within virtually every mobile phone, boast a complement of fully-integrated switch-mode and linear regulators. And, in the case of a high-end smart phone, these can individually control as many as 30 circuit blocks.

However, the relatively high current levels that the core, system controller hub and memory systems require make it more cost-effective, and reasonable in terms of chip power dissipation, to partition supplies into those that can be fully integrated and those that better suit driving external MOSFETs. Using external MOSFETs also frees the designer to specify more efficient devices as they become available – changes in MOSFET design methods, which now focus on switching speed rather than resistance levels, reinforce the need to take this external component approach.

Dedicated PMICs improve efficiency and shrink board size

When precisely configuring the power management requirements of processors such as the Atom or Snapdragon, a long list of essential and desirable attributes should be considered. Essential requirements include a full complement of power supplies to efficiently down-convert input voltages to levels that suit the Atom platform's multiple power planes. Similarly, some form of supervision and control is essential to handle the system's start-up and shut-down sequences without any external intervention.

To provide a minimal footprint solution a dedicated PMIC is essential. This will include all the hardware and software 'hooks' necessary to seamlessly connect with the Atom, system controller hub and DDR2 / EFI memories.

Dedicated companion PMICs come with several benefits, most notably lowering the number of external components, thereby shrinking the required board space. By comparison, a discrete-component approach to satisfying all of the Atom platform's requirements can consume as many as 20 active and 180 passive components. The discrete approach also requires a microcontroller that runs all of the time to monitor and control transitions between the processor's operating modes. A state machine within the PMIC that replaces a conventional microcontroller can reduce this function's power consumption from several mA to around 100uA, and renders the need for programming obsolete.

Looking once more at the Atom, to provide a universal solution for all Atom Z5xx-series parts, the PMIC must integrate an IMVP-6 compliant switch-mode regulator that provides up to 4A of core power. A synchronous buck-converter that drives a pair of external MOSFETs suits downconverting input voltages of 3.6 – 5.25V to the levels that the Atom's VID pins dictate with minimal power loss. The voltage control loop should achieve around ±1.5 per cent accuracy, and including a pulse-skipping mode can greatly contribute towards conserving power under light load conditions. Using a switching frequency of 1MHz allows the use of inductors as small as 1.5uH.

5.2A is required by the system controller hub and its front bus interface while another 3.2A is necessary to power the memory system that supports up to 2GB of DDR2 RAM. Two similar integrated buck converters - that again drive external MOSFET pairs - optimally suit these power domains and require voltage accuracies of around ± 3 per cent. Sensing the output voltage at the point-of-delivery maintains best tolerance, while using 1MHz-level switching frequencies constrains filter component footprint. Allowing for a maximum of 1100mA, the lower current needs of the platform's hardware engines make it possible to fully integrate a further buck converter that runs on a fourth phase of the internal frequency of 2MHz. It's desirable to drive all of these buck converters from a spread-spectrum clock source, with a spread of about ±45kHz being sufficient to minimise EMI concerns.

The six remaining power domains have current demands that are low enough to permit low-noise, low-dropout-voltage linear regulators that are easy to integrate. Proprietary techniques can reduce their quiescent power consumption to a point where separate low-power modes are unnecessary. Ideally, an additional dedicated regulator should be included to sink and source current, driving the DDR2 RAM's termination resistors and maintaining their mid-point reference voltage.

The PMIC should also satisfy the Atom platform's clock-source needs, which must comply with Intel's CK610 specification. Three fractional-division PLLs with spread-spectrum capability that operate from a 14.31818MHz crystal reference provide a good solution to this. The inclusion of a charge pump will maintain the 5V domain, even if the input supply falls below this level. And, adding a two-channel, 10-bit analog-to-digital converter, which is capable of running autonomously, eases the monitoring of voltages and temperatures, to ensuring the system remains within its design parameters.

Conclusion

This new generation of processors significantly helps designers to meet the growing demand for truly portable PCs without compromising on functionality or battery life. Competition in the market has led to a plethora of devices that sit between the standard netbook and ultra-portable sub-netbook. This does, however, make it increasingly difficult for manufacturers to offer differentiated products. Through precisely tailored power management solutions designers will be able to make the next leaps forward in terms of battery life. This improved efficiency means lighter, smaller form factor devices can be created with fewer components, that run more complex operating systems, and can remain connected via Wi-Fi, Bluetooth, GPS and 3G mobile broadband for many hours without needing to recharge. Two years ago netbooks may have been intended as simplistic, inexpensive PCs but advances in processing technology, technology integration and power management have ensured they're now the ultimate portable business machines.

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Optimizing Operation Under Real-World Conditions

Clock sources with integrated power supply noise rejection simplify power supply design in FPGA-based systems

By their nature, FPGAs are power hungry devices with complex power delivery requirements and multiple voltage rails. A single chip commonly consumes multiple watts of power while operating from 1.8V, 2.5V and 3.3V rails. Activating high speed on-chip SERDES can increase power consumption by several watts and complicate the power delivery strategy. When FPGA power consumption increases, performance requirements on sensitive analog and mixed-signal subsystems also increase. Chief among these are the clocking subsystems that provide low jitter timing references for the FPGA and other board-level components.

By Juan Conchas, Timing Marketing Manager, Silicon Laboratories

Power hungry systems cannot be free of power supply noise. In general, system designers try to use low noise linear power supplies whenever possible. However, excessive power dissipation usually prevents the use of linear regulators. When using a linear device, regulating from 3.3V input to 1.8V output is only 54% efficient regardless of the load current. Low conversion efficiency burns power in the regulator instead of the load and makes linear devices unsuitable for many high performance applications.

The use of low dropout regulators (LDOs) helps improve efficiency by reducing the input to output voltage difference that the regulator produces. For example, 2.5 to 1.8V regulation yields 72% efficiency for all loads. This is generally a good practice for loads up to 500mA. However, when the load consumes 1 to 3A of current, LDOs are less helpful. When a regulator enters dropout, it no longer regulates effectively. Its pass element behaves like a resistor, unable to respond to changes in load current or input voltage. This effect diminishes the noise rejection of the regulator, defeating the purpose of using it to provide power to sensitive circuit blocks. To maintain good regulation and noise rejection, LDOs must be powered by considerably higher input voltages than their dropout specification dictates, decreasing efficiency. To avoid dropout conditions, multiple LDOs can be placed in parallel to reduce the load current through each regulator. Complicated and costly, this alternative is not an attractive solution.

A more practical way to increase efficiency and maintain regulation over a wide load current range is with the use of switching regulators. The high 85 to 95% efficiency of switching

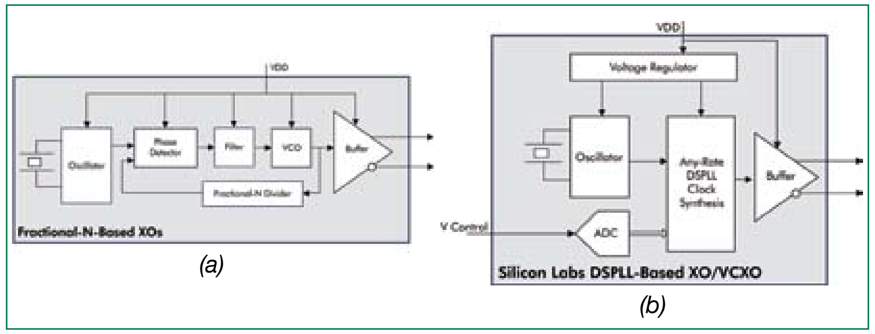

Figure 1: (a) The most common way to generate high frequency clock signals, the fractional-N based XO has multiple VDD vulnerabilities. (b) The Silicon Labs Si5xx DSPLL-based XO/VCXOs employ an all-digital approach with on-chip regulation that rejects noise on the power supply and eliminates sensitive VDD nodes.

regulators often makes them the only power conversion alternative for FPGAs. The boost in efficiency comes with a noise penalty, with as much as 50 to 100mVp-p of peak-to-peak voltage ripple. Due to the high power consumption of FPGA logic and I/O, switching ripple lower than 50mVp-p is generally expensive and impractical.

Another noise source is the FPGA itself. The fabric system clock may run at tens to hundreds of megahertz. When high power digital logic operates, it generates noise transients that ripple through the various power planes. Fast transients create high energy spurs that power supply filters struggle to smooth out. Since most power supply decoupling is optimized to present low impedance around one or a few frequencies, it is difficult or even impossible to clean up all high frequency noise on the power supply rail. This noise tends to propagate to other subsystems through the power supply, especially those in close proximity with the FPGA.

FPGAs present another challenge. When blocks of logic or I/O switch between low and high power operating states, the load current fluctuates dramatically. As the logic blocks enter a high power operating state where the logic undergoes intensive processing, the power supply tends to experience a load droop. As the logic block transitions to a lower power state, the load droop disappears and the power rail returns to a nominal state. Multiple events can create such a load droop and the overall interaction of these events is generally impossible to predict or control. Such load variation creates a low frequency envelope on the rail that is generally much less than 100kHz. This noise envelope can be cleaned up using additional regulators, but this adds cost and board space and may reduce power supply operating margin.

For these reasons, sensitive analog components tend to present a challenge when sharing the same power rails as FPGAs. In many cases, users may experience unexplained performance degradation or anomalous, unpredictable behavior. The traditional solution is to isolate each sensitive timing subsystem on its own power island using linear regulators to filter low frequency noise and extensive LC filtering using ferrite beads and ceramic decoupling capacitors to cover higher frequencies. However, this is not an ideal solution because it adds cost and increases layout complexity. Further, it breaks up the power planes, reducing their effectiveness in providing low impedance and tightly coupled ground return. A better solution is to maintain a continuous power plane that remains as intact as possible throughout the board. However, in order to take advantage of this, each subsystem must be able to tolerate noise on the power supply.

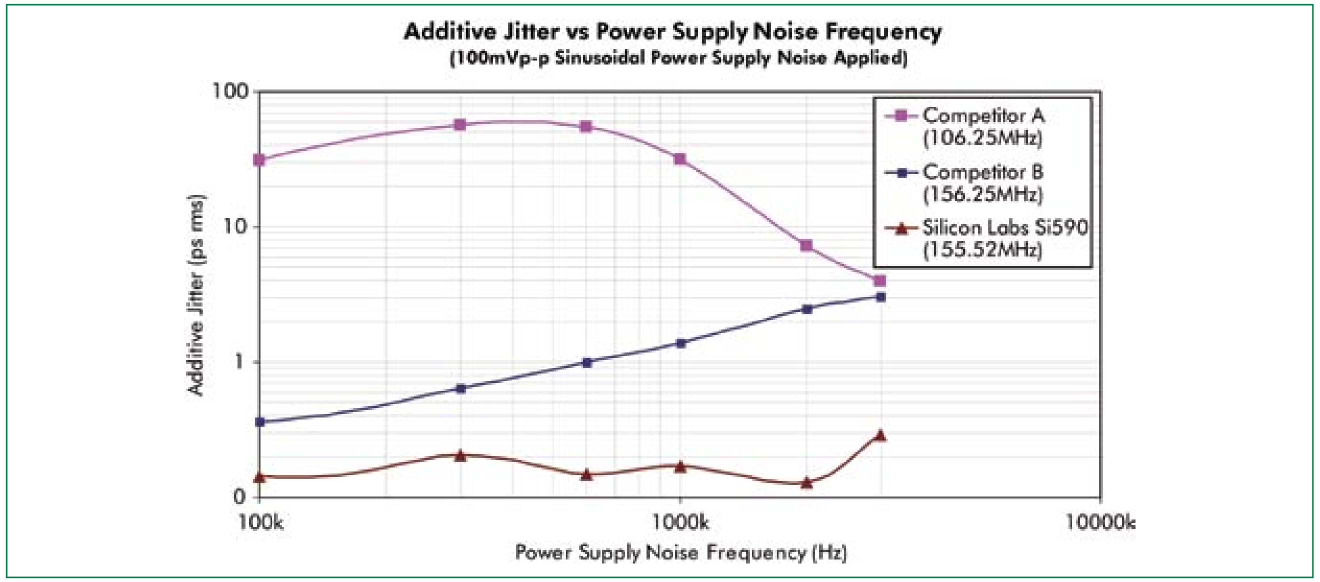

Figure 2: Many XOs have sensitive VDD inputs and struggle to meet output jitter specs in noisy environments. Two traditional XOs with 1ps and 0.9ps maximum data sheet jitter specifications violate spec, adding up to 50ps of jitter with 300kHz noise ripple. The Silicon Labs DSPLL-based XO/VCXOs adds less than 1ps of jitter under all power supply noise conditions.

Today's FPGAs depend heavily on low jitter clock sources to meet end application requirements. FPGAs may drive backplanes, optical modules, or GMII/ XGMII interfaces, all of which require extremely low jitter timing references. Operating in the noisy environment that FPGAs create has become a major challenge for FPGA reference clocks.

Figure 1a and Figure 1b shows two types of crystal oscillators. Crystals have been used for decades to set the heartbeat of most electronic systems. They provide low phase noise, good frequency accuracy, and adequate performance for many high performance applications. Despite these advantages, crystals have a major limitation: Fundamental frequency oscillation is limited to frequencies lower than 50MHz. For most high performance applications, the crystal must be followed by a PLL that multiplies the low frequency reference by the appropriate amount to generate the output frequency of interest. PLLs are used to multiply the initial frequency by an integer value such as 3 or a fractional value such as 3.125.

The fractional-N topology of Figure 1a is comprised of a crystal oscillator followed by an analog phase detector, analog compensation filter, analog VCO, and a fractional-N feedback divider. The output frequency equals the input frequency scaled by the ratio 1/N. A low noise buffer is used to drive the external load circuitry. Many applications such as Gigabit Ethernet, Fibre Channel, and High Definition Serial Digital Video (HD-SDI) rely on low jitter clock sources with output frequencies ranging from 100 to 156.25MHz. Under ideal supply conditions, a fractional-N PLL can be designed to provide good jitter performance of less than 1 ps RMS integrated over the 10 kHz to 20 MHz band. In contrast, in an environment with a noisy power supply, an oscillator may struggle to meet the phase jitter specified in the datasheet. Using analog sub-circuits creates vulnerable nodes where noise can be injected. When noise enters the system, it often becomes amplified, generating output phase jitter.

In contrast, the Silicon Labs DSPLL-based approach uses digital processing to implement a PLL that multiplies the crystal reference frequency to a higher frequency. The crystal is never pulled. All frequency control and trimming is carried out using digital commands. The compensation filter is based on a digital signal processor that does not use capacitors or other passive components. Finally, the VCO is controlled digitally without using analog circuitry. To offer additional VDD isolation, an on-chip linear regulator and in-package power supply decoupling capacitor are used to further ensure noise rejection. Due to these advancements, every Silicon Labs DSPLL-based XO/VCXO has the ability to generate high frequency clock signals with sub-picosecond jitter performance in noisy real-world environments.

Figure 2 shows the power supply rejection ratio performance of fractional-N PLL-based XOs compared to Silicon Labs DSPLL-based XOs. Although fractional-N PLL-based XO is rated to achieve 0.9ps maximum RMS jitter, suitable for high data rate FPGA SERDES, the rated specification applies only in ideal environments. With 100mVp-p of power supply noise, competing solutions generate up to 40 ps RMS of additive jitter, becoming unusable in high-speed serial links. Silicon Labs DSPLL-based XO/VCXO products do not suffer from this limitation, adding only 0.1 to 0.3ps RMS of jitter across the tested frequencies.

Other DSPLL timing devices offered by Silicon Labs are low jitter integrated PLLs used for jitter attenuation and clock multiplication. These devices also employ a DSPLL-based architecture that eliminates VDD noise sensitivity. When using the Si5xx XO/ VCXOs or Si53xx family of any-rate clock multipliers, designers can take advantage of high efficiency switching power supplies while maintaining excellent jitter performance. In addition, designers are free to implement continuous power and ground planes without the need to sprinkle linear regulators around the board, offering the lowest impedance, least interrupted ground plane design. On-chip power regulation enhances system performance, minimizes board area, reduces system cost, simplifies design and improves time-to-market.

In conclusion, today's FPGA–based designs require improved clocking with greater immunity to power supply switching noise observed in real-world applications. With low jitter that meets high speed serial link requirements and integrated power supply noise rejection that optimizes operation under real-world conditions, Silicon Labs' family of DSPLL-based clocks and oscillators is an ideal complement to FPGAs in high performance applications.

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Power Supplies

Selecting the Right Power Module

flowSEL – enhancing the designer's toolkit

Vincotech already offers a very powerful tool for the simulation of power modules under operating conditions with its successful flowSIM. But what about finding which power module is the right one for a given application? For motor drive applications, the tool flowSEL offers an easy way. Based on a short list of application parameters, flowSEL returns a useful selection of suitable power modules.

By Andreas Johannsen, Product Marketing Manager, Industrial Products, Vincotech

The market of power semiconductor components offers a broad selection of solutions for industrial drive applications from different suppliers and with different characteristics. For example Vincotech, a German power module supplier, offers about 20 different product families of standard frequency inverter applications, with about 120 different modules. How does the designer choose the right solution for a given application?

The common way is to compare the data sheets of different modules. But if you have the choice between a few dozen modules, this will certainly be a very drawn-out activity. Another issue is the dynamic characteristics of motor drive applications. The behaviors are changing several times a second and depend on several external influences. To check if a power semiconductor achieves all the requirements is only possible by doing complex calculations. Doing this manually is very time consuming and exhausting.

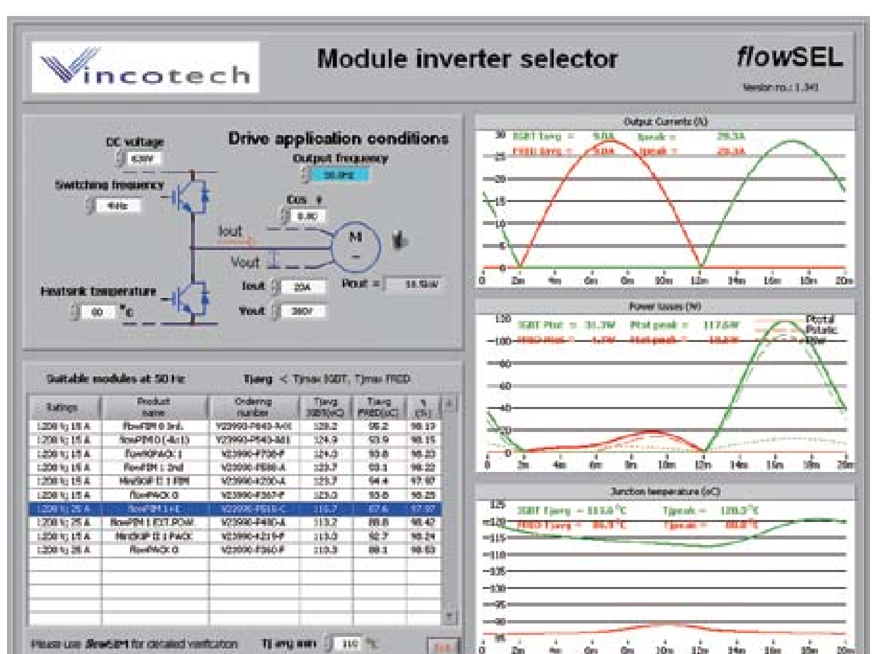

Figure 1: The flowSEL screen.

SPICE – The universal approach

One way to solve these issues

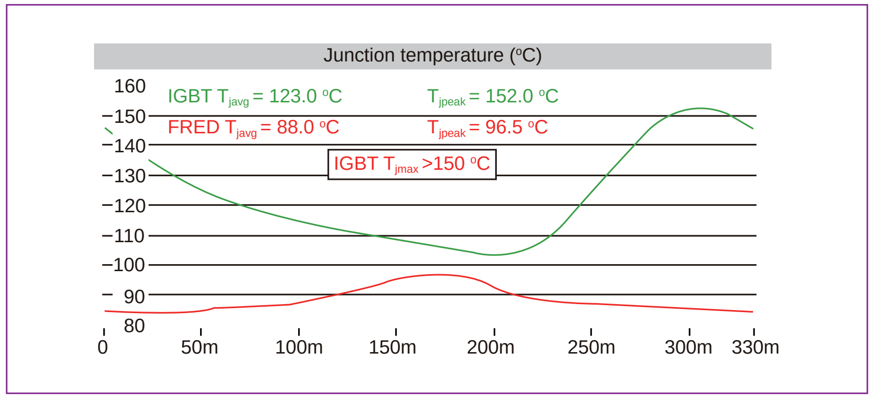

Figure 2: Tj max warning.

is the usage of simulation tools. A very common tool for simulation of electronic circuits is SPICE. It contains numerical models of electronic components and enables the possibility to simulate electronic circuits under dynamic conditions. The first issue is to get accurate numeric models of the used power semiconductors. Only a few suppliers are offering SPICE models of their products. Another issue is that SPICE is a very universal tool. For an accurate simulation, the whole application has to be reproduced in SPICE. For power semiconductor applications not only the electronic, but also the thermal behavior is very important. To build up a complete electrical and thermal model of a motor drive application in SPICE might be a very complex challenge. Another issue is the needed simulation time. The switching time of an IGBT is a few nanoseconds. To make conclusions about the thermal characteristics of a power module multiple seconds have to be simulated. According to the Nyquist–Shannon sampling theorem, a few billion of simulation steps have to be proceeded to get an adequate result which results in extensive simulation time.

Proprietary simulation tools – The better choice

Some suppliers of power components providing simulation tool, which are customized for the special requirements of applications for power semiconductors. An example is *flow*SIM from Vincotech. It contains the characteristics of most of their power modules by measured data. This makes it possible to create very accurate simulations with all important parameters of a typical power module application at very comprehensive simulation time. The short simulation time allows the simulation of multiple modules at different application parameters and still maintaining the development schedule.

***flow*SEL – The combination of simulation and selection**

With tools like *flow*SIM, the simulation issue seems to be solved and the module verification can be done early at the design cycle before even building up hardware. But how to know which of the dozen of power modules that can be simulated are the most promising for the given application? To answer this question Vincotech offers a very unique tool called flowSEL. It's focused on the selection process of power modules for motor drive applications. To get a list of usable power modules only a few application parameters are necessary. (See also the box at the upper left side of Figure 1).

- DC link current
- Inverter switching frequency (PWM frequency of the power semiconductors)
- Output frequency (motor frequency)
- Output voltage (RMS motor voltage)
- Output current (RMS motor current)
- Motor power factor (ratio between effective and apparent power)
- Heatsink temperature

Based on these parameters and the measured semiconductor characteristics stored in the tool, flowSEL creates a list of usable power modules in real-time. The items in the list display module name, order code, nominal chip ratings, the averaged surface temperature of the IGBTs and FREDs and the efficiency of the power section simulated (ratio between input and output power). The rectifier stage is not simulated, as it is normally not the limiting factor within a power module.

$T_{j\,avg}$ – The yardstick for the power module

By selecting a module from the list, the graphs on the right hand side are showing the current, power loses and junction temperature of the IGBT and FRED over the time of one phase (see Figure 1). This enables the possibility to see where the losses are generated and if the selected module fits to the application requirements. The most important criterion for the module selection is the averaged junction temperature $T_{j\,avg}$. The maximum acceptable $T_{j\,avg}$ for a power module is determined by the maximum chip rating given in the module data sheet and a certain margin for lifetime reliability normally around 25 °C. Only modules where the calculated $T_{j\,avg}$ is equal or below this value are shown in the selection table. Also important for the selection is the maximum junction temperature. The maximum recommended junction temperature again is limited by the technology of the semiconductor and given in the datasheet (generally 150 or 175°C). flowSEL shows a warning, when the calculated maximum junction temperature exceeds the recommended value (see Figure 2).

Optimize trade-off between module price and lifetime

To narrow the module selection, the minimum value for $T_{j\,avg}$ can also be specified (see value for $T_{j\,avg}$ min at the bottom left in Figure 1). The difference between $T_{j\,avg}$ and Theatsink describes the load cycles during short power cycles and the difference between $T_{j\,avg}$ and ambient Temperature describes the thermal swing during start up and long power cycles with full power swing. Therefore the higher this parameter the higher the stress for the power module will be. By increasing the minimum value for $T_{j\,avg}$ the larger modules will disappear and only smaller power modules will be shown in the short list, being closer to the predefined design limit of $T_{j\,max}$ minus 25°C Finally this results in the smallest available modules and in line normally lowest in cost still fulfilling the given limits.

Close to 0Hz - Simulation of very low output frequencies

In some power module data sheets the power dissipation and maximum current rating are specified for an output frequency of 50Hz. But for some applications, the behavior at frequencies down towards 0Hz is relevant and therefore becomes more critical. At higher frequencies, above 30Hz the load is distributed over the three phases and the maximum power capability of a module is determined by the averaged power dissipation. But if the motor moves very slowly, every single phase is stressed for a longer time. The heat can not be distributed and the junction temperature will be higher therefore these conditions need to be checked. With flowSEL it is possible to simulate motor frequencies down to 100mHz, a sufficient approximation of 0Hz conditions.

The power comes back – The motor as a generator

When a motor is slowed down, energy is pushed back into the frequency inverter. This could be also an important operating condition for industrial drives. When the motor is accelerating, most losses are generated by the IGBT. When decelerating, the current is conducted by the FRED diodes and its maximum power capability is limiting the application. With flowSEL, it is possible to switch the simulation between "Motor"-mode for acceleration and "Generator"-mode for deceleration. This enables the user to simulate both operating conditions.

After preceding the simulation with flowSEL, the customer gets a selection of power modules, which seem to be suitable for his application. In the next step the needed form factor and functionality (inverter only, inverter with rectifier, brake, power factor correction etc.) has to be selected. And with the simulation tool *flow*SIM, a more detailed simulation is possible.

Conclusion

The selection process for a power module is a challenging task. With ubiquitous tools like SPICE, the simulation costs a lot of effort and can take very long time. With *flow*SIM, the simulation can be processed in real-time with minimum effort. This enables the ability to compare several power modules under different conditions and makes the selection process significantly easier and more thorough.

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Renewable Energy

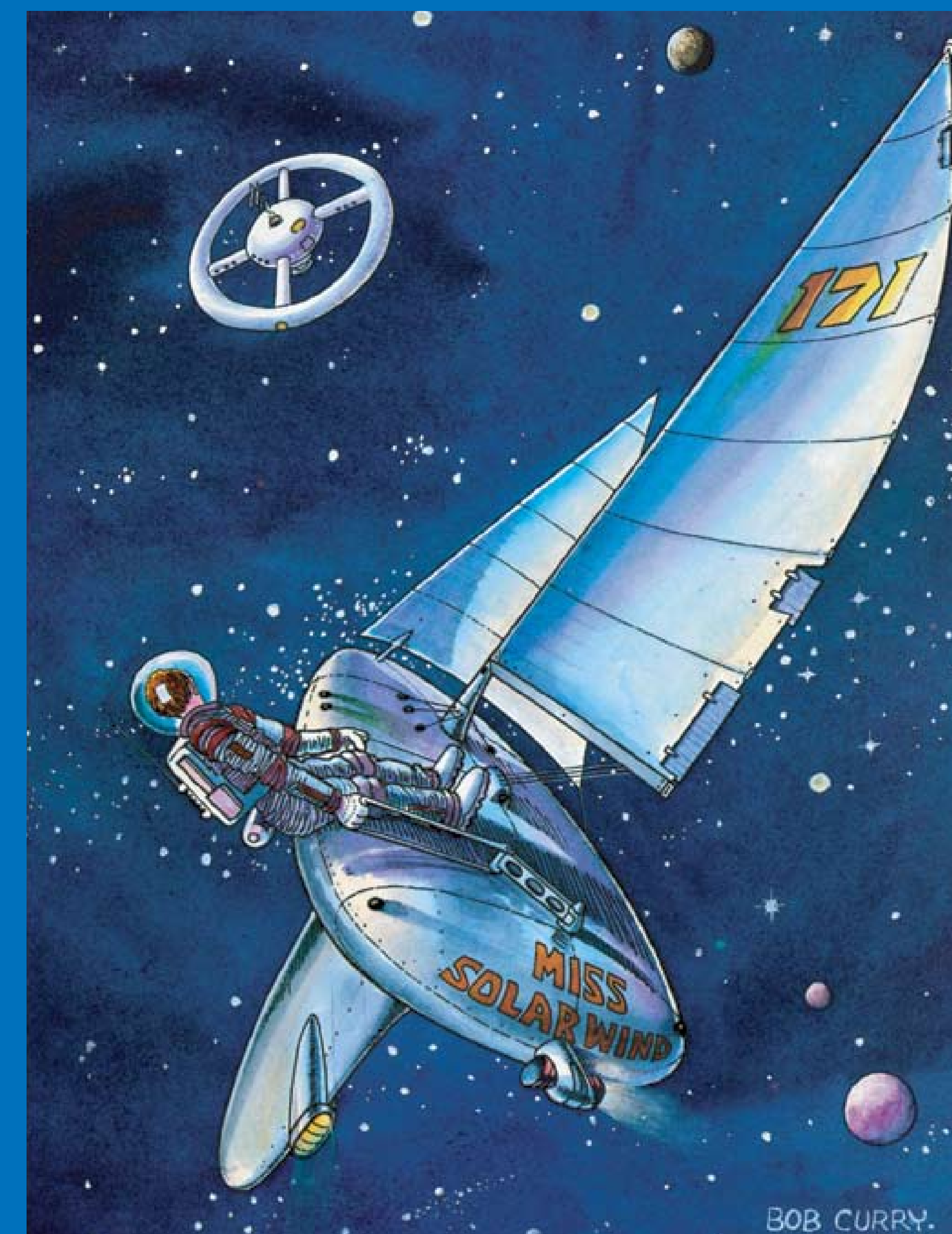

Image courtesy of Omni Magazine / Bob Curry (circa 1984)

The Solar Inverter Conundrum

Achieving peak performance

Achieving demanding product requirements such as high efficiency, wide DC input voltage range, ¢/watt and product lifetime are already difficult enough. However, many challenges faced by designers are out of their control, for example, government regulation, IP protection (300-500 patent applications per month on PV power converter issues (excluding cells and modules) in 2006), competition and pricing. Where the hardware designer really has a direct influence is in choosing the correct power devices to get the best system performance.

By Mark Thomas, IGBT Product Marketing Manager, Infineon Technologies

In this article, I would like to identify devices from Infineon's portfolio to help designers get the most out of their designs and to help answer the Solar Inverter Conundrum:

"Which discrete power device should I use and where should I place it to get the best performance out of my solar inverter?"

To begin, I have broken down a general inverter topology to indicate which devices would be best suited for each function.

Here Infineon is well represented with benchmark products in terms of performance and price. The discrete portfolio voltage classes range from 50V for the OptiMOS™ devices up to 1200V for the TRENCHSTOP™ IGBTs and SiC Schottky diodes. Whilst CoolMOS™ is available from 500V to 900V. Additionally, Infineon offers:

- CoolSET™ Flyback integrated PWM+MOSFET and PWM ICs,

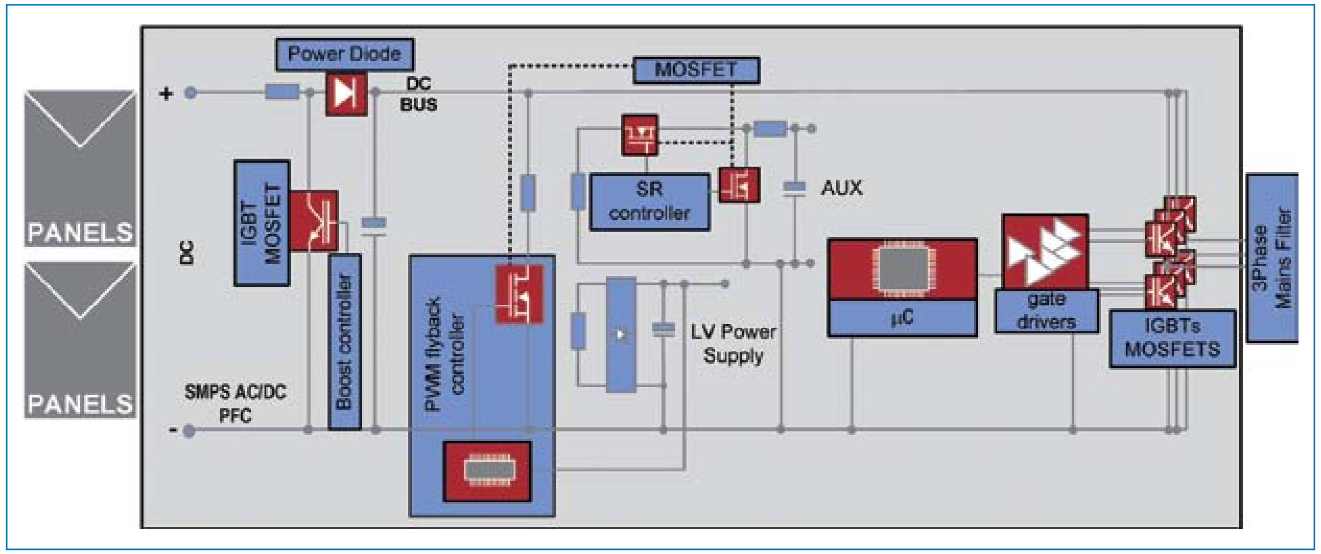

Figure 1: 3-Phase transformerless inverter topology.

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- CoolSET™ Quasi-resonant flyback integrated PWM+MOSFET and PWM ICs
- LLC PWM converter ICs
- µCs
- Driver ICs

Infineon is a one-stop shop system solution provider giving designers the ability to tackle the tough targets set by the industry with devices from one supplier.

From the topology shown above, four product types are highlighted. These are listed below in Table 1 and colour coded to help easy identification in Table 2.

To help designers answer the solar inverter conundrum, Table 2 lists an expanded view of the main functions shown in Figure 1, plus the colour coding to help easy identification. The devices have been selected as the best fit to get the highest efficiency, ¢/watt and robustness.

As can be seen from Table 2, "a one device fits all" philosophy is simply not possible to promote. However, with Infineon's comprehensive high performance discrete portfolio, there is the opportunity to fine-tune the system for maximum efficiency capability.

For a brief look at the four highlighted product types, let's start with the CoolMOS™ product families.

Four CoolMOS™ product families are listed in Table 2. These are the 600V CFD, CP, C3 and C6 families.

Thanks to the superjunction technology, the CoolMOS™ family offer best in class high-speed switching devices with very low conduction losses. The CP and C6 families are the latest generations available and offer the market's lowest RDSon values. For high efficiency, reliability and stability, these are must have devices.

Meanwhile the CFD CoolMOS™ family offers an intrinsic fast recovery body diode with extremely low reverse recovery charge and high commutation ruggedness.

TRENCHSTOP™ IGBTs

The 600V and 1200V TRENCHSTOP™ families are a great choice for the high- and low-side free wheeling switches.

The IKW30N60T, IKW50N60T and IKW75N60T are the solar inverter high runners, due to excellent conduction and switching loss behavior. With many low Vce(sat) optimized IGBTs available on the market, we see the switching losses from these devices being extremely high and when it comes to overall conduction + switching losses. Down to 500Hz, the TRENCHSTOP™ families come out on top.

For 1200V, there is a choice between two product families. Either the Vce(sat) optimized family, for example the IKW40T120, or faster TRENCHSTOP™ 2 family like IKW40N120T2. At 1200V, there really are no better devices available on the market.

One thing to bear in mind when implementing Infineon IGBTs is the gate resistor value. We see customers doing cross-referencing with IGBTs from other vendors and not taking care in selecting gate resistors. Typically, a high gate resistor value is used, say around 100Ω. For Infineon IGBTs, a smaller gate resistor is recommended, say 5Ω to 20Ω. (please consult the datasheets for ideal values). Choosing the correct gate resistor gives you the highest efficiency and offers excellent dv/dt controllability to achieve EMI requirements.

All TRENCHSTOP™ devices,

Device	Infineon Device Family
MOSFET	CoolMOS™
IGBT	TRENCHSTOP™ IGBT 600V/1200V
Power diode	thinQ!™ 2nd and 3rd Gen SiC diodes
Driver IC	EiceDRIVER™

Table 1: The high voltage team from Infineon to get the most out of high efficiency solar inverters.

Inverter Function	Infineon Solution
Overvoltage protection	CP 600V
Freewheeling switch / High frequency switches	CFD 600V
	TRENCHSTOP™ IGBT 600V, 1200V
Free wheeling diodes	SiC SBD 1200V
Polarity selection	TRENCHSTOP™ IGBT 600V, 1200V
Boost switch	TRENCHSTOP™ IGBT 1200V
	CP 600V
Boost diode	SiC SBD 600V,1200V
Buck switch	C3 800V
Buck diode	SiC SBD 1200V
Push-pull switches	CP 600V
Phase shift ZVS FETs	C6 600V
Rectification diodes	SiC SBD 600V Gen 2
LLC FETs	C3/C6 600V / 650V
IC drivers	1ED / 2ED

Table 2: Detailed breakdown of system with device recommendations where 99% efficiency has been seen in demonstrators.

whether 600V or 1200V, have a positive Vce(sat) temperature coefficient meaning paralleling is easy.

The TRENCHSTOP™ cell design has the distinct feature for the solar segment of high cosmic radiation robustness. Due to the unique trench-cell design, our devices exceed the high safety and reliability targets the industry needs.

On top of that, we can calculate FIT rates according to inverter operation profiles. This gives the designer piece of mind regarding lifetime warranties.

From feedback, what really is great for the designer is the opportunity to use a single TRENCHSTOP™ IGBT with an Infineon SiC Schottky diode. Again, Infineon is a market leader in SiC technology and has recently released the 3rd Generation portfolio where there is greater performance with improved pricing.

For silicon carbide, investing a little more does bring big returns. Infineon offers the thinQ!™ 2nd and 3rd generation Silicon Carbide Schottky diodes in 600V and 1200V.

Features:

- No reverse recovery/no forward recovery charge
- Switching behavior independent of forward current, switching speed and temperature
- Significant (3-5 times) higher surge-current capability
- First ever Silicon Carbide Schottky diode with stable avalanche
- Improved surge current capability
- Stable overvoltage characteristic

To finish off this system overview, there are the Drivers ICs. For solar inverters, the EiceDRIVER™ family, using core-less transformer technology, is the ideal partner to CoolMOS™ and TRENCHSTOP™ devices and offers a level of robustness unsurpassed by other driver ICs available on the market. The core-less transformer technology provides galvanic isolation from the power switch, extremely short propagation delays and compared to optocoupler solutions, no parameter degradation over time. This allows for the lowest pulse width distortion and the best deadtime control seen on the market.

Summary

Infineon has the portfolio to offer solutions for high efficiency solar inverter designs. It is the one-stop shop for high performance power-silicon discretes with TRENCHSTOP™ IGBTs, CoolMOS™, Silicon Carbide (SiC) Schottky diodes plus core-less transformer Driver ICs - A tailor made portfolio specifically for the high performance solar market, providing designers with the best power devices available.

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Special Report – Renewable Energy

Full Power Conversion

Power semiconductors for wind turbines

The increased requirements in grid code standards, use of permanent magnet synchronous generators and the possibility to reduce wear-out of gear boxes are important factors favouring the use of full converters in wind turbines. This has been hampered in the past by limitations in the required power semiconductors. Nevertheless, recent advances in the semiconductor technologies have reduced these disadvantages and make the full converter a viable solution for wind turbines application.

By Björn Backlund, ABB Switzerland Ltd Semiconductors, Lenzburg, Switzerland

The doubly Fed Induction Generator (DFIG) is today the dominating solution for wind turbines. Since the generator must operate fairly close to the line frequency and the possibilities to control the power are limited, systems using converters for the full generated power are increasing their share of the market. This is due to the fact that the generator frequency gets de-coupled from the line frequency, enabling simplifications and savings in the mechanical drive chain including both the generator and the gear-box. In addition, the better control possibilities makes compliance with the grid code standards easier. The full converters has the disadvantage that all the power have to flow through power semiconductor devices which due to the device characteristics will have a large influence on the system performance. Recent developments in the power semiconductors have enabled the reduction of these limitations and it is now possible to build compact converter units with decent efficiency also at a switching frequency needed for an acceptable harmonic content on the output voltage.

Topologies and voltage ratings

Due to the better availability of asymmetric and reverse conducting turn-off power semiconductors compared to symmetrical devices, the VSI-topology (Voltage Source Inverter) has achieved a dominant position in the field of frequency conversion. For low voltage conversion the 2 level VSI, figure 1 to the left, is the solution of choice but this simple inverter topology is also used for medium voltage circuits. However, the voltage ratings of the available power semiconductor components remains a limiting factor, since serial connection of power devices is a complex issue with many related technical difficulties, and therefore the output voltage of the 2-level VSI with commercially available components is limited to about 2400Vrms.

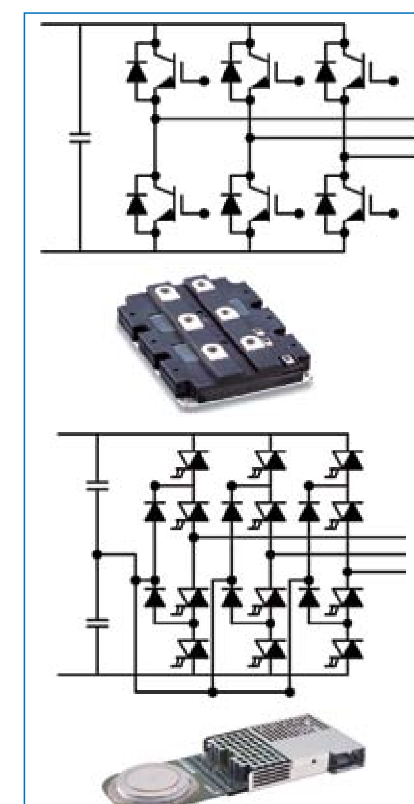

Figure 1: The 2 and 3 level topologies.

To accomplish a higher output voltage without series connection of power devices other topologies are needed and the most common is the 3-level NPC inverter, figure 1 to the right which enables an output voltage that is twice as high as a 2-level inverter with the same power semiconductor voltage rating. This topology is the main solution for the Medium Voltage Drives (MVD) on the market since with existing devices it is possible to achieve output voltages of up to 4.16kV without series connection of devices and/or converters.

Power semiconductors for medium voltage wind applications

For full converters there is basically a choice between two families of turn-off devices, the IGBT (Insulated Gate Bipolar Transistor) and the IGCT (Integrated Gate-Commutated Thyristor) where the IGCT is mainly developed for medium voltage applications only.

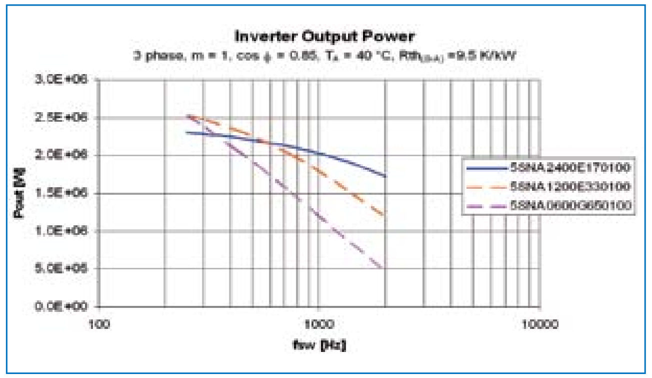

Figure2: 2-level inverter output power for HiPak IGBT modules at given conditions.

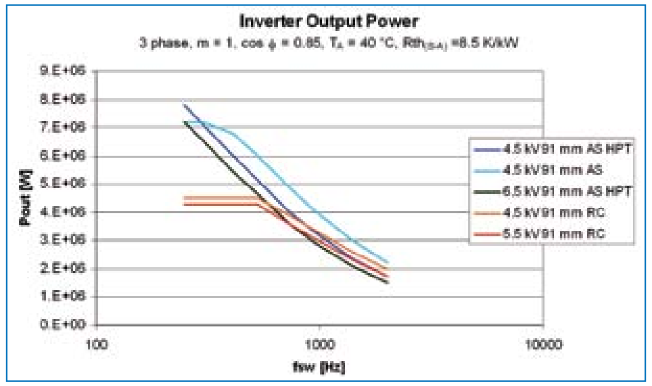

Figure 3: 2-level inverter output power for large IGCTs at given conditions.

Insulated Gate Bipolar Transistor IGBT

The IGBT is a well established device for power conversion and is available in many different types of packages, mainly with an insulated base plate and made for low voltage applications. Nevertheless, for medium voltage systems the number of possibilities is reduced to a few package types. For the comparison in figure 2 we have used the common module type HiPak. When comparing 3 different voltage ratings we see that higher voltage devices that require thicker silicon with the associated higher switching losses will have a stronger frequency dependency of the possible output power then low voltage devices. Hence, this will reduce their possible usage for applications requiring high switching frequencies.

Although among the largest module sizes on the market, the HiPak needs parallel connection of devices or inverters to reach the main stream power levels of 1.5 – 2MW, but with a well designed modular system of inverters these power levels can be reached.

The recent introduction of the SPT+ platform has increased the power density in the HiPak IGBT modules with up to 20%. Due to the improvement it is possible to either increase the output power of the inverter without making any changes to the circuitry and without sacrificing the robustness and controllability that has become a trademark for the SPT-chip family, thus shifting the curves in figure 1 on the direction of the upper right corner.

The quest for improved ratings has not stopped by the introduction of the SPT+. Further possibilities to improve the IGBT performance were explored and a very promising technology is in the pipeline. The Reverse Conducting IGBT (RC-IGBT, referred to as the BIGT (Bi-mode Insulated Gate Transistor) in its advanced design), promise another performance increase in at least the same magnitude as the change from SPT to SPT+ thus shifting the curves in figure 1 even further. By using the same die both as diode and as IGBT the power density can increase significantly since the available chip area within a module is more efficiently utilised.

Integrated Gate Commutated Thyristor IGCT

The IGCT has since its introduction in 1997 established itself as the device of choice for Industrial MVDs but it is also used in wind energy applications. The IGCT is available only as press-pack devices as asymmetric and reverse conducting devices where the latter has an integrated free-wheel diode. Figure 3 shows a comparison between the available asymmetric IGCTs in form of possible output power for a 2-level inverter at common conditions. The bending of the curves at low frequencies is due to SOA-limitations of the devices. Included in the figure is the new HPT-IGCT which gives an increase in the IGCT-SOA (Safe Operating Area) of up to 50% which opens new perspectives for control and fault handling compared to the standard devices.

As can be seen many wind turbine sizes could be covered with 2-level inverters using IGCTs. Nevertheless, it is more advantageous to use the IGCT in a 3-level connection since such a topology gives a better output voltage without the need to having very high switching frequencies. Such an inverter would also cover all of the currently available sizes of wind turbines without the need for series or parallel connection of the power semiconductors.

Furthermore, the technology development of the 10kV IGCT and diode, enabling voltages in a 3-level configuration of up to 7.2kV open up new fields for the use of power semiconductors in power conversion. By using the advanced corrugated p-base design from the HPT-IGCT, the envisaged turn-off capability is much higher than what could be previously expected for a turn-off device of this voltage level. 91mm 10kV IGCT and diode technology demonstrators have been produced and show very promising results and good switching behaviour.

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Power LEDs - Reading Between the Lines

Accurate performance assessments from datasheets

Understanding and comparing LED performance appears straightforward. Get the datasheets, compare numbers for light output, efficacy and lumen maintenance, and make a decision. Unfortunately, any purchase and design decision based simply on the top line numbers – the specs on the early pages – without analysis of how the LEDs will perform in the desired application under operating conditions can lead to unsatisfactory results, expensive redesigns and significant business risks.

By Rudi Hechfellner, Director of Applications and Steve Landau, Director of Marketing Communications, Philips Lumileds

The excitement - even hype - about the potential of power LEDs to revolutionise the lighting industry has been joined by scepticism among some lighting designers and architects. This is likely the result of the failure of some early solid state lighting solutions to live up to their promises in terms of light output, efficiency or operating lifetime. In many cases, assumptions that the performance of an LED as stated on a datasheet would translate directly to that level of performance in a luminaire. In fact, this is never the case and the performance numbers quoted by LED manufacturers are not the same as what will be realized in an application that functions in a completely different environment.

As this article will show, there is no alternative for the lighting equipment manufacturer to a rigorous examination of the relevant data in the datasheet. This analysis will uncover the actual performance and lifetime of a power LED under the conditions that will apply in the luminaire's operating environment.

Why all LEDs are not born equal

A 60W GLS light bulb is a standard, commodity product. Power LEDs, by contrast, are not commodities that adhere to a single industry standard. Even if power LEDs from different vendors shared identical packaging and pinout (which few do), differences in performance would mean that one brand could not be simply interchanged with another.

There are a number of reasons why LED manufacturers' products differ considerably. Solid-state lighting is a young and developing industry, and innovations are constantly being introduced by manufacturers to improve performance characteristics and to give their products a competitive edge.

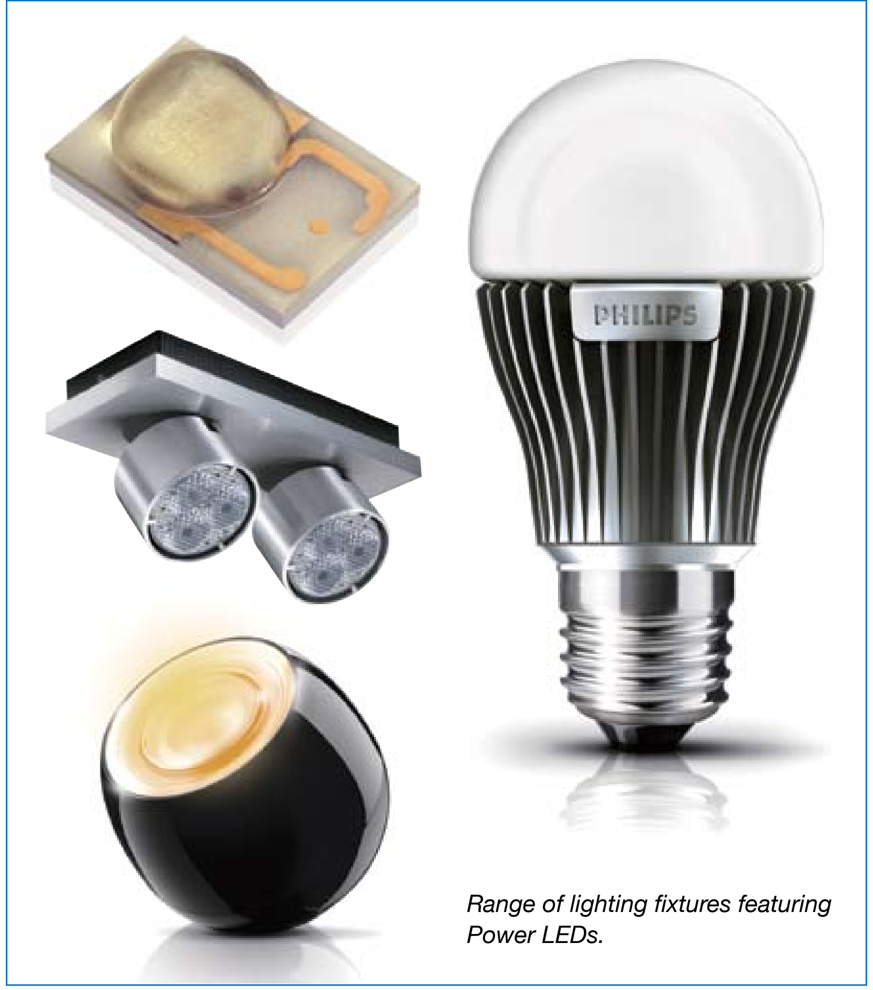
Some of the factors that result in product differentiation are:

• The design, manufacture and materials used to create the LED.

• Phosphor development. Different phosphors react differently to heat and to light.

• LED packaging can affect how light exits the package, how much heat can be dissipated and how optics are attached.

So multiple and complex factors within the control of the power LED manufacturer affect the raw performance of their LEDs, with the result that no two brands of LED will perform identically in a luminaire.



Range of lighting fixtures featuring Power LEDs.

This is important to understand, as superficial descriptions of power LEDs can give the impression of a standard output analogous to the standard wattage label applied to GLS bulbs. When two different LED manufacturers describe parts as providing 'min. 100lm at 350mA', it is true that, in certain tightly defined circumstances, including but not limited to an input current of 350mA, both power LEDs will produce at least 100lm.

But change those circumstances even a little and the performance of the two LEDs can begin to diverge significantly. The two potentially conflicting key parameters that affect the performance of an LED are:

• Drive current – up to a certain threshold, the higher the current applied to an LED, the more light it will produce and the hotter it will get.

• Operating temperature, the hotter an LED gets, the less light it will produce.

These two factors combine to affect light output (lm), efficacy (lm/W), lumen maintenance and ultimately the actual performance of a lighting solution.

No matter which brand of LED a lighting manufacturer uses, luminaire design decisions for drive current and thermal management will entail trade-offs. For instance, a decision to choose a high drive current for higher light output could cut the number of LEDs required to hit the target for light output, which will have a helpful impact on BOM cost. But there will be a trade-off in terms of lower efficacy for the LED and higher operating temperature.

All brands of LED will be subject to these trade-offs. But the size of their effect – the amount of pain they inflict, if you will – is very different from one brand of LED to another. This is where the factors described earlier – differences in LED design and manufacturing – show their impact.

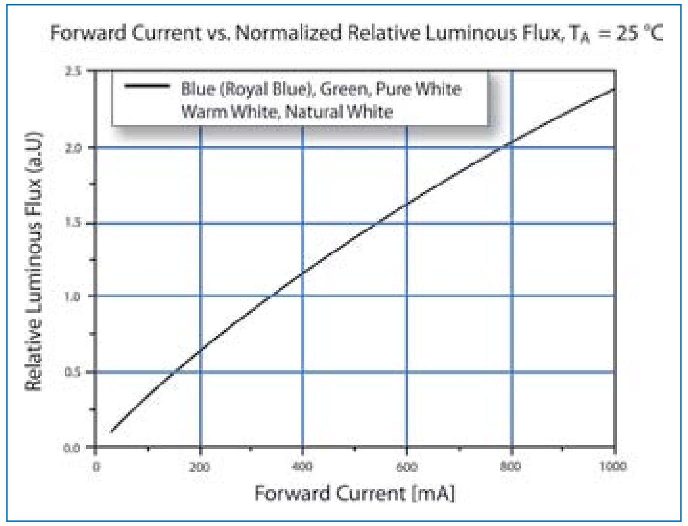


Figure 1: Example of Flux Normalisation graph.

The fact that stark differences in performance between one LED and another will emerge once they are embedded in a real luminaire is very far from obvious from the first page of a power LED's datasheet. But the tools to make an informed choice do exist in the datasheet. The designer simply needs

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	Data sheet Min. Flux	Data sheet drive current	Data sheet test temp	Data sheet test time
MFR 1	91lm	350mA	T_A 25C	25ms
MFR 2	107lm	350mA	T_J 25C	25ms
MFR 3	130lm	700mA	T_A 25C	25ms
MFR 4	100lm	350mA	T_{Pad} 25C	25ms

T_A: Ambient Temperature T_J: Junction Temperature
T_{Pad}: Solder Pad Temperature

Table 1: Headline product specifications for miniature power LEDs.

to know how best to find and use them.

This is perhaps best illustrated by example. For our example we will calculate for a simple, single LED desk lamp in order to make the figures as easy to follow as possible. But the principles and methods shown here can be applied to any solid-state lighting design in any application.

So let us imagine that you are the lead project engineer at a lighting equipment manufacturer, and you have to work to the following brief. You are to design a desk lamp with the highest possible light output. The lamp must be capable of producing light output after 50,000 hours of operation at a level that is at least 70% of output when the lamp was new.

A key part of this design project will be to choose an appropriate brand of power LED as the light source. The first stage in evaluating LEDs is to compare the raw light output figure as shown at the front of the datasheet issued by the manufacturer. Since the application is a desk lamp, space for mounting LEDs in the lamp will be constrained. Therefore this example compares high performance power LEDs from four leading suppliers, identified here as MFR 1-4. This example uses only publicly-available datasheet information as provided for its own LEDs by each of the manufacturers.

This first-stage comparison is shown in Table 1.

This data does not allow a like-for-like comparison, as the MFR 3 part is specified at 700mA. This explains the much higher light output value. Interestingly, different manufacturers adopt a different approach to specifying the temperature at which the device was tested, and this gives further scope for confusion. The effect of such differences emerges quite clearly as we progress further into the evaluation.

For the purposes of the design brief, however, this data is only a starting point. The brief was to maximise light output consistent with the lifetime goal of 50,000 hours. By driving the LEDs at 350mA (as per the datasheet figures), we would not be maximising light output, so let us instead compare all four LEDs at the higher figure of 700mA (see Table 2).

For three of the parts, this means applying the Flux Normalisation graph found in each datasheet (see Figure 1 for a typical example). The graph will provide a factor to use for each specific LED to calculate the light output produced at the higher current.

As we now see in Table 2, the MFR 3 emitter is no longer the leader in light output but the comparisons here are still some way from being apples-to-apples and in the actual operating environment.

So how do we calculate the actual light output we will get at the operating temperatures our desk lamp will experience in real life? For this we need the Temperature De-rating graph provided in every manufacturer's datasheet. First, we must specify the conditions in which our LEDs will operate: the ambient temperature (in degrees Centigrade); and the thermal performance of the luminaire, expressed as a value for thermal resistance. Thermal performance will be strongly affected by any thermal management methods applied, such as heat-sinking.

Manufacturer	Data sheet Min. Flux	Normalize to drive current	Normalized Min. Flux @700mA	Data sheet test time	Data sheet test time
MFR 1	91lm	700mA	164lm	T_A 25C	25ms
MFR 2	107lm	700mA	182lm	T_J 25C	25ms
MFR 3	130lm	700mA	130lm	T_A 25C	25ms
MFR 4	100lm	700mA	165lm	T_{Pad} 25C	25ms

Table 2: Raw comparison of LEDs at 700mA drive current.

Manufacturer	Data sheet Minimum Flux	Actual Drive Current	Normalized Min. Flux@25C	Data Sheet TJ max.	Operating TJ (calculated)@25CA, Rth50K/W	Determine Flux De-rating Factor	Actual Flux
MFR 1	91lm	700mA	164lm	145C	135C	72%	118lm
MFR 2	107lm	700mA	182lm	150C	128C	78%	142lm
MFR 3	130lm	700mA	130lm	125C	141C		
MFR 4	100lm	700mA	165lm	150C	130C	81%	133lm

Table 3: Comparison of light output under real operating temperature conditions.

Manufacturer	Calculated Lumens	Lumen Maintenance L70 Claim	Data sheet TJ max	L70 / 50Kh conditions	Actual Operating TJ (calculated)	Calculated current to achieve lumen maintenance	Final Calculated Lumens
MFR 2	142lm	50,000 hours	150C	TJ ≤ 85C TA ≠ 25C	128C	407mA	107lm
MFR 4	133lm	50,000 hours	150C	TJ ≤ 135C & If ≤ 700mA TA N.A.	130C	700mA	133lm

Table 4: LED output consistent with 50,000-hour lifetime requirement.

Using conservative assumptions (a high ambient temperature, which puts a relatively high stress on the LEDs, and a modest amount of heat-sinking), the light output comparison in Table 3 has changed strikingly when compared with Table 2.

The first interesting point to note is that the MFR 3 part cannot be used at all under these conditions: the high ambient temperature drives the temperature at the LED up to 141°C, 16°C above its maximum rated value.

Also interesting is the rate at which the output from the MFR 1 part declines under these conditions, when the LED's temperature rises to 135°C: while the part boasted an impressive 164lm output at 700mA before taking operating temperature into account, in real conditions it produces 118lm, markedly less than the two remaining emitters.

We now have a much more realistic basis for comparing different brands of LED. But we still have not taken into account at all the requirement for 70% lumen maintenance after 50,000 hours.

Again, all datasheets provide lumen maintenance graphs showing the rate at which light output declines over time.

But it is important to look carefully at the operating conditions that apply to valid data sets (see Table 4). For the MFR 4 emitter, these operating conditions are consistent with the lumen maintenance graph's conditions: the device is able to provide 50,000 hours of use at a junction temperature of 135°C; in the desk lamp example, the LED will actually run at 130°C. So we now know that the MFR 4 LED will produce 133lm when new, and will still provide at least 70% of peak output after 50,000 hours.

Table 4 also shows the conditions under which the MRF 2 part can provide 70% lumen maintenance at 50,000 hours: the junction temperature – the temperature at the LED itself – must be 85°C or less.

But in our example, when driving LEDs at 700mA for high light output, the MFR 2 device runs at a much higher 128°C. The simplest way to compare the MFR 2 emitter with the others in our example while achieving a 50,000-hour lifetime is to lower the drive current to a value at which junction temperature is 85°C. To achieve this, current must be reduced to 407mA, and at this low current the LED only produces 107lm, versus the 133lm from the MFR 4 LED at the full 700mA. Additionally LED drivers are typically available for 350 mA or 700mA. Since 407mA is not standard, a customer solution would likely have to be created which could add cost to the solution.

This is not the only approach that can be taken. Other options include:

- Easing the specification, either by reducing the product's lifespan to less than 50,000 hours or reducing the lumen maintenance requirement to less than 70%
- Improving the thermal management of the device, perhaps by increasing the heat-dissipation capability of the heatsink

Clearly, any such measures carry a cost, either in BOM (for a bigger heatsink for instance) or in reduced product performance.

Conclusion

The conditions that apply in the raw statements of performance shown in Table 1 and typical of LED datasheets are very different from those that apply in real luminaires. When all operating conditions are taken into account – a realistic drive current for those applications that need bright light, the real temperature at which the device will operate, and compliance with lumen maintenance requirements – the actual light output, and the comparison between different brands of LED, look very different. Only through analysis of the LED performance metrics based on the actual application and intended environment can an appropriate selection decision be made.

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Clean Success

Analog Devices helps Northern Power Systems' wind turbines generate clean energy

Northwind 100 wind turbines utilize ADI's broad portfolio of technologies including precision ADI components and SHARC digital signal processors to maximize energy extraction and optimize system controls

Reported by Cliff Keys, Editor-in-Chief, PSDNA

As environmental and economic concerns associated with fossil fuel production and consumption continue to grow, so too does the market for clean, renewable energy. Wind power in particular is gaining wide popularity as an inexhaustible means to offset oil, coal and gas-centric energy production. Over the past ten years, global wind power capacity has continued to grow at an average cumulative rate of over 30 percent annually, owing to growing global demand for emissions-free power generation infrastructure that can be installed quickly, virtually everywhere in the world.

Northern Power Systems (Barre, Vermont, USA) is positioned at the forefront of the wind power technology movement, offering community and utility-scale wind turbine systems differentiated by their innovative 'gearless' turbine designs, efficient energy capture capabilities, and low maintenance requirements.

The company's flagship Northwind 100 wind turbine is designed for community-scale wind power generation installations, enabling municipalities, businesses, farms, schools and other organizations to produce power at the source of the need, even in locations where wind speeds are relatively low. To help ensure that Northwind 100 systems deliver the highest possible energy yield and return on investment, Northern Power Systems relies on precision ADI digital signal processors, data converters and other components along with ADI's technical support to maximize system management efficiencies.

Elegance in design

Northern Power Systems' wind turbine technology is based on its proprietary permanent magnet direct drive (PMDD) design architecture, which precludes the need for a gearbox in between the turbine's rotor and generator. By directly coupling the rotor with the generator, Northern Power Systems' engineering team significantly reduced the number of moving parts within the system, which ultimately yields a more reliable machine that requires less maintenance than traditional gearbox-based turbines. This 'less is more' design approach epitomizes Northern Power Systems' engineering philosophy, and ultimately led the company's engineering team to seek out a similarly elegant signal processing platform that wouldn't compromise performance or functionality. They found what they were looking for in Analog Devices.

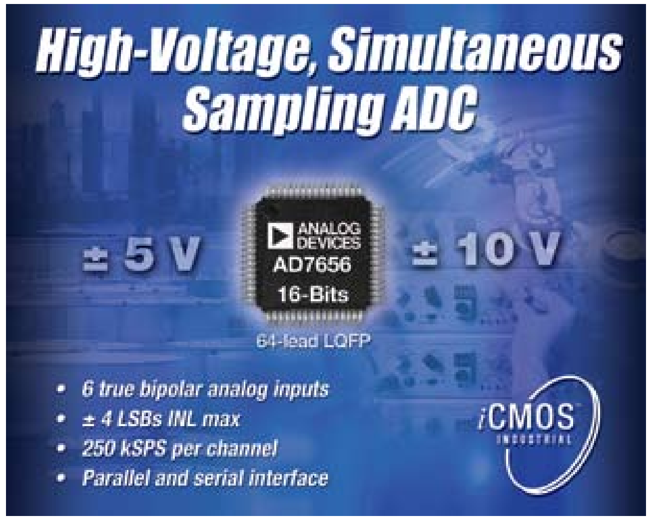
Leveraging ADI SHARC digital signal processors, data converters and other advanced components to ensure high-performance system operation, Northern Power Systems' Northwind 100 delivers 100 kilowatts of rated power for community wind applications such as schools/universities, businesses, farms, and municipalities. ADI's expertise in next-generation energy infrastructure assures that companies like Northern Power Systems are equipped with advanced components across the entire signal chain to enhance the value, performance and innovation of their system designs.

ADI SHARC digital signal processors, data converters and other advanced components ensure high-performance system operation.

High-performance signal processing

Within a Northwind 100 turbine, wind capture and energy conversion functions are facilitated by the system's rotor, generator and power converter components. The rotor converts the wind's aerodynamic energy to mechanical shaft torque; the generator converts the mechanical shaft power to electrical power at variable frequency and provides reaction torque to the rotor; and the power converter converts the variable frequency generator output to constant frequency for feeding into the grid.

A Northwind 100 powers the McGlynn Elementary School in Medford, Massachusetts.



ADI's 16-bit analog-to-digital converter.

The Northwind 100 generator's power flow is regulated by the power converter to compensate for variable wind speeds, which helps to maximize energy extraction. An electrodynamic braking system managed by the turbine and power converter embedded software allows the generator to apply reactive torque to the rotor when needed to regulate power output. This capability ultimately enables a Northwind 100 wind turbine to provide a steady flow of clean power to a local grid, simplifying grid interconnect infrastructure and maintaining grid stability. Eliminating the need for a gearbox transmission dramatically reduces lifecycle maintenance and increases system reliability.

At the heart of this system is ADI's 32-bit floating point SHARC 21363 digital signal processor, which hosts real-time closed-loop control algorithms to efficiently control the Northwind 100's generator and power converter subsystems, based in part on incoming data provided by the ADI AD7656 16-bit analog-to-digital converter (ADC) embedded in the data acquisition hardware and ADI dual-axis iMEMS® ADXL203 accelerometer sub-assembly part affixed to the turbine's nacelle. Delivering core processing performance up to 333 MHz/2 GFLOPS with support for IEEE 32-bit/40-bit floating point and 32-bit fixed point operations, SHARC 21363 processors employ an enhanced Single Instruction, Multiple-Data (SIMD) architecture to provide the real-time processing bandwidth and atomicity required to keep these subsystems running in precise coordination.

SHARC 21363 processors feature integrated 3 Mb SRAM/4 Mb ROM on-chip memory and a rich peripheral set to accommodate a wide range of configuration options. The Northwind 100's data acquisition platform hosts the ADI AD7656, which provides the high-speed signal sampling and data conversion that feeds into the system's real-time closed-loop control algorithms. This is facilitated by the SHARC 21363's six high-speed serial ports (SPORTs), yielding a seamlessly connected signal chain that helped minimize design complexity.

ADI powers innovation

Analog Devices' VisualDSP++ easy-to-install, easy-to-use software development and debugging environment for the ADI processor family enabled Northern Power Systems to streamline the product development process. VisualDSP++ is a member of ADI's CROSSCORE family of software and hardware tools, which also features the EZ-KIT Lite evaluation kit, all of which helps developers shorten design cycles and speed time to market.

With high-performance Analog Devices components at the core of the Northwind 100 wind turbine, Northern Power Systems' customers are assured ultra efficient power generation that reduces energy costs and minimizes the community's environmental footprint. For utility-side and consumer-side applications, Analog Devices enables technology developers like Northern Power Systems to design intelligent systems that promote energy efficiency and maximize investments in clean, renewable power.

www.analog.com

Accuracy Enables Efficiency

Miniature Iso-Amp measures current and voltage in small wind power systems

Isolation amplifiers (iso-amps), working in conjunction with shunt resistors, provide accurate current measurements in power converters even in the presence of high switching noise. When used with a resistive divider, they work as precision voltage sensors. The current and voltage information is required by the controller for calculation and effective control in order to achieve optimum conversion efficiency in typical small wind power systems. Featured with high common mode noise rejection, high isolation voltage, built-in safety insulation, and very small footprint, miniature iso-amps provide an ideal solution for small wind power turbines.

By Hong Lei Chen, Technical Marketing Engineer, Isolation Products Division, Avago Technologies, Singapore.

As one of the most promising alternative energy resources, wind power will continue to grow fast, despite the financial crisis and economy recession, at an annual rate of 22.4% average for the next five years. Large wind power farms are expanding to offshore deep water regions, such as the 25-megawatt Arklow Bank Wind Park in the Irish Sea, and the Cape Wind, America's first offshore wind farm, coming with

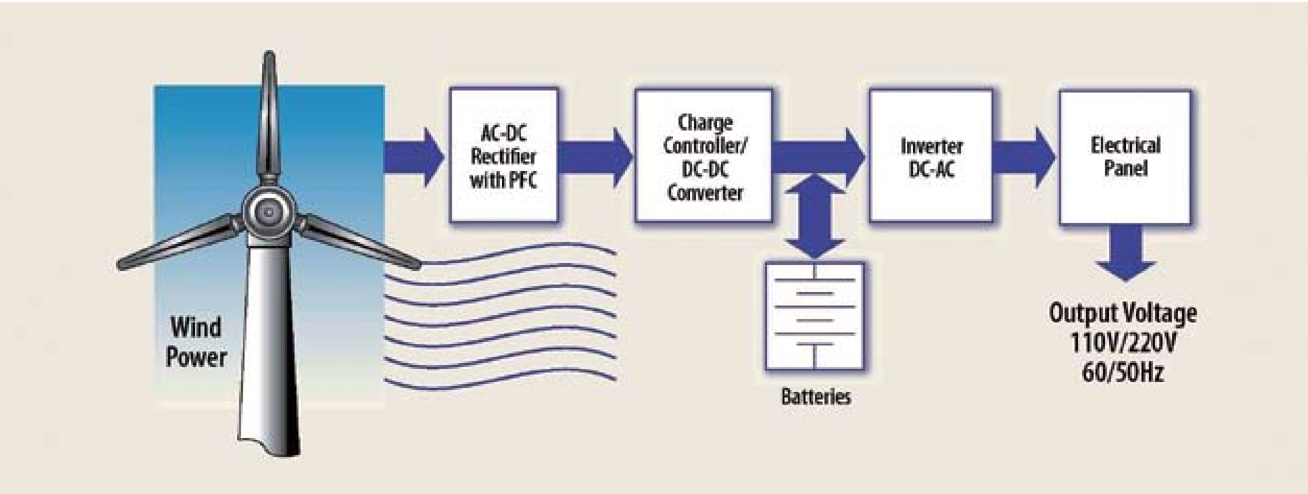


Figure 1: Simplified block diagram for small wind power generation system.

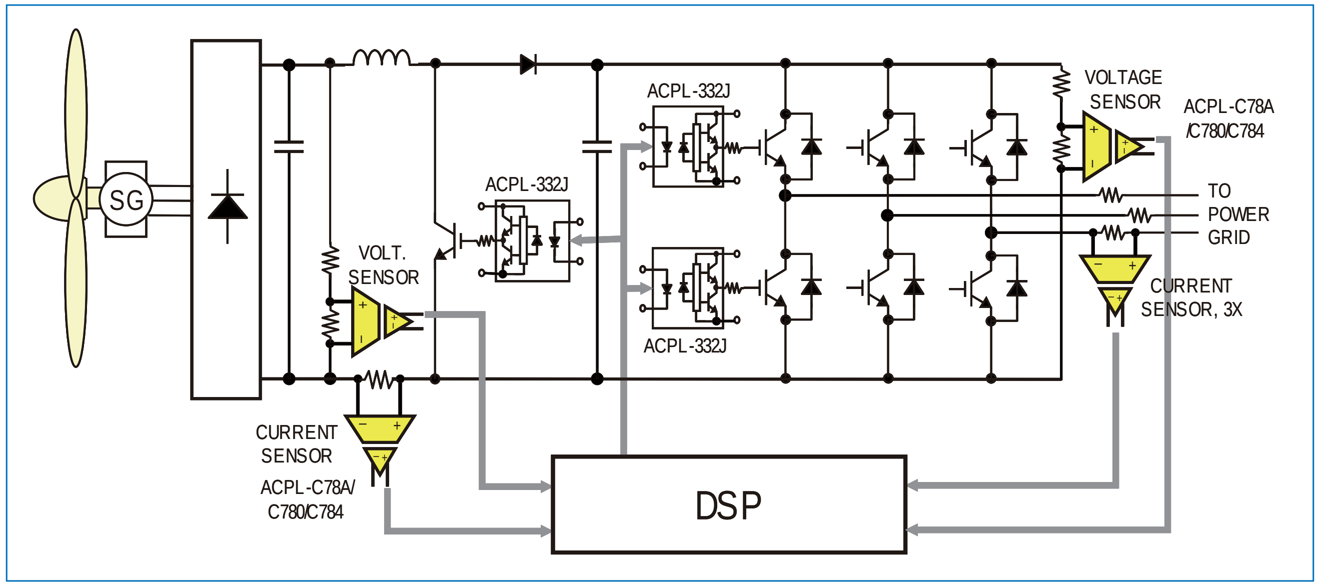


Figure 2: Block diagram of a small wind turbine using AC-DC-AC converter.

420-megawatt capacity.

Despite the attention given to large multi-megawatt wind turbines, which are projected to continue growing both in size and number of installations, most of the opportunities for power inverter manufacturers are in the small wind turbine market (<100kW). Although the market for wind power inverters is small compare to the solar photovoltaic market, the small wind market is experiencing a number of significant developments, including the emergence of Building Integrated Wind Energy (e.g., the 1kW AVX 1000 and the 60kW WindCube®) and the further development of Vertical Axis Wind Turbines (e.g., UGE 10KW VAWT).

Focus market for small wind turbines

The US market for small wind turbines grew 78% in 2008 with an additional 17.3MW of new capacity. This compares to 53% capacity growth worldwide with 38.7MW new installations in the same period. US manufacturers accounted for 49% of global small wind sales in 2008, maintaining their historically dominant position.

For the commercial segment of the US small wind turbine market (21-100kW), the growth was due largely to increased private equity investment that allowed manufacturing volumes to increase. The residential segment (1-10kW), the largest segment of the market, was driven by both investment and cost down with volume up. The rising residential electricity price and increased public awareness of the technology also played a part behind the growth.

In Europe, there are more than 40 established manufacturers active in the small wind power industry. Mainly located in Germany and Spain, these manufacturers produce small wind generators with power ratings from sub-kW to a few hundred kW.

A small wind system

A small wind system (Figure 1) usually includes a turbine, a generator, an AC-DC rectifier, a charge controller and a rechargeable battery module, an inverter, wiring, and a tower supporting the whole system. The charge controller and battery module are often required to meet the needs of off-grid wind energy systems in difficult and remote locations.

Efficiency is the key

Due to the variable wind speed characteristics, many wind solutions feature variable speed control technology to maximize energy capture from the wind and minimize turbine drive-train loads. Different variable speed control strategies have been proposed and discussed in the industry, with a common goal – optimum efficiency.

Besides the speed control section, the inverter plays a crucial role in enabling the power conversion process in a wind power system. In the case of wind turbines, variable-speed generation devices, an inverter is essential for the devices to connect to the grid and supply code-compliant power. Inverters can be either single (commercial) or three-phase (industrial) discrete components or modules and are controlled by a DSP to provide high-efficiency power conversion. High-performance inverter systems require precision timing control of power devices as well as safety isolation to prevent hazardous high voltage switching transients from damaging the controller and operator.

As an example, in a 30kW power conversion system, a simple AC-DC-AC converter and modular control strategy for grid-connected wind

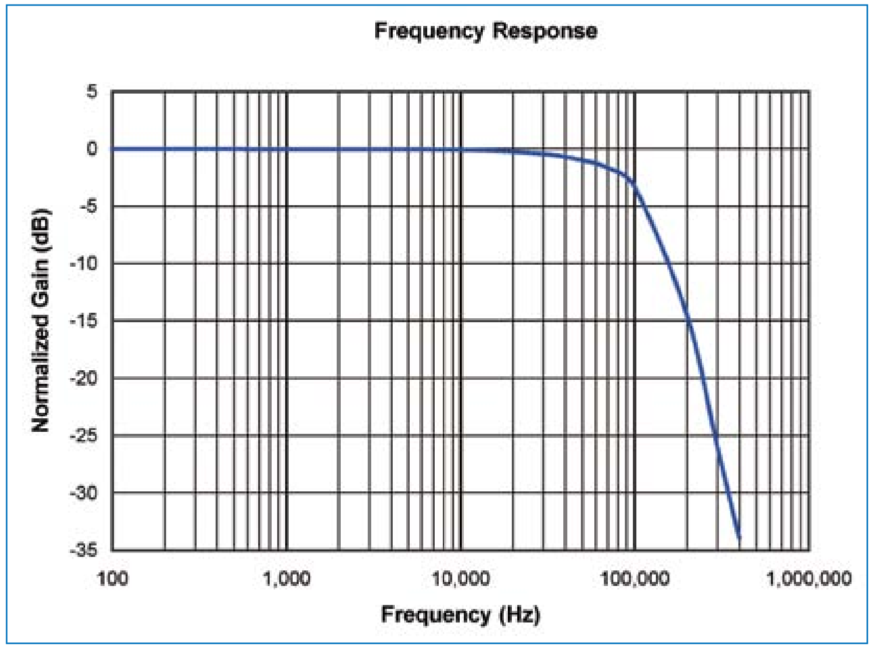


Figure 3: Gain-frequency response of the ACPL-C78X.

system was implemented.

Figure 2 shows a similar block diagram of the power converter. As the voltage and frequency of generator output vary along with the wind speed change, a DC-DC boosting chopper is utilized to maintain constant DC link voltage. The input DC current is regulated to follow the optimized, predetermined current reference for maximum power point operation of the turbine system. On connecting to the grid, PWM signals control the IGBTs through ACPL-332J gate drivers to supply currents into the utility line by regulating the DC link voltage of the inverter.

In order to achieve optimum system efficiency, the converter illustrated in Figure 2, and many others show that important current and voltage information must be fed back to the DSP for calculation and effective control. This information may include DC link current, generator phase currents, inverter output phase currents, and DC link voltages. This need poses opportunities for current/voltage sensors with requirements of not only sufficient accuracy, response speed, but also high switching noise rejection and safety insulation, at a competitive cost.

Iso-amp measures current and voltage

With advantages of better linearity, low cost, and design flexibility, shunt current sensing is a classical method for current measurement despite the drawback of power loss on the shunt. From developments of better thermal performance and lower resistance in shunt technology, power loss can be minimized by reducing shunt signal level.

Specifically designed to meet the stringent requirements in power conversion systems, the ACPL-

Figure 4: SSO-8 package (left), 30 percent smaller footprint vs. DIP-8 package.

C78A/C780/C784 miniature iso-amps accept signal of ±200mV, which is ideal for direct connection to shunt based current sensing applications. By choosing an appropriate shunt resistance, any range of current can be monitored, from less than 1A to more than 100A.

The ACPL-C78X family uses advanced sigma-delta A/D converter technology and fully differential implementation to realize 1% gain accuracy (ACPL-C78A), 0.004% extremely low nonlinearity and DC to 100kHz wide bandwidth (Figure 3). Available in a stretched small outline-8 (SSO-8) package with 8mm clearance and creepage (Figure 4), the ACPL-C78X offers robust galvanic isolation with safety approvals of 1140V working voltage per IEC/EN/DIN EN 60747-5-2, 5kVrms/1min double protection per UL 1577, and 15kV/μs common-mode rejection.

Conclusion

Though the market forces driving the wind energy industry vary from region to region, from feed-in tariffs successfully implemented in Europe, to a combination of regulations, subsidies and tax incentives employed in North America and Asia, this industry is set to grow quickly. Despite the eye-catching multi-megawatt wind machines going offshore into deep water regions, most of the opportunities for power inverters are in the small wind turbine market.

The ACPL-C78X miniature isolation amplifiers provide accurate current and voltage measurements that are required in typical small wind power designs to achiever optimum efficiency. The high switching noise rejection and high insulation voltage capabilities ensure smooth inverter operation and safety of the controller and operator.

www.avagotech.com

Where will it all come from?

Reported by Cliff Keys, Editor-in-Chief, PSDNA

The topic of renewable energy is sure to continue to be centre-stage for many years to come. The idea of us all using energy derived only from clean renewable sources is a long way off and will likely never be achieved. At best we can strive to consume less wastefully and to be sensitive to the policies of our governments and administrations regarding future sources of energy.

In Washington, the climate bill faces the finance committee. It now seems a long haul lies ahead and that it is unlikely there will be any more immediate major committee action on climate-change legislation. A comprehensive bill to cut greenhouse-gas emissions will not be voted on until later in 2010.

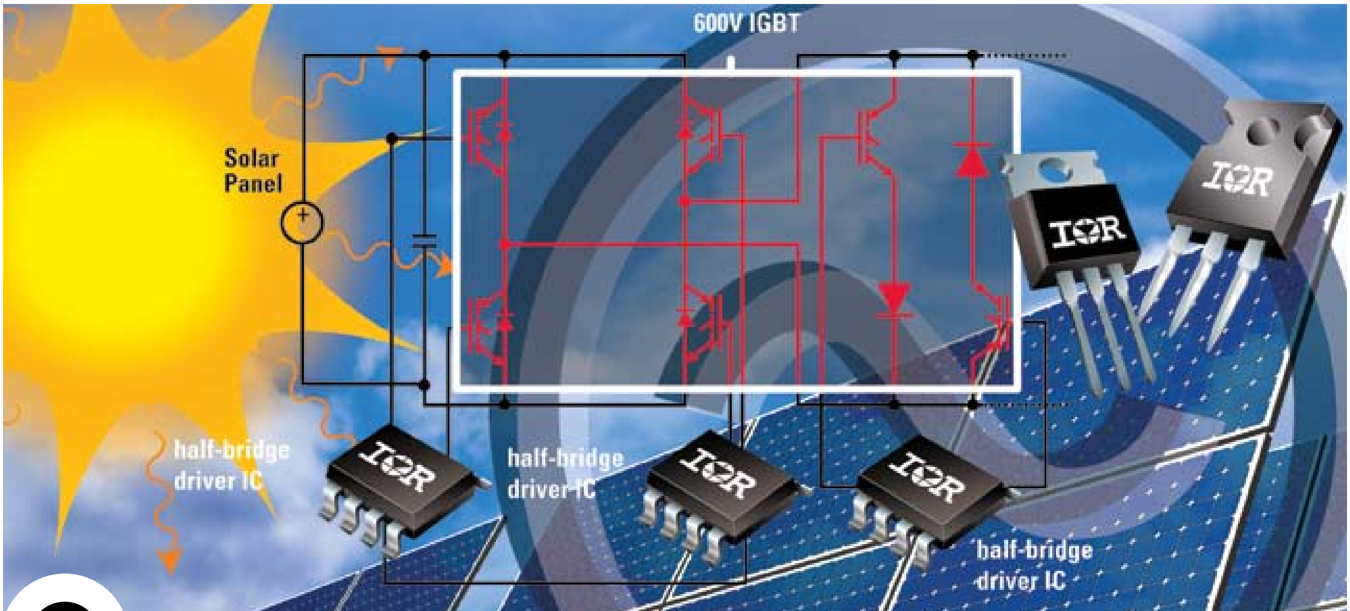
In the lighting efficiency sector, DuPont, Wilmington, Del., has been awarded a $2.25 million grant from the U.S. Department of Energy for a two-year project to develop a solid-state lighting source using low-cost organic light emitting diode (OLED) solution-processing manufacturing techniques. The project will leverage

the company's experience in OLED development for displays, while tailoring the technology to the unique requirements for solid-state lighting, an advanced technology that can significantly reduce energy consumption compared with incandescent and fluorescent lamps. Solution-processing is a cost-effective technique for the manufacture of OLEDs due to its lower capital investment, reduced fixed costs and efficient use of materials. The benefits are seen through manufacturing large areas at low cost while delivering completely new, highly efficient lighting concepts.

The global PV inverter market showed strong recovery in the third quarter of 2009 with shipments reaching record levels and the outlook for the market becoming increasingly positive. Over 2.5GW of PV inverters were shipped in the third quarter of 2009 according to IMS Research, marking an impressive recovery for the industry, which had stalled in the first half of the year. Global revenues are estimated to have reached about $900m, 30% up on the same quarter in 2008 and nearly double the previous quarter.

In the real world, energy is a complex ecological and financial issue. Even with growing implementation of PV and Wind sources, it will be interesting to see where governments and administrations specify the source-mix of our power for the future.

www.powersystemsdesign.com/greenpage.htm



600 Volt Solar Inverter Solutions

IR's Energy Efficient Portfolio for Grid-Connected Solar Inverter Output Circuits

600V Fast Switching Trench IGBTs for PWM*

Part Number	Package Type	Rated Current T_{CASE} = 100C , V_{GE} = 15V	$V_{ce(on)}$	td(on)	tr	td(off)	tf
IRGB4059DPBF	TO-220	4.0A	2.15V	20 ns	15 ns	85 ns	35 ns
IRGB4045DPBF	TO-220	6.0A	2.14V	26 ns	12 ns	95 ns	32 ns
IRGB4060DPBF	TO-220	8.0A	1.95V	28 ns	17 ns	117 ns	35 ns
IRGB4064DPBF	TO-220	10.0A	2.00V	27 ns	16 ns	98 ns	33 ns
IRGB4056DPBF	TO-220	12.0A	1.97V	30 ns	18 ns	102 ns	41 ns
IRGB4061DPBF	TO-220	18.0A	2.15V	40 ns	25 ns	120 ns	40 ns
IRGP4062DPBF	TO-247	24.0A	2.04V	40 ns	24 ns	125 ns	39 ns
IRGB4062DPBF	TO-220	24.0A	2.04V	40 ns	24 ns	125 ns	39 ns
IRGP4063DPBF	TO-247	48.0A	2.10V	55 ns	45 ns	165 ns	45 ns

600V Half Bridge Gate Driver ICs*

Part Number	Package Type	Io+	Io-
IRS2113STRPBF	SOIC	2.5 A	2.5 A
IR2114SSTRPBF	SOIC	2.0 A	3.0 A

600V Low Uce(sat) IGBTs for less than 1kHz*

Part Number	Package Type	Ic at 100°C	$V_{ce(on)}$ at Rated Current	Qg	$R_{th(j-c)}$
IRG4PC50SDPBF	TO-247	41A	1.28V	180 nC	0.64 °C/W
IRG4PC40SPBF	TO-247	31A	1.32V	100 nC	0.77 °C/W
IRG4BC30SPBF	TO-220	18A	1.4V	50 nC	1.2 °C/W
IRG4BC20SDPBF	TO-220	10A	1.4V	27 nC	2.1°C/W

*Also available in 1200V

Features

- Optimized 600V trench IGBTs, 600V standard speed IGBTs and HVIC for the inverter side
- 30% reduction in power loss using trench and standard speed planar IGBT combination versus ultrafast speed planar IGBT alone

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