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NORTH AMERICA

Empowering Global Innovation — *January/February 2009*

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ENERGY EFFICIENCY

Special Report - Energy Efficiency

ISSN: Pending

Power Systems Design NORTH AMERICA

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Registration of copyright: January 2004
ISSN number: Pending

Send address changes to:
circulation@powersystemsdesign.com

Free Magazine Subscription,
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Volume 1, Issue 1

Onward and Upward

As we launch forth into a new and somewhat bewildering year, we at Power Systems Design launch our magazine's coverage of the power community into North America with our new edition to the PSD family, Power Systems Design North America. Now we have a community of like-minded power specialists spanning China, Europe and North America each region with it's own localized content production and distribution.

With a global power audience of over 61,000 we have now, I believe, a tremendous opportunity and a vast resource at our fingertips with technologies, products and companies that operate on a local or global basis, we can report and share the news, views and technical expertise for which our industry is renowned.

APEC comes but once a year. To many, including myself, it is the single most relevant event for the power industry in North America. This year it is held between February 15 –19 in Washington DC. I look forward to seeing you there.

The financial predicament the world finds itself in has its own turmoil which is affecting all of us in the industry. It's not a comfortable time or place to be, with the insecurity and unpredictability of the future. It does not feel good, I know. The good news is that our industry will prevail and continue to flourish. We'll take the hits and roll with the punches, but in the end we'll come out of it.

In all my years in the semiconductor industry, too many to admit while keeping my youthful self-esteem, I have seen many ups and downs. We're now certainly in one of the downs, a bad one, but it will pass.

Many will try 'thinking out of the box', others will try 'hiding in the box', some will look for 'another box' but most will successfully find a way of making 'the box' a leaner and meaner and more viable vessel, hopefully steered by those who are most capable of the task.

So who needs power? Stupid question for sure. Where do we go with all the great technologies and products that will help save our industry, our environment as well as our credit cards? We have a golden opportunity. With the energy crisis now biting at our extremities, we have top class engineering on a global scale to get us off the dependency on conventional energy sources and the toxic nature of its by-products. This seems so important and yet so obvious, that even the politicians must see it, and more importantly, to nurture the very industry that will be the ultimate saviour of this multi-faceted peril.

I look forward to serving our extended audience and would like to invite feedback to enable me to give you what you need in the format and style that you want it. Please check-out our website and the online content, give me your feedback and have a look at our fun-strip Dilbert, at the back of the magazine.

All the best!

Cliff Keys

Editor-in-Chief, PSDNA
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Ferraz Shawmut Thermal Management

Ferraz Shawmut is the Electrical Protection division of the international industrial group Carbone Lorraine who design, produce and sell innovative solutions to enhance energy efficiency and safety of electrical equipment and systems.

The company expanded into the cooling unit business ten years ago, now called Ferraz Shawmut Thermal Management and has become a global partner in innovation for industry, offering cutting edge solutions in cooling.

Backed by worldwide organizations Carbone Lorraine and its Electrical Protection division, Ferraz Shawmut Thermal Management is now ready to advise and serve large OEM customers wherever they may located.

The business has operations in the world's three major areas of economic activity:

- Europe: La Mure, near Grenoble, France, where the business was founded
- North America: Toronto, Canada (since acquiring R-Theta in 2008)
- Asia: New plant in Shanghai, China.

Ferraz Shawmut Thermal Management's provides global solutions to meet the market's entire range of needs for high-tech cooling:

- High-performance design-to-order air cooling with the full R-Theta range
- Phase change cooling with Transcal heat pipes
- Water cooling for maximum thermal performances, with the Multical and Calistor solutions

These solutions can be developed into complete systems covering all elements in the thermal loop.

Acquisition of R-Theta Thermal Solutions Inc.

R-Theta Thermal Solutions Inc., a Canadian company based in Toronto, joined forces with Ferraz Shawmut Thermal Management in 2008. With this acquisition, the scope of Ferraz Shawmut's cooling unit business has grown in three ways:

- Product range of high tech solutions in water and phase change cooling now embraces R-Theta's high performance air cooling solutions

R-Theta Thermal Solutions Inc.

- Geographical coverage is significantly broader, with a North American base joining the European plant in La Mure, France, and a new operation in Kunshan, China
- Revenue is enhanced by R-Theta's sales, essentially in the North American market.

Ferraz Shawmut Thermal Management's global business continues to grow as it follows the industry's continuous improvement in the performances of electronic components that require efficient cooling as well as the increasing use of electronics. The company's growth is due to the compact, light-weight solutions to extract heat efficiently.

www.ferrazshawmut.com

James Harrington Wins Prestigious Premier's Award for Fuel Cell Innovation

Since graduating from Loyalist College in the Electronics Engineering Technician program back in 1969, Jim followed his passion for research and exploration as an electronics and mechanical product designer. Since 1970 he has been developing research and exploration equipment in astrophysics, geophysics and oceanographic applications. Today he is recognized worldwide for the design and fabrication of Canada's first successful fuel cell assisted sailboat, "The Sloop Jim D". Jim was nominated by Loyalist for the 2008 Premier's Awards program in the Technology category, and has been selected the provincial winner for the community college system. He will receive the award in February 2009.

After graduating, Jim spent 10 years in Mississauga working in the geophysics industry before moving to Canada's Herzberg Institute of Astrophysics. During that time he assisted in the design and construction of the high flux telescope for the Ulysses spacecraft that was launched from the space shuttle in 1990 on a trip to Jupiter and around the sun. The mission ended in March 2008, and was a successful voyage of discovery. He also recommended and then assisted in the construction of the first three-component magnetometers for the Black Brant sounding rockets used to study the Aurora Borealis.

Now living in Victoria, B.C., Jim operates a company called AGO Environmental Electronics. He spends much of his time as an inventor and recreational sailor. While sailing his 42-foot ketch he decided that there had to be a better way to power a boat than with diesel, to eliminate the smoke, smell and noise. He wondered if a fuel cell that he recalled seeing on the Apollo spacecraft might be the answer. He teamed up with a friend from the University of Victoria fuel cell laboratory and they developed a two horsepower outboard. The fuel cell, a high powered solar panel powered by hydrogen, charges the battery power box that in turn runs the motor. This year he developed a conversion kit to easily change gas outboards to electric 230VAC 3 phase using standard off-the-shelf components. This system was installed on an 18-foot cabin cruiser that has operated in Victoria Harbor throughout the summer of 2008, powered by batteries charged by the solar panels. He received the "Best Innovation Award" from the Esquimalt Chamber of Commerce at its 2008 Annual General Meeting.

"Jim Harrington's career achievements are outstanding," said Loyalist President Maureen Piercy. "It is gratifying that he credits the advanced math, physics and electronics that he learned at Loyalist as important building blocks to help him begin to see possibilities. Certainly those possibilities are endless, and Jim has proven that with his inventions and ongoing research and development. He is a worthy recipient of the Premier's Award, and the College is extremely proud of his accomplishments."

For his part, Jim said that he was honored with the award. "I really am surprised and honored. It is not something that you ever expect, but I appreciate this recognition very much."

The Premier's Awards are presented by the Premier of Ontario or the Minister of Training, Colleges and Universities at a special event held in conjunction with the Annual Meeting of Colleges Ontario in February 2009.

www.loyalistcollege.com

Alliance Formed to Manufacture Advanced Automobile Batteries in the U.S.

A row of plug-in hybrid electric vehicle (PHEV) battery cells (Photo courtesy of Argonne National Laboratory).

Leading U.S. battery and advanced materials companies, with support from one of the country's largest national laboratories, have formed the National Alliance for Advanced Transportation Battery Cell Manufacture, known as the "Alliance," to manufacture advanced lithium ion battery cells for transportation applications in the United States. Lithium ion batteries are anticipated to replace gasoline as the principal source of energy in future cars and military vehicles. Today, United States automobile manufacturers and defense contractors depend upon foreign suppliers — increasingly concentrated in Asia — for lithium ion battery cells.

The founding members of the Alliance include 3M, ActaCell, All Cell Technologies, Altair Nanotechnologies, Dontech Global, EaglePicher Corporation, EnerSys, Envia Systems, FMC, MicroSun Technologies, Mobius Power, SiLyte, Superior Graphite, and Townsend Advanced Energy. Additional battery developers and materials suppliers are anticipated to join the Alliance. The U.S. Department of Energy's Argonne National Laboratory, a national research laboratory and leading developer of new battery technologies, has been active in encouraging the Alliance and will continue to serve in an advisory role as the Alliance begins operations.

The Alliance seeks to develop one or more manufacturing and prototype development centers in the United States, which will be shared by Alliance members. Developing the capability to mass manufacture advanced battery cells is anticipated to require an investment of $1 to 2 billion over five years. Most of that investment is expected to come from the federal government, because lacking current orders for advanced transportation batteries, no U.S.-based battery companies can assume the risk of making such an investment. The Alliance will permit the most efficient use of available government support by having Alliance members share in the use of a large ultra-modern manufacturing facility rather than having to compete for smaller, less ambitious forms of government support.

Lithium ion battery cell manufacture is heavily subsidized in many countries. The Alliance hopes to level the playing field.

U.S. auto makers are expected to play an important role in the Alliance. "U.S. truck and auto makers and representatives of the Department of Defense will be invited to serve on the Alliance's advisory board," says Alliance attorney James J. Greenberger of Reed Smith LLP. The advisory board will help the cell makers move towards standardized cell formats that will simplify manufacture and ultimately lower the costs of cells.

www.uchicagoargonnellc.org

PSS Flyback Controllers Meet Energy Efficiency Regulations

CamSemi, emerging leader in power management ICs for optimized energy-efficient offline power conversion, has announced a breakthrough in the Primary Side Sensing (PSS) market, following on the success of its C2470 series of Resonant Discontinuous Forward Converter controllers.

The C2140 series offers 'best in class' current and voltage regulation of +/- 5% and targets high volume, universal input applications rated up to 8W. The parts also feature easily programmable cable compensation and switching frequency adjustment to enable greater design and manufacturing flexibility.

These novel PSS controllers help manufacturers of chargers for mobile phones, Bluetooth headsets, digital cameras and other high volume consumer products to cut component count, while developing more reliable and lower-cost designs to meet Energy Star 2.0, European code of conduct and other worldwide energy-efficiency regulations. The C2141PX2 and C2142PX2 parts are rated at 4W and 8W respectively, packaged in SOT23-6 and are available in volume now.

CamSemi's C2140 family completely eliminates the need for optocouplers and all secondary-side feedback circuitry, as well as any additional components that designers may need to specify to improve the current regulation from a typical PSS flyback design. The controllers use sophisticated patented algorithms combined with digital techniques to more accurately monitor the output voltage and provide tighter current regulation than has previously been possible. This novel approach enables quasi zero voltage switching, which drives up operating efficiencies and delivers improved current regulation to maintain the optimum lifetime of lithium ion batteries.

These devices include easily programmable cable compensation of up to 10% to give tight voltage regulation at the end of the cable, while helping to minimize the copper content (and therefore cost) of the cable. The compensation is fully adjustable in the design phase allowing one standard design to be quickly modified to accommodate different cable lengths or gauges. The controllers can also be easily adapted to match the required switching frequency of the end application by simply specifying one external component.

"CamSemi's new products not only offer the best current regulation of any PSS controller on the volume market today but have been specifically designed to give manufacturers much more freedom in optimizing often conflicting design and production requirements. Our 'one size fits all' approach means one controller can meet a range of cable compensation and switching frequency requirements and without manufacturers having to maintain inventory of multiple parts," said David Baillie, CEO of CamSemi.

CamSemi C2140 controllers are designed for use with low cost bipolar transistors and have protection features such as over-temperature, input over-voltage and output short-circuit included as standard to further simplify designs and reduce system costs.

An abbreviated datasheet for the C2140 family is available online with more detailed information and support direct from CamSemi or one of the company's distributors.

The company's unique solutions and approach can help manufacturers of mains-powered electronics develop smaller, lighter and more energy-efficient products while also reducing their design timescales and system costs.

www.camsemi.com

What Does Being 'Green' Really Mean?

By Tony Armstrong, Director of Product Marketing, Power Products, Linear Technology Corporation

A New Year is upon us and I am sure that we all hope it is going to be better than the one we left behind! Nevertheless, while 2008 was a turbulent year economically for most of us, one bright spot was in the area of "Green" technology. Virtually everywhere, new semiconductor products were introduced that were more environmentally friendly by virtue of their lower power consumption and/or high efficiency conversion. These features reduce a system's overall power consumption and our dependency on fossil fuels. This is made possible since lower power consumption directly equates to less electricity needed to power them which means less fossil fuel is needed to generate the electrical energy in the first place. Correspondingly, this helps to reduce the greenhouse gases that have such a negative effect on our atmosphere and climate.

Production Source	Percentage
Fossil Fuels	71.4
Nuclear	20.7
Hydro	5.6
Other	2.3
Total	100

Table 1: Electrical Production sources for the United States.

Consider that the total electrical consumption of the United States is approximately 4 trillion kW annually. That's a 4 - with 12 zeros after it. The largest production source for electricity generation is fossil fuels, illustrated in table 1.

Since fossil fuel consumption has a significant impact on the total production of greenhouse gases, the more we can do to reduce the need for them, the better off the world will be. Whether it is coal, gas or oil, it does not matter - the effect is the same.

So the question for the analog power semiconductor world is: What does green really mean for an analog power IC? To fully understand, we need to appreciate what an analog power IC needs to do in order to mitigate the effects on an end-system's total power consumption.

Consider the power consumption of servers – those high-powered computers that run the internet, deliver millions of YouTube videos and keep the economy running – their electricity use doubled between 2000 and 2005, and could spike another 75 percent by 2010. Or, put another way, in 2005 it took the equivalent of 14, 1,000-megawatt power plants to keep online the world's data centers owned by Internet giants like Google, Microsoft and Yahoo.

For a power management IC to be used in an energy-saving DC/DC converter design inside a server, it must possess very high efficiency of conversion properties and also, a low quiescent current in normal, standby and shutdown modes to minimize power consumption. This is particularly important since many systems can spend the majority of their time in a standby or low power modes in which they continuously consume power, making conversion efficiency at light load a critical factor.

The more efficient an IC can be, then the less energy it will consume in the conversion process. For example, consider two separate ICs used in a DC/DC converter delivering 5A at 5V (25W) to an appliance load. If the first IC is 95% efficient then we have:

P_{OUT}/Efficiency = P_{IN},

Or, in this instance, $P_{IN} = 25/0.95 = 26.3W$

However, if an alternative IC is only 91% efficient, then we have:

$P_{IN} = 25/0.91 = 27.5W$

The difference in this example is 1.2W of energy. Thus, in the second instance an additional 1.2W must be generated to power the appliance. This not only increases the demand for power, but also puts extra strain on the thermal design aspect of the system since the DC/DC converter must also dissipate this power loss as heat. Similarly, in a low power mode, where the output current might only be 200mA, then the power loss is 50mW. This is still significant since some systems can be in lower power mode for up to 90% of their total operational time.

In conclusion, while some analog vendors claim their products handle power consumption in a wise manner, the user needs to consider what the IC can deliver in terms of efficiency of conversion and total quiescent current consumed to really know and understand what being green really means.

www.linear.com

Energy Concerns Drive Demand

Firstly, I'd like to say how pleased I am to be writing our first MarketWatch article for PSD on behalf of IMS Research. The power industry is currently an exciting place and has been a key focus for IMS Research for a considerable time. We produced our first power market study in the early 1990s, and now have ten of our analysts dedicated solely to this topic. As our first contribution, I can think of no better topic to discuss than energy efficiency. IMS Research tracks all parts of the power industry and energy efficiency and energy savings are two of the most significant underlying factors determining demand for power components. These issues have driven above "average" growth for several years and, though the electronics industry is currently facing a gloomy short-term economic picture, they should ensure out-performance for many years to come.

By Ash Sharma, IMS Research

Energy efficiency and energy savings affect almost every area of the power industry and though there are too many to discuss individually in this article, some of the most interesting examples are motor drives, energy efficient lighting, solar power, efficient power supplies, hybrid vehicles, smart meters and white goods.

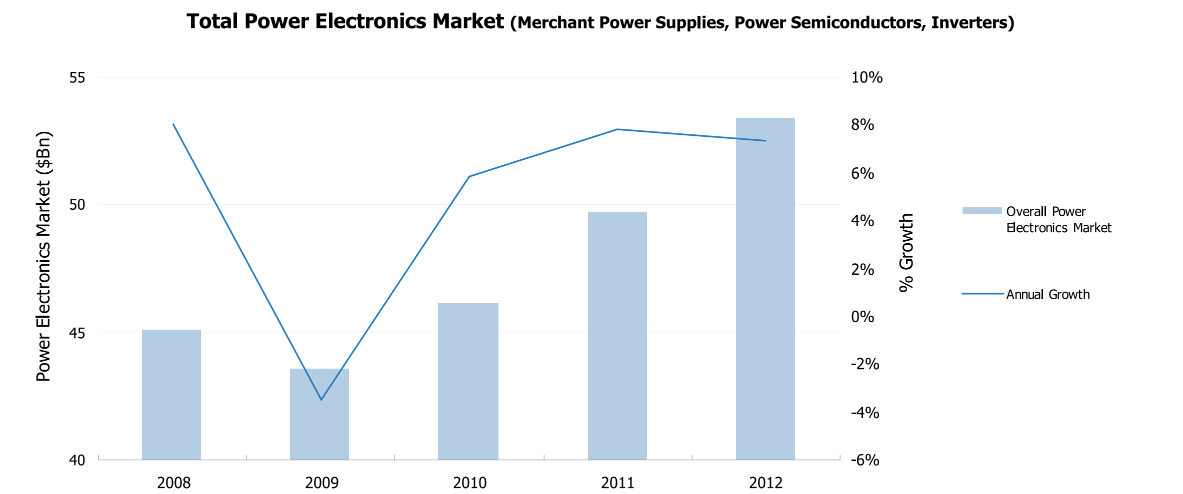
Unprecedented demand has been seen over the past two years for industrial motor drives. In 2008 shipments grew by some 10-15% driven by the need to more intelligently control motors in order to save energy. Such strong demand has allowed suppliers of IGBT modules to record massive revenue growth with the market growing to $1.5 billion in 2008. Though this sector is not likely to experience as positive a result in 2009, the long-term outlook is very favourable.

Although not quite as large, another attractive sector for suppliers of IGBT modules (and many other power components) is solar inverters.

There's been an explosion in growth of solar inverters in the past three years, largely led by Germany, which introduced very attractive incentives to promote solar technologies. In 2007 some 2.9GW of new solar capacity was installed globally. At the end of 2008, this is likely to have surged to 5.1GW. This has presented huge opportunities for suppliers of inverters and their components as well as other companies, such as National Semiconductor, who are looking to exploit the huge growth in solar modules by introducing new products which shift the intelligence away from the inverter and towards the panel.

In spite of the economic downturn, growth in solar installations is anticipated to remain strong in 2009, although some large projects may face difficulties in obtaining finance. Despite the fact that oil prices have recently dropped sharply, the argument for solar power generation remains strong. The price of PV modules is widely expected to fall sharply this year, with module production ramping up significantly to reverse last year's supply-demand imbalance. This factor, coupled with the long-term incentives offered by government regardless of the current economic climate, should ensure the market continues to grow in 2009.

Another high growth opportunity for power component suppliers is hybrid vehicles, although short-term growth will inevitably be constrained by the slowdown in consumer spending and the current financial problems of the automotive industry. Longer-term, the growth outlook is much more positive. Penetration of hybrid vehicles is projected to increase to more than 5% over the next five years from less than 2% last year. This forecast, coupled with the huge power content of hybrid vehicles, presents a very attractive opportunity for suppliers. As well as massive IGBT content for the inverter stage, additional DC-DC converters, controllers, battery management ICs and power discretes push the power electronic content up significantly.



Outside of these relatively new and high growth sectors, other opportunities still exist in more mature markets where the demand for greater energy efficiency is driving growth. Some examples include the drive towards 80+ and now towards 90+ power supplies. This initiative, supported by companies such as Dell and HP, has forced companies to manufacture more efficient power supplies for computing applications, supporting average selling prices and driving demand for more efficient power ICs. The need for more efficient and intelligent use of energy has also impacted board-level DC-DC power conversion. As input voltages have dropped and the number of rails has grown, there has been a steady increase in demand for more efficient regulator and controller ICs as well as a faster transition from linear to switch-mode regulators. This trend is further supported by the increase in power consumed by computing and consumer applications as well as increased concerns from businesses and consumers alike regarding their energy bills.

There's so much more to discuss on this interesting topic and we look forward to bringing insightful comment and analysis on power electronics markets during the rest of 2009. It seems sure to be the most challenging year for the industry for quite some time!

www.imsresearch.com

Frequency Response of Switching Power Supplies

Switching power supplies – ultra wide band circuits

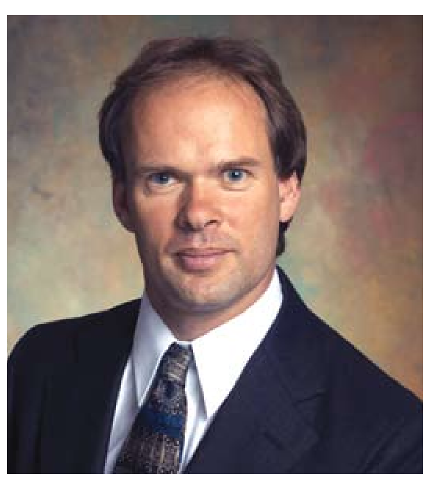
In this article, Dr. Ridley starts a series of three articles on switching power supply frequency response. The first article introduces the frequency ranges of interest in a switching power supply, and some of the difficulties of frequency response analysis.

By Dr. Ray Ridley, Ridley Engineering

S power supplies have a reputation for being difficult circuits to design, troubleshoot, and manufacture. Some of the reasons for this have been covered in past articles in Power Systems Design Europe[1]. There is another fundamental issue encountered with power supplies that makes them a special class of electronics: they generate an extraordinarily wide range of frequencies.

Sometimes it is easy to point at RF fields and be in awe at the extremely high frequencies encountered, in the multi-GHz range. Anyone who has worked in these fields is familiar with the critical parameters of circuit layouts, microwave circuit elements, matching networks, and other specialties. The 100kHz switching power supply seems relatively easy by comparison.

A major challenge of the switching



power supply design is encountered in the extreme range of frequencies that must be considered. Figure 1 shows the typical frequency bands for a switching power supply.

There are two significantly separate regions of Figure 1. The first region concerns the frequencies up to half of the switching frequency. These are the relevant control frequencies of the converter, where the control loop responds to changes in the system such as changing loads, or changing input voltages.

The second region is from the switching frequency and up. For these frequencies, the power supply is a noise or EMI generator. The power supply is not expected to respond to a control stimulus in these frequency ranges, and the job of the power supply designer is to suppress and manage the high frequency noise components.

Control Frequencies

Control Frequencies of a power supply can extend down as low as 0.01Hz, and as high as several hundred kHz, depending on the switching frequency (typically in the range of 20kHz to 2MHz.)

Many power supplies are now

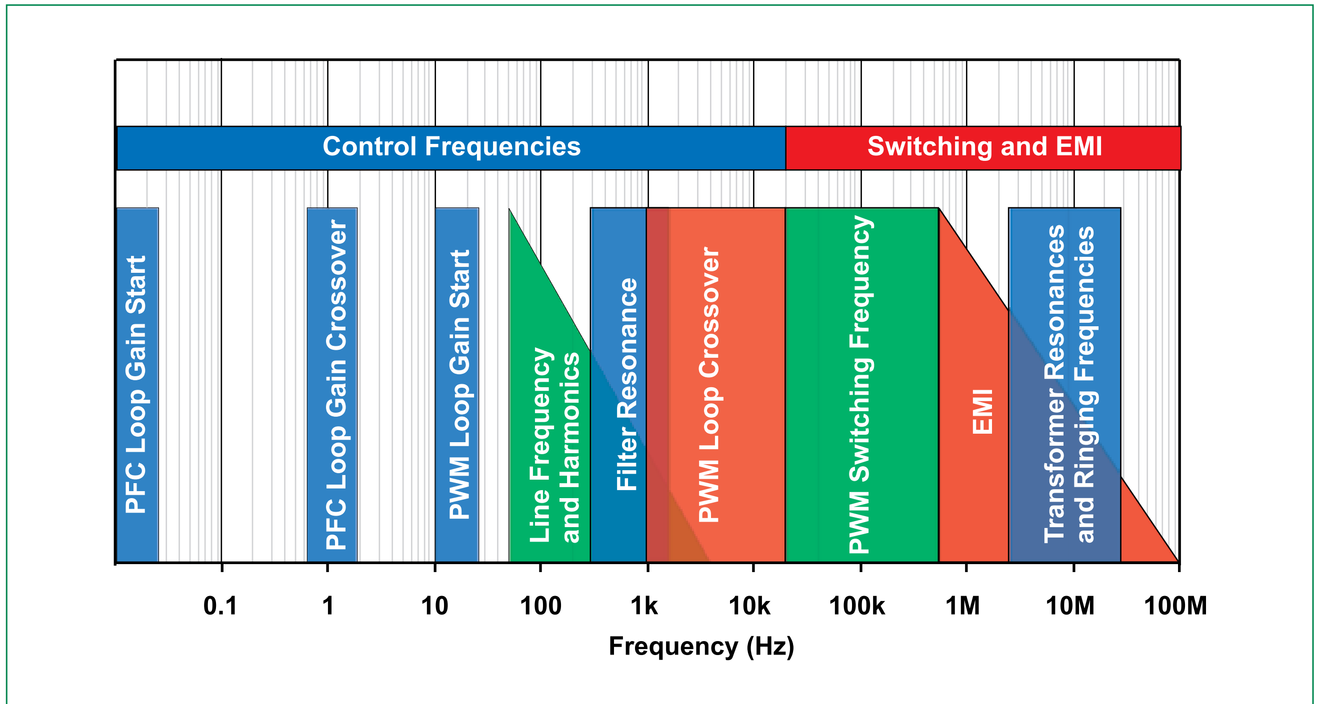


Figure 1: Frequency Bands for a Typical Switching Power Supply.

designed with two stages of power conversion – a switching power factor correction circuit (PFC) which shapes the AC input current waveform, and a switching DC-DC power supply which isolates and regulates the output from the input source power.

The function of the PFC circuit is to make the input of the system look like just a resistive load, even though there are large bulk capacitors to be charged at the input. To achieve this, the primary purpose of the PFC circuit is to shape the input current into a rectified AC waveform. (A feedback loop from the output capacitor after this circuit is used to set the average current level during the AC line cycle.)

If the input current waveform is to have low distortion, the feedback signal setting the current level must remain essentially constant during a single line cycle. This means that the loop around the PFC circuit must be slow – with a bandwidth of perhaps no more than 1Hz. This PFC circuit requirement sets the first two bands of Figure 1 – the PFC loop gain is typically measured in the range from 0.01Hz to 10Hz.

10Hz is typically where a loop gain Bode plot is initiated for the switching power supply. This frequency is chosen since it is below the significant noise frequency caused by the AC input line. The AC input line generates noise at 50 or 60Hz with a single-diode rectifier, and at 100 or 120Hz with a bridge rectifier. The control of the power supply is expected to respond to prevent the line-frequency harmonics from appearing on the output of the power supply.

The resonance of the LC filter of a switching power supply is typically around 100 times lower than the selected switching frequency. For a 100 kHz power supply, a resonance of 1 kHz is typical.

The loop gain of the converter can be as high as about 1/10th the switching frequency[2], and as low as perhaps 100Hz. While the actual crossover itself is not a design objective, raising the crossover frequency is usually a method to improve performance without making significant changes to power components. Loop gain measurements are continued above the crossover frequency and up to the switching frequency, to verify the gain margin of the system.

Noise Frequencies

The switching frequency of the power supply is both the carrier of the control and power information. It is a generator of noise which must be attenuated before it gets to the output and input lines of the system. Since PWM converters are designed to be as efficient as possible, the rise and fall times of the square-wave waveforms are very fast. The fast edges of switching action generate harmonics from the fundamental of the switching frequency out to 10MHz and beyond.

The abrupt switching also excites resonances in the circuit due to magnetics and junction capacitances, and peaks in the EMI spectrum can be seen at frequencies in the multi-MHz range.

Control Signal and Noise All At Once

Once of the specially challenging aspects of switching power supplies is that the noise frequencies from 50Hz up to 100MHz all coexist at the same time. When probing the circuit with an oscilloscope, you must use many different time bases in order to see the frequencies that you are looking for, and to troubleshoot system issues.

Specialized equipment is used in addition to a high-performance oscilloscope. A spectrum analyzer is used to detect individual frequencies that make up a waveform, and to accurately show magnitudes at very low signal levels in order to verify EMI compliance.

Below the switching frequency, a frequency response analyzer is used to generate a low-level sinusoidal stimulus, one frequency at a time, and measure the response of the system to the single stimulus. This must be done in the presence of noise which can far exceed the measured signals. In addition, the frequency response analyzer must compare two signals in the system, both in terms of their amplitude and phase difference. This will be discussed further in the next article in this series.

Fig. 2 shows the challenge encountered in with power supply waveforms. Fig 2a shows the output voltage of a flyback power supply, with the time base set at 20 ns per division. Multiple high frequencies can be observed in this waveform, and a spectrum analyzer would be needed to separate and measure them.

Fig 2b is set at 2μs/div, showing the switching frequency noise and harmonics. Notice that the high frequency noise dominates the waveform amplitude.

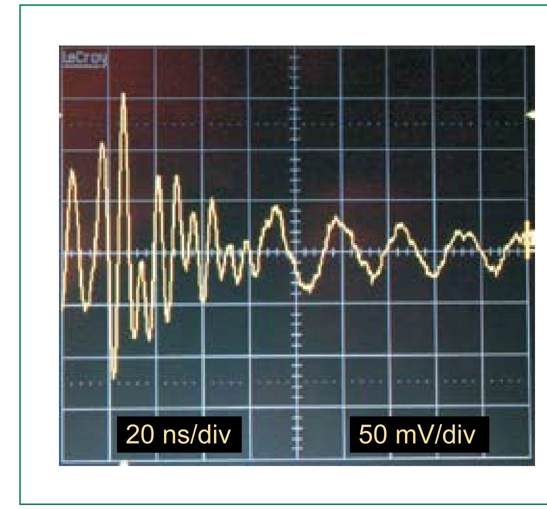


Figure 2a: Power Supply Output Noise 20ns/div.

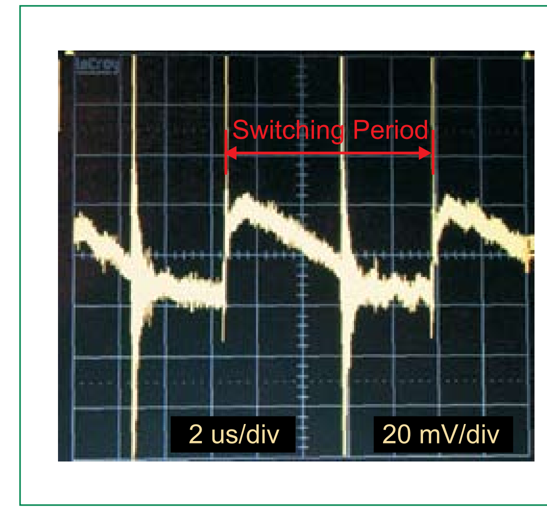


Figure 2b: Power Supply Output Noise 2μs/div.

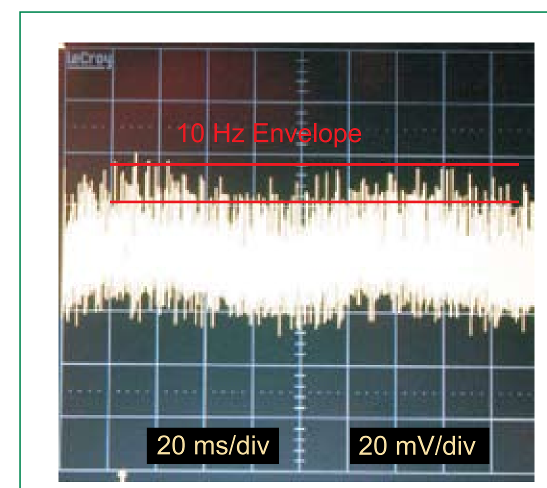


Figure 2c: Power Supply Output Noise 20ms/div.

Fig. 2c shows the same waveform at 20ms/div, a time base six decades away from Fig. 2a. A low frequency envelope can be seen in the waveform of Fig. 2c, but it is buried in the switching noise of the converter. A frequency response analyzer will be needed to measure this signal properly to obtain control amplitude and phase information.

Summary

Switching power supplies generate noise, and must respond to controls at frequencies which cover a range with 10 orders of magnitude. Controls respond from dc to half the switching frequency, and noise is generated from the switching frequency up to 100 MHz. One of the major challenges of the power supply designer is to separate the signal from the noise in order to create a rugged and stable system. In the next few articles, this column will explore further the control measurement and design issues involved in this process.

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www.ridleyengineering.com

On the Road

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

Emerson Network Power

I talked with Conor Quinn, Director of Technical Marketing at Emerson Network Power. He outlined the significant improvements in power supply efficiency along with the drivers and enablers behind these improvements. As he describes below, these advances contribute directly to a reduction in energy usage and associated equipment operating costs.

Power Supply Efficiencies

A rapidly changing landscape

The direct and indirect costs of fossil fuel usage are now a topic of great public interest. In many industries, this is resulting in a push to deliver higher-efficiency systems. For example, this issue is now directly impacting large data centers, where gains of one percent in computing efficiency can result in gains of two-to-three percent in data center efficiency through a reduction in cooling and distribution requirements. Switch mode power supplies are at the heart of many of these improvements – in many cases, power supply losses have been halved over the last few years.

Market Demand and Incentive Programs

Many of us are familiar with the Energy Star logo that is used to identify and promote energy-efficient devices and appliances. This voluntary U.S. program, in addition to similar worldwide programs, are also influencing design and purchasing decisions in the power supply industry. In some cases, these programs have driven efficiency improvements into products. In other cases, these programs are leveraging improvements driven by both industry consortia and existing market demand.

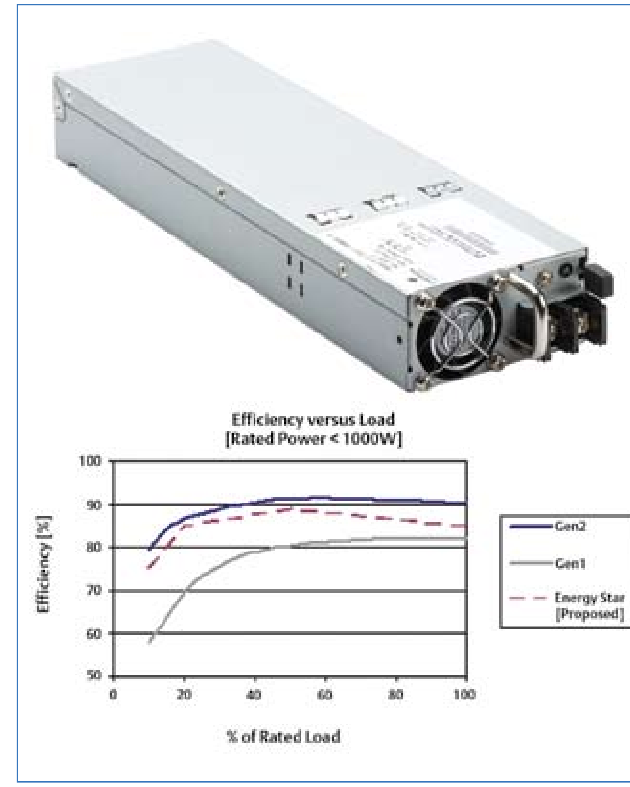
Efficiency Improvements and Reduced Power Dissipation

Consider, for example, the proposed standard for computer servers. For servers consuming less than 1000W, minimum efficiency thresholds are required for certification by consortia such as Climate Savers Certification and for approval within the Energy Star program (illustrated in Figure1). In order to keep pace with these types of requirements, power supplies from Emerson Network Power and other industry participants now incorporate the necessary technology to meet these stringent standards (reference 'Gen2' curves). Compare the Gen2 efficiency curve with the curve for an older Gen1 product, and the advances over the last few years are obvious. While an improvement of ten percentage points in efficiency (from 80 percent to 90 percent) may sound impressive, it is even more important to consider that this reduces power dissipation by 50 percent, i.e. wasted power is reduced from 20 percent of output power to ten percent.

Matching System and Power Supply Performance

The data in Figure 1 provides a closer look at the importance of matching system goals and power supply goals. A few years ago, density was the dominant driver in the power supply industry and was enabled through efficiency improvements. The limiting factor in this type of design is the power dissipation at full load. Therefore, the power supply efficiency tended to be highest at the point of highest power dissipation, i.e. full load. (Reference the 'Gen1' curve of Figure 1)

However, in many applications—including the majority of enterprise and data-center servers—the power supplies are configured in a 1+1 redundant configuration. Therefore, under normal operating conditions, each power supply is running at (or



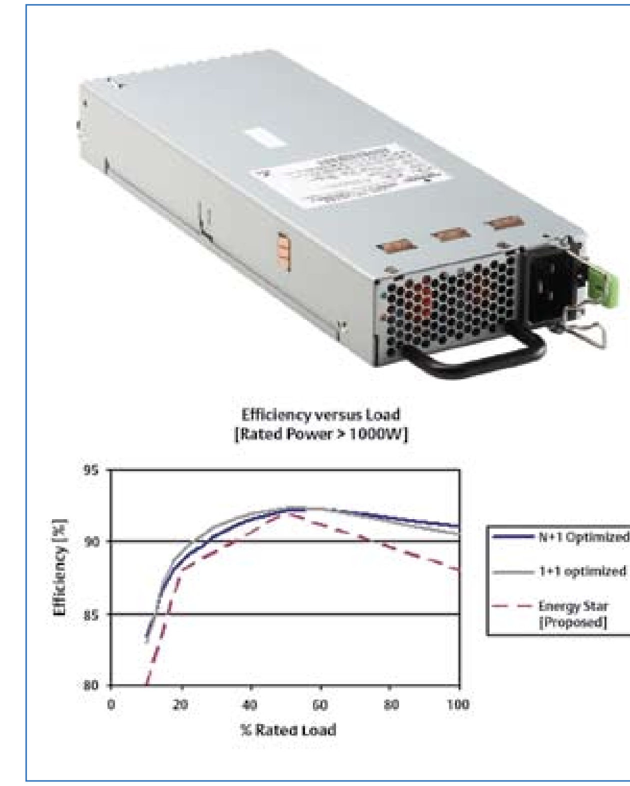


Figure 1: Minimum efficiency thresholds are required for certification.
Figure 2: Proposed Energy Star thresholds for power supplies rated >1000W.

more likely below) half-load. As the cost of energy is now the dominant driver, this dictates that the efficiency should be optimized at, or below, the half-load operating point. (Reference the 'Gen2' curve of Figure 1.)

Improvements have also been made at lighter loads. Efficiencies at or above 80 percent are now possible at 10 percent load. This is an important detail because in many data center applications, servers can idle at light loads for long periods of time. As servers may be disabled or enter standby mode rather than idling at low power in the future, the concept of virtualization may help somewhat in this regard. This also has the potential to further reduce energy costs.

Higher power systems often exhibit different characteristics. In most cases, operation at high line (208Vac or 230Vac) is the norm and further efficiency optimization is possible. This is evident in the proposed Energy Star thresholds captured in Figure 2 for power supplies rated at higher than 1000W. These thresholds are three to five percentage points higher than the sub-1000W thresholds of Figure 1.

Also, not all applications implement 1+1 redundancy and re-optimization of the efficiency curve can be beneficial. For example, Figure 2 shows an example of increased full-load efficiency at the expense of reduced light-load efficiency.

Enablers

Traditionally, efficiency improvements have been heavily dependent on the continued introduction of lower-loss power semiconductors. Topology choice can also allow better utilization of available semiconductors. As packaging becomes denser, interconnect technologies and functional integration are also key enablers that increase efficiency. For example, a bus-bar may now serve two purposes; in addition to serving as a current distribution element, it may also act as a heat spreader.

A more recently-emerged enabler is digital control. While many of the traditional techniques allow efficiency optimization at certain points on the efficiency curve, digital control offers the ability to sense and adjust the operation of the power supply so that efficiency can be dynamically optimized over the entire load range. In addition to adjusting internal and external operating parameters, these parameters can also be accurately reported to the system where they can be used for further system level optimization.

www.powerconversion.com

PMOLEDs Save Power and Cost

I talked with Dialog's CEO Jalal Bagherli. Dialog Semiconductor creates energy-efficient, highly integrated, mixed-signal ICs optimized for personal mobile and automotive applications. With its unique focus and expertise in system power management, Dialog brings decades of experience to the rapid development of integrated circuits for power and motor control, audio and display processing. He told me OLEDs will feature heavily in the next generation mobile phones.

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

Dialog won the 2008 National Microelectronics Institute (NMI) award for Innovation.

The company matched its own innovation to the needs of another idea focused on exploiting the critical market requirements in mobile displays for low power and low cost. OLED technology has for some time been viewed as the successor to LCD, bringing advantages in low power and better picture and video quality. Introducing a new innovation in Passive Matrix technology, Dialog is pushing forward with a semiconductor product innovation to enable the benefits of OLED to meet the aggressive cost requirements of the mobile phone market - an innovation that will have significant impact in one of the largest global markets.

Dialog announced earlier that its first ground breaking SmartXtend™ technology based driver ICs would be used by TDK of Japan as part of its PMOLED video display demonstration using a 3inch W-QVGA panel. The displays are targeted as a next generation solution for main displays in mobile phone and portable media consumer devices, overcoming the performance limitations of LCD and more expensive active matrix OLED displays.

Dialog is forming partnerships with PMOLED module makers such as TDK to enable a complete display solution (ie PLMOLED panel with Dialog's Display driver chip as a complete module) to be offered to end OEM customers in mobile phone, media player and infotainment markets. The majority of PMOLED makers are based in Korea and Greater China.

Jalal Bagherli, CEO Dialog Semiconductor.

The reason for securing multiple module partners is to ensure that sufficient capacity will be available when the giant Tier1 phone makers decide to use such a panel in their mainstream phones. Jalal added that the expectation is that a modest volume of around 0.5m units will start production in 2009 and that the volume would start to grow significantly into multi-million units in 2010 with continuing growth thereafter, dependent on Dialog and its panel partners delivering a complete product to market by 2H 2009.

SmartXtend™ technology allows the main displays of mobile devices – particularly those offering W-QVGA and QVGA resolution – to utilize passive matrix OLED displays rather than LCD or active matrix OLEDs. Passive matrix OLEDs are inherently a lower cost display to manufacture than other display technologies while providing superior advantages in terms of video quality, viewing angle and performance.

SmartXtend™ technology, which utilizes a number of innovative design techniques including a unique multi-line addressing scheme, accurate dynamic current matching and state-of-the-art power management, forms the basis of a new family of display drivers being developed by Dialog Semiconductor for passive matrix OLEDs. SmartXtend™ is designed to significantly extend the lifetime of passive matrix OLED displays; it reduces the peak current greater than 30% and power consumption by as much as 50% compared to the conventional passive matrix driving schemes.

Dialog's current development of a family of driver ICs with its partners is scheduled for volume production in 2H 2009.

www.dialog-semiconductor.com

Latest Generation DC-DC Power Modules

Questions that need to be asked

When evaluating DC-DC power modules for a specific application, care must be taken to fully examine the capabilities of the various options. It is vital that the designer goes through the selection process by carefully comparing a product's electrical and thermal performance, physical dimensions, and reliability specifications with the application requirements.

By Tamara Schmitz, Zaki Moussaoui, Principal Applications Engineers and Sarika Arora, Product Marketing Manager, Automotive/Industrial & Communications Group, Intersil Corporation

There are many new, higher power density options coming to market in the non-isolated point-of-load DC-DC converter space. Intersil's ISL8201M DC-DC module is one such example offering excellent efficiency and thermal performance in a compact 15x15mm QFN package. The low-profile of this package (3.5mm) enables utilization of unused space on the bottom of PC boards for high density point of load regulation. Here follows a series of important questions and answers as a guide throughout the selection process.

Why are power modules becoming more and more prevalent in power design architectures?

Many of today's telecommunication, data communication, electronic data processing and wireless network systems are powered with distributed power architectures. These complex systems require power management solutions capable of monitoring and precisely controlling the power supply. To achieve this level of performance, most designs utilize an FPGA, microprocessor, microcontroller or memory block.

This level of design sophistication has placed a heavy burden on application designers serving these communication infrastructure companies. Their choice is simple: either invest significantly to improve their in-house power management proficiency or rely on the expertise of outside design companies. Neither of these options is particularly desirable.

What are the benefits of point-of-load DC-DC power modules?

Recently, a new option has emerged: the point-of-load DC-DC power module. These modules combine most or all of the components necessary to deliver a plug-and-play solution that can replace up to 40 different components. This integration simplifies and speeds designs while reducing the power management footprint.

As the name suggests, these power modules are placed on the printed circuit board close to the circuits they power, which aids in voltage regulation. The importance of this placement increases as subsystems operate at higher currents, lower voltages and higher clock frequencies.

The key to getting the performance you need from these modules – while staying within your budget and space requirements – requires a firm grasp of the different technologies available.

Why not use an open frame or in-line DC-DC power module?

The most traditional and common of the non-isolated DC-DC power modules are still the single in-line packages (SIP); see Figure 1. These open frame solutions certainly made progress in minimizing design complexity. However, most simply employ standard packaged parts

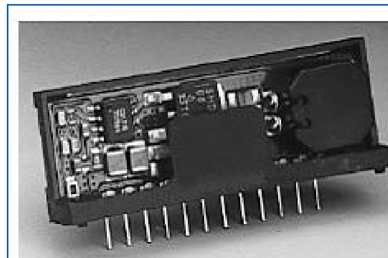


Figure1: Traditional SIP Open Frame Module.

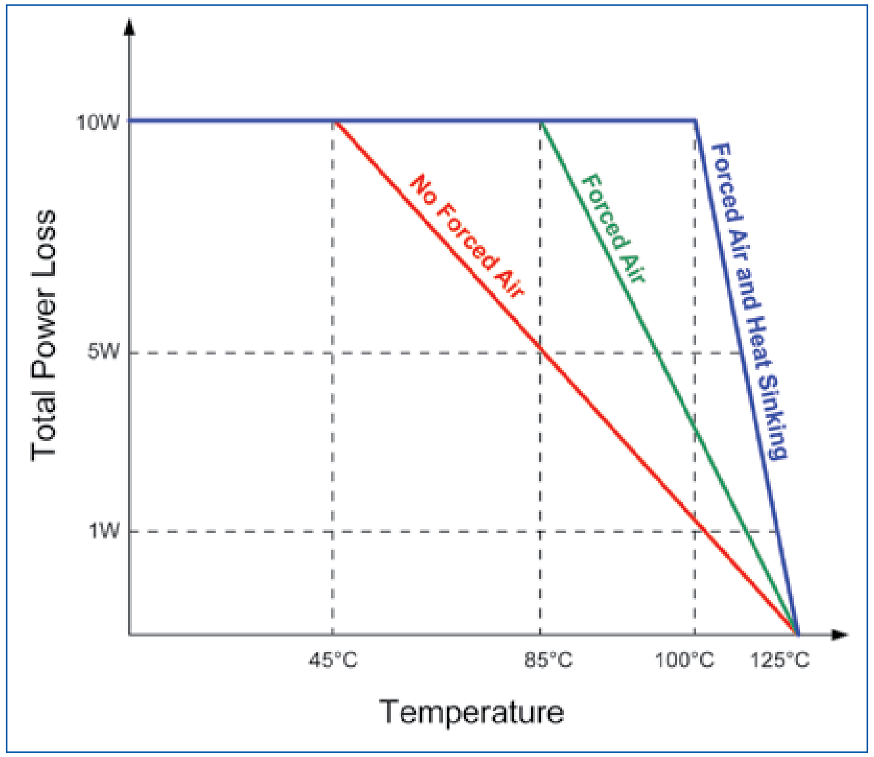


Figure 2: Typical Derating Power Loss Curve.

on a printed circuit board. They are typically lower frequency designs (around 300kHz) and their power density is not stellar. Thus, their size makes them a poor choice for many space-constrained applications. The next generation of power modules needed to make significant progress in reducing the form factor to improve design flexibility.

What type of regulator is typically used in point-of-load solutions?

Most point-of-load converters are non-isolated buck regulators. They strive for high conversion efficiency by employing synchronous rectification. Size is a central issue, while optimizing for high efficiency and thermal management.

Why is size a central issue?

These are power management devices handling sizable currents. The efficiency determines the type of thermal management necessary. Many of the larger modules require heat sinks and system fans. The inclusion of a fan adds to maintenance costs, since the fan adds grime to the system and can get gummed up itself. Reliability and repair costs are reduced if the power management system can be designed without needing that direct airflow.

What has to change in order to reduce the size of the power module?

To achieve the higher power density designers need, power management providers must push up the switching frequency to reduce the size of the energy storage elements. However, increasing the switching frequency with standard components, yields lower efficiency, predominantly due to MOSFET switching losses. This has driven the industry to find ways to cost-effectively reduce parasitic impedances in the driving and power path of the MOSFETs in a DC-DC module, producing molded modules about the size of a single integrated circuit.

How much can the use of heat sinks and forced air improve performance?

Heat-fatigue phenomenon in power modules is caused by inefficiencies in the power conversion and the limited available space to dissipate it. This can ultimately increase the rate of temperature rise and consequently reduce the life of the product. In order to minimize the effect of temperature

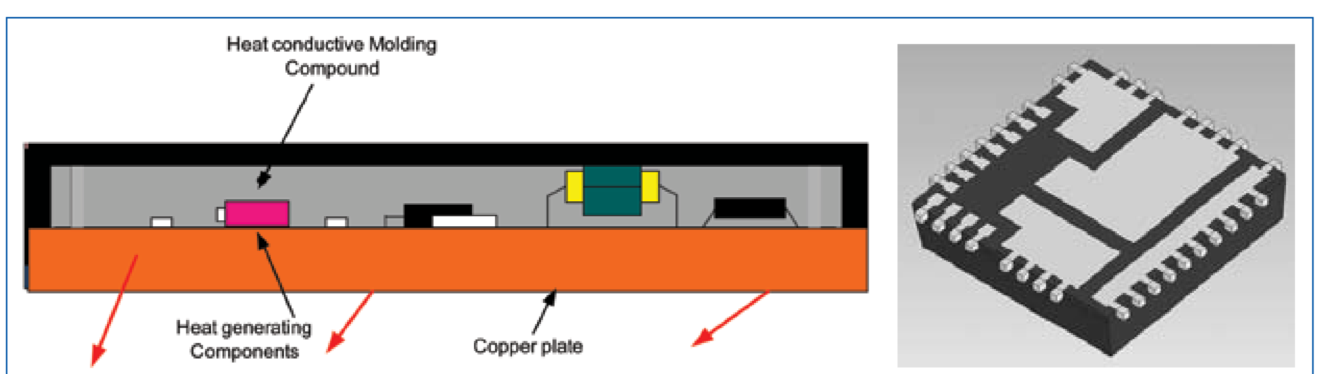


Figure 3: ISL8201M Conceptual Package Drawings.

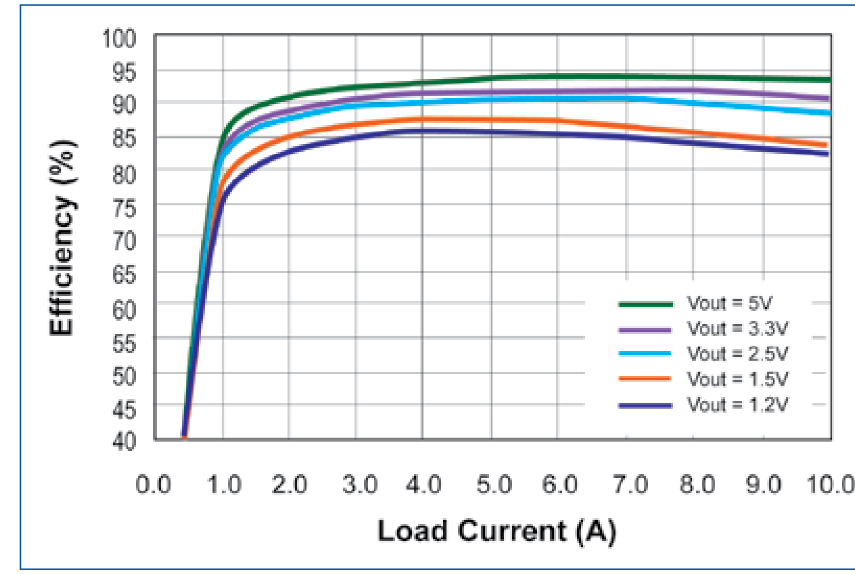


Figure 4: ISL8201M Efficiency Curves (V_{in} = 12V).

on the Mean Time Before Failure (MTBF), the system designer should take into consideration heat sinking, available airflow, and de-rating curves based upon the power losses of the module.

Why does the Total Power Loss curve in Figure 2 cover such a wide range of temperatures?

In many applications, power modules are required to operate in challenging environments. When comparing the power capability of a module, the analysis of the electrical capability should not be limited to that at 25°C , but also consider the system ambient temperature, airflow and the method of heat transfer away from the module. For example the QFN package used in the ISL820xM series from Intersil is designed to offer an optimum heat transfer through the PCB so the large copper plate under the module will improve the overall power performance.

What causes temperature runaway?

Temperature runaway is another phenomenon that causes a major failure. It is often caused by a solder joint crack. If the module is subject to mechanical vibration or several temperature cycle shocks, a crack is likely to develop in the solder joint which can eventually separate the component from the substrate. This will cause an increase in the electrical resistance, which in turn increases the temperature stress. These events may repeat until the cycle reaches wire-shear mode and results in catastrophic failures. In the ISL8201M, system designers receive an extensively qualified and tested solution for the reliability benchmarks.

Are single IC solutions available?

The ISL8201M module from Intersil integrates most of the components required for a complete DC-DC converter, including the PWM controller, MOSFETs, and inductor. Its input voltage range is 3-20V and it has 10A current capability. It achieves much higher switching frequencies than the traditional SIP DC-DC modules with good efficiency and thermal performance by eliminating the MOSFET packages and co-packing the parts in a compact 15x15x3.5mm QFN package (see Figure 3). The ISL8201M is the first in a family of modules with further size and performance improvements in development.

What efficiency can I expect from the ISL8201M DC-DC module?

The ISL8201M achieves very good performance from an efficiency perspective. Greater than 80% efficiency can be expected for load currents larger than 1.5A for a wide

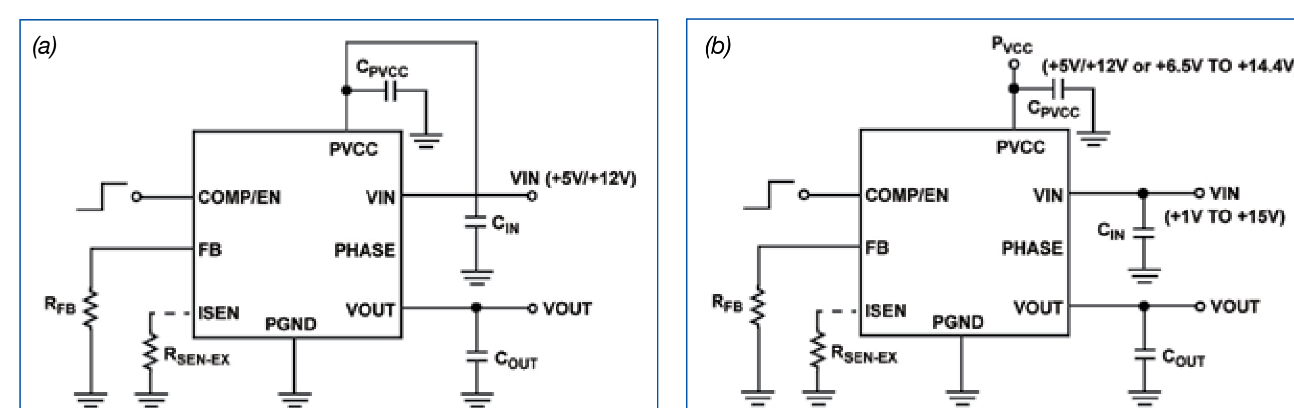


Figure 5: Typical application schematic (a) for single power supply and (b) for separated power supply.

range of voltages (1.2V to 5V), see Figure 4. The expected efficiency increases to 90% for voltages at the higher end of the range (3.3V to 5V) and for moderate load currents with voltages as low as 2.5V. One point of interest is in the top right: the ISL8201M can deliver 10A at 5V with an excess of 90% efficiency. The flatness of the curves attests to the good quality of the load regulation. Additionally, the excellent thermal performance of the QFN package allows for very compact designs that do not require a heat sink. This allows the part to achieve a power density of approximately 200W/in^3, roughly 4 times that of conventional open-frame modules.

Does the ISL8201M have a complicated application diagram?

The typical ISL8201M application schematic for input voltage +5V or +12V is shown in Figure 5. The diagram on the left shows the shared connection of the power supply pin and the input voltage. Separation of these two pins is equally acceptable and is shown on the right. External component selection is primarily determined by the maximum load current and input/output voltage.

How do I choose the input capacitance?

The input capacitance provides a low impedance input to the regulator. The size of the input filter capacitor should be based on how much ripple the supply can tolerate on the DC input line. The larger the capacitor, the less ripple expected because the device has more charge storage capability. However, consideration should be taken for the higher surge current during power-up. The ISL8201M provides the soft-start function that controls and limits the current surge. The value of the input capacitor can be calculated by this equation:

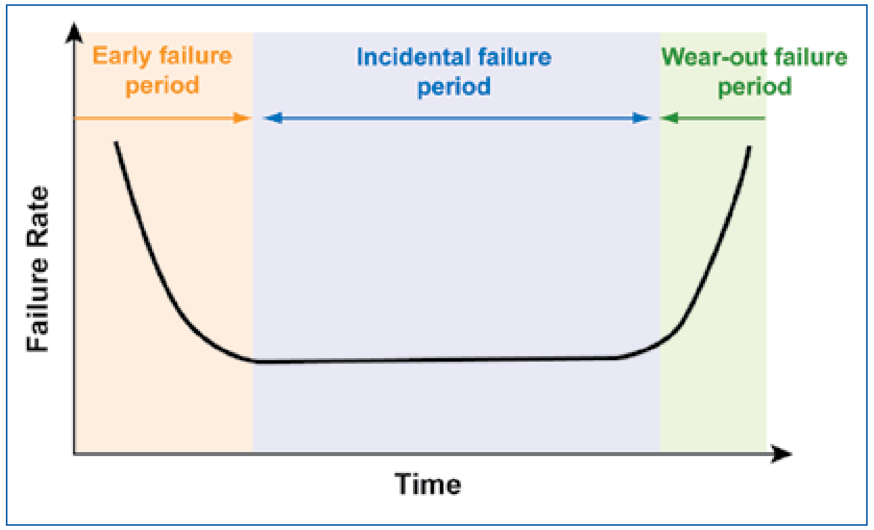


Figure 6: Life cycle Failure Rate.

$$C_{IN} = \frac{I_{IN} \times \Delta t}{\Delta V}$$

where:

C_{IN} is the input capacitance (µF)

I_{IN} is the input current (A)

Δt is the turn on time of the high-side switch (µs)

ΔV is the allowable peak-to-peak voltage (V)

In addition to the bulk capacitance, some low Equivalent Series Inductance (ESL) ceramic capacitance is recommended to decouple between the drain terminal of the high side MOSFET and the source terminal of the low side MOSFET. This is used to reduce the voltage ringing created by the switching current across parasitic circuit elements.

What are POR and OCP?

The Power-On-Reset (POR) function continually monitors the bias voltage at the PVCC pin. When power is applied, the POR circuitry delays any operation until a threshold has been exceeded (4V nominal). When this threshold is surpassed, the POR function initiates the Overcurrent Protection (OCP) sample and hold operation (while COMP/EN is ~1V). When the sampling is complete, V_{OUT} begins the soft-start ramp.

The overcurrent function protects the converter from a shorted output by using the low side MOSFET ON-resistance, $R_{DS(ON)}$, to monitor the current. A resistor (R_{SEN}) programs the overcurrent trip level. This method enhances the converter's efficiency and reduces cost by eliminating a current sensing resistor. If overcurrent is detected, the output immediately shuts off. It cycles the soft-start function in a hiccup mode (2 dummy soft-start time-outs, then one real one) to provide fault protection. If the shorted condition is not removed, this cycle will continue indefinitely.

How does the self-start feature work?

Functionally, the soft-start internally ramps the reference on the non-inverting terminal of the error amp from 0V to 0.6V in a nominal 6.8ms. The output voltage will thus follow the ramp, from zero to final value, in the same 6.8ms. The ramp is created digitally, so there will be 64 small discrete steps. There is no simple way to change this ramp rate externally.

V_{OUT}	0.6V	1.05V	1.2V	1.5V	1.8V	2.5V	3.3V	5V
R_{FB}	Open	13k	9.76k	6.49k	4.87k	3.09k	2.16k	1.33k

Table 1: Feedback resistance values for setting the output voltage.

After an initialization period, the error amplifier (COMP/EN pin) is enabled, and begins to regulate the converter's output voltage during soft-start. The oscillator's triangular waveform is compared to the ramping error amplifier voltage. This generates phase pulses of increasing width that charge the output capacitors. When the internally generated soft-start voltage exceeds the reference voltage (0.6V), the soft-start is complete and the output should be in regulation at the expected voltage. This method provides a rapid and controlled output voltage rise; there is no large inrush current charging the output capacitors.

Neither internal MOSFET will turn on until the soft-start ramp voltage exceeds the output; V_{OUT} starts seamlessly ramping from there. If the output is pre-biased to a voltage above the expected value, neither MOSFET will turn on until the end of the soft-start, at which time it will pull the output voltage down to the final value. Any resistive load connected to the output will help pull down the voltage (at the RC rate of the R of the load and the C of the output capacitance).

What should guide my decision for selecting the output capacitor?

The output capacitor aids in stable fixed-frequency operation and provides a damped output response to changes in a stepped load. The ISL8201M is designed for low output voltage ripple. The bulk output capacitor (C_{OUT}) is chosen with low enough Equivalent Series Resistance (ESR) to meet the output voltage ripple and transient requirements. C_{OUT} can be a low ESR tantalum capacitor, a low ESR polymer capacitor or a ceramic capacitor. The typical capacitance is 330µF and decoupled ceramic output capacitors are used. The internally optimized loop compensation provides sufficient stability margins for all ceramic capacitor applications. Additional output filtering may be required by the system designer, if further reduction of output ripple, high-frequency switching noise or dynamic transient spikes is required.

How do I program the output voltage?

The ISL8201M has an internal 0.6V ± 1.5% reference voltage. Programming the output voltage requires a dividing resistor (R_{FB}), see Figure 5. The output voltage can be calculated as shown:

$$V_{OUT} = 0.6\,x \left(1 + \frac{9.76k}{R_{FB}}\right)$$

Note: The ISL8201M has an integrated 9.76kΩ resistance in the module (Dividing resistor for top side). The resistance respects to different output voltage are as follows:

What is the switching frequency of the ISL8201M?

The switching frequency is a fixed 600kHz clock which is determined by an internal oscillator.

What issues affect reliability in power modules?

We have previously discussed the reliability issues associated with using a fan. Now we will discuss the reliability of the power module itself. Reliability issues are important when dealing with power modules due to the number of co-packaged parts, heat-fatigue phenomenon due to high power density and, finally, the attachment mechanism failure.

The failure rate of electrical systems and parts follows the bathtub curve shape (see Figure 6). The steepness and sharpness of transition from one state to the other in this curve depends upon the choice of the components used, the rating of those components and their compatibility with the rest of the components in the module. For example, using a 30V MOSFET in a 20V input capable DC-DC module would be acceptable as long as care was taken in the choice of the driver, the Schottky diode and the snubber circuit.

Since there seems to be a lack of standardized test conditions, what do I consider when evaluating the efficiency of a power solution?

When comparing efficiency, make sure to take into consideration input voltage, output voltage and current level at the point where the efficiency is being compared. Transient response is another parameter that needs some analysis in order to have a valid comparison. You need to make sure that the input and the output voltages are identical, the output capacitors have the same values and similar parameters (ESR, ESL, etc.) and, finally, that the transient current steps applied are of the same magnitude and rate.

DC/DC converters are the best choice for higher efficiency and lower power dissipation with the ability to supply high currents. The ability to increase the internal switching frequency has enabled manufacturers to fit a large portion of the power management circuitry on a small printed-circuit board (SIP, Figure 1) and now in a single package (ISL8201M family). With its internal soft-start, auto-recovery overcurrent protection, enable option, and pre-biased output start-up capabilities, the ISL8201M is the variable-output step-down power supply of choice in the non-isolated point-of-load DC-DC converter space.

Finally, what can designers expect from the next generation of power modules?

As with most things in the electronics industry, one can expect solutions to get smaller while integrating more functions. Intersil is now sampling the ISL8200M, which has similar or better performance characteristics to the ISL8201M, but is much more compact at just 15mm x 15mm x 2.2mm. Beyond the much lower profile, the device has integrated current sharing allowing users to parallel up to six modules, as well as remote sensing and tracking.

www.intersil.com

Solar Power

Green Lighting

Solar-based HBLED lighting solutions

In the last fifteen years, energy demand has grown ten times and the cost of energy has increased four times. Blackout and brownout conditions have occurred in United States and other countries and could continue as energy demand increases and energy generation fails to keep up.

By Raghavan Sampath, Field Application Engineer at Freescale Bangalore

According to a recent report from the North American Electric Reliability Corp., electricity demand in the U.S. alone is expected to grow by 141,000 megawatts in the next decade while only 57,000 megawatts of new resources have been identified. This leaves a shortfall of 84,000 megawatts, an amount equivalent to 160 large power plants.

LED Efficiency (Lumen/watt)

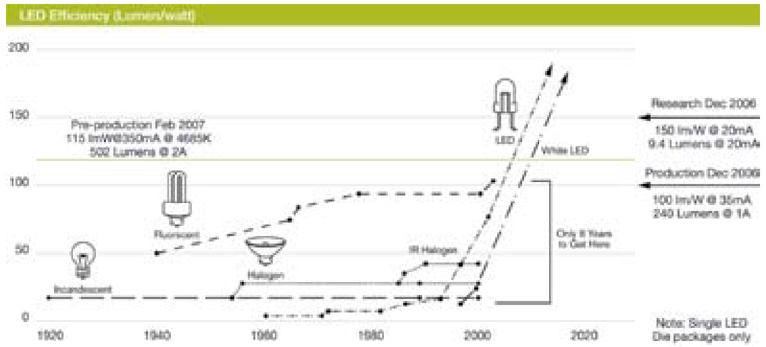


Figure 2 — Source: Philips-Lumileds, Cree, Seoul Semi

Light Source Comparative Study

Lamp Type	Homemade Kerosene	Incandescent	Compact Flourescent	WLED
Efficiency (Lumens/watt)	0.03	5–18	30–79	25–50
Rated Life (Hours)	Supply of Kerosene	1,000	6,500–15,000	50,000
Durability	Fragile and Dangerous	Very Fragile	Very Fragile	Durable
Power Consumption	0.04–0.06 liters/hour	5W	4W	1W
CCT °K	~ 1,800°	2,652°	4,200°	5,000°
CRI	~ 50	98	62	82
$ After 50,000 Hours	1251	175	75	20

Figure 1 — Source: Light up the World Foundation

Making electricity (much of it power lighting applications) creates 37% of all greenhouse gases, according to the United States Energy Information Administration. Hence, we should start looking at alternative energy resources, such as solar power, which is a green technology and does not cost as much as hydroelectric, geothermal or nuclear energy generation. In the 21st century, there are as many as 300 million homes in under-developed countries deprived of adequate lighting.

The reasons can vary, but may include affordability (the cost is too high), lack of infrastructure and supply and demand mismatches. Many remote homes still use homemade kerosene lamps or candles for lighting. These dim, yellow, smoky light sources are hazardous and are not eco-friendly. In the long run, they are more expensive light sources than bright, white, solar-powered high brightness light emitting diodes (HBLEDs).

Why HBLED for Lighting Longer life

LEDs last longer than any other light source, in excess of ten years in many applications. They contain solid state technology similar to that used in the latest microprocessors. These solid state devices have no moving parts, no fragile glass environments, no mercury, no toxic gasses and no filament. There is nothing to break, rupture, shatter, leak or contaminate. Unlike typical conventional light sources, LEDs are not subject to sudden failure or burnout. There is no point in time at which the light source ceases to function. Instead, LEDs gradually degrade in performance over time. Most LED's are predicted to deliver an average of 70 percent of initial intensity after 50,000 hours of operation. In an application where the light source would be used for 12 hours per day, 365 days per year, this could result in a system lifetime of over eleven years with only 30 percent degradation (70 percent lumen maintenance) from initial luminous output.

Reduced maintenance costs

Since LED-based light sources last up to ten times longer than a normal light source, there is no need for frequent replacement, reducing or even eliminating ongoing maintenance costs and periodic re-lamping expenses. This can be particularly important in critical, regulated lighting applications, such as buoys, beacon lights, emergency exit lighting, back up lighting and security lighting that would normally require scheduled, periodic bulb replacement.

More energy efficient

LED light sources are more efficient than incandescent and most halogen light sources. White LEDs today deliver more than 20 lumens per watt and are predicted to achieve greater than 50 lumens per watt in the future. When choosing solid state lighting as an alternative, it is important to consider the total system level benefits. For example, with superior lumens per watt performance, LEDs used in a building lighting system consume less energy per hour than competing lighting sources, making them more eco-friendly and cost-effective.

LED benefits

- Reliable (100K hours)—reduced maintenance costs
- More energy efficient—green, cost-effective solution
- Instant on and fully dimmable without color variation—pulse width modulation (PWM) control
- No mercury—conforms to environmental regulations
- Low-voltage DC operation—eliminates high-voltage connections

How Solar Powered LED Lighting Works

A solar panel converts solar energy to electric voltage, which is stored in a battery. Freescale's 8-bit HCS08QG4/8 microcontroller (MCU) with a two-channel sixteen bit timer is used for battery charging and monitoring and to drive the LED's. PWM is used for battery charging and an analog-to-digital converter (ADC) is used for monitoring the battery voltage. If that voltage falls below 50 percent of a full charge, the LED's brightness is automatically reduced to 50 percent by varying the duty cycle of the second PWM channel. The idea is to provide light for longer durations, even at lesser brightness. If the battery voltage drops to ten percent, then the MCU turns the LED off to ensure the battery is not completely drained.

Choosing the Right Microcontroller

Multiple alternatives exist in selecting an MCU for the solar powered LED application; the HCS08QG4/8 device offers an excellent combination of the features needed at a very competitive cost.

The MC9S08QG8/4 extends the advantages of Freescale's HCS08 core to low pin count, small-package options. QG devices are low voltage, with on-chip in-circuit flash memory programmable down to 1.8V. They include the standard features of all HCS08 MCUs, including wait mode and multiple stop modes, strong analog capabilities, a complete set of serial modules, a temperature sensor and robust memory options.

Applications

Solar-powered HBLED lighting can be used for street lights, home lighting, emergency lights and rural lighting. Traffic lights are operational for the entire day in most cities and street lights for much of the day. Substituting HBLED technology for the traditional halogen or compact fluorescent lamp (CFL) solutions can provide enormous savings in terms of reduced energy consumption and lower maintenance costs. The International Finance Corporation (IFC), the private sector investment arm of the World Bank Group's "Lighting the Bottom of the Pyramid" project, plans to sell solar powered LED lighting systems to 1.6 billion people around the world that are not connected to the electrical grid. Lacking access to electrical lighting, many of these people and their businesses instead rely on carbon fuels, such as kerosene, for their lighting needs. By using solar energy and LED lighting in these locations, we can reduce the health hazards and greenhouse gas emissions associated with the burning of fossil fuels.

Solar-based LED Lighting

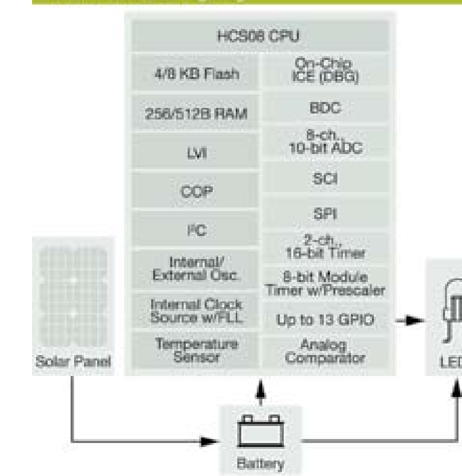


Figure 3

MC9S08QG8/4 Features

Features	S08QG
Core	HCS08
Flash	8K/4K
RAM (byte)	512/256
Bus Frequency	10 MHz
ADC	Up to 8 channels (10-bits)
Analog Comparator	Yes
Keyboard Interrupt	Up to 8-pins
Timers (up to)	One 16-bit timer (2 channels) One 8-bit timer
SCI	1
SPI	1
I²C	1
Operational Voltage	1.8—3.6V
Package	8 DIP/SOIC/QFN 16-pin DIP/TSSOP/QFN

Figure 4

A Last Note on Energy Savings

In 2006, China was the world's second largest electricity consumer, generating 2,475 billion kWh. Twelve percent of that went to lighting. By 2020, if LED efficiency reaches 150 lm/W and penetrates just 30 percent of the Chinese market, the energy savings could reach 200 B kWh per year.

Conclusion

LED lighting technology is a significant, quantifiable, energy and cost reducing lighting alternative that provides low maintenance solutions for a wide variety of lighting applications. By using significantly less electricity than more traditional lighting methods, LEDs also help the environment by cutting electric power generation and its associated greenhouse gas emissions.

www.freescale.com

GaN-Based Power Device Platform

The arrival of a new paradigm in conversion technology

As silicon MOSFETs approach performance maturity and the cost of figure of merit (FOM) improvements become increasingly uneconomical, new materials and transistor structures have emerged to deliver the next generation cost effective power conversion solutions. Advances in GaN-on-silicon based power devices, including a CMOS compatible device fabrication processes, promise to drive the commercially available figure of merit performance bar to a significantly enhanced level. Initial fabricated device results and subsequent studies predict that the FOM will be at least an order of magnitude better than current state-of-the-art silicon MOSFETs, enabling DC-DC solutions that signal a new paradigm in high frequency, high density, highly efficient cost effective power conversion.

By Michael A. Briere, Executive Scientific Consultant, ACOO Enterprises LLC, contracted to International Rectifier

Ever since the introduction of the first commercially viable power MOSFETs, trademarked HEXFETs, from International Rectifier in 1978, the power conversion landscape has not been the same. By driving rapid adoption of switched mode power supplies, displacing bipolar devices and linear power supplies, silicon based MOSFETs have taken a dominant place in the marketplace for more than 30 years. During this period, this device platform has evolved from planar HEXFETs to TrenchFETs and superjunction FETs to achieve some two orders of magnitude improvement in figures of merit (FOM) like R(on) and R(on)*Qsw to satisfactorily serve a wide variety of markets.

However, this silicon power device is now approaching maturity. As a result, cost of any further incremental enhancement is becoming uneconomical. That means, going forward, this silicon device will fail to deliver the required cost/performance ratio to efficiently power future servers, data centers, communications infrastructure, ubiquitous computing, mobile electronics and other similar next generation and emerging applications.

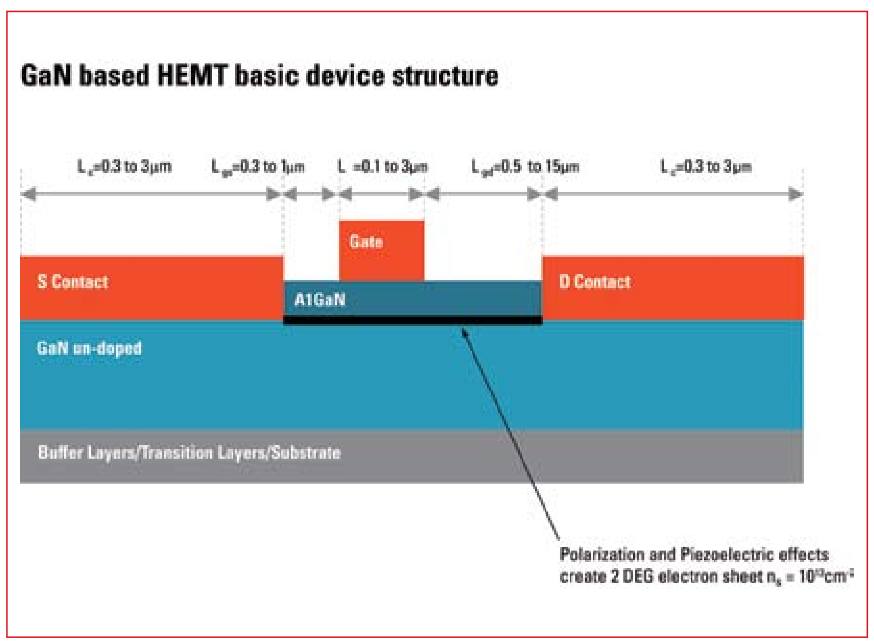


Figure 1: Cross section of a basic GaN-on-silicon high electron mobility transistor (HEMT).

Accordingly, new materials and transistor structures are needed to fill this performance gap. Although, silicon carbide (SiC) FETs have emerged to address these issues, there are a few drawbacks. Despite progress made in last 10 years, this platform suffers from significant cost premiums due to limited quality material supply, as well as the inherent cost structure of the material. In addition, SiC based technology is not highly scalable in substrate size, material supply and device fabrication platforms.

Similarly, high voltage gallium nitride (GaN) based power devices have also been in development for more than 10 years, especially in Japan. Most likely, the results of this work have been deployed internally within industrial Japanese organizations like Fuji Electric, Matsushita Electric, Oki, Toshiba and Hitachi. Meanwhile, a small US based start-up company, Velox Semiconductor, has attempted to take advantage of GaN based power device developments. Recently, it has announced a partnership with STMicroelectronics for commercialization of its GaN based Schottky diodes. While Nitronex has launched Gan-on-Si based power devices for RF applications.

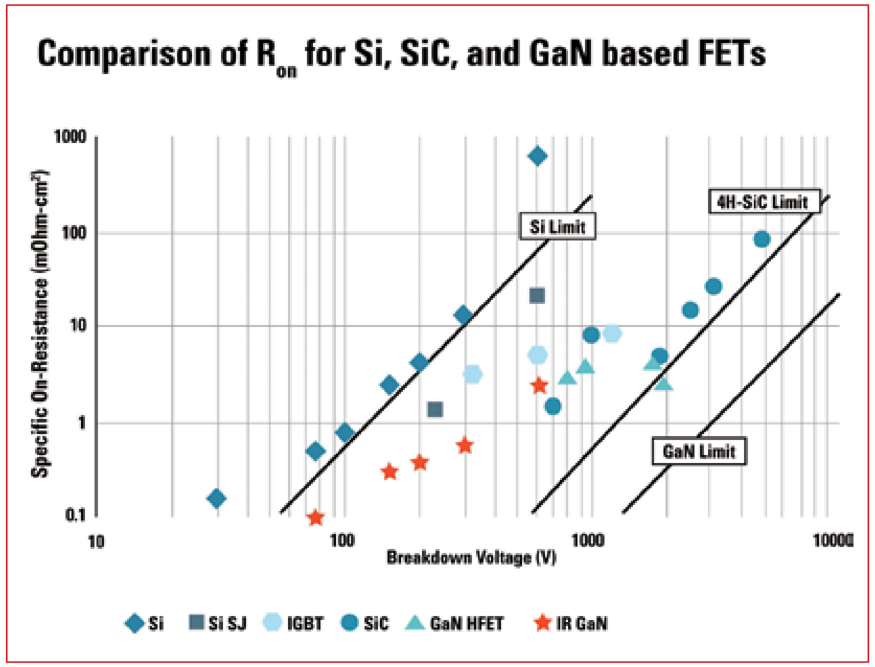


Figure 2: In the 600 - 1200V application range, GaN based power devices have the potential of improving $R_{DS(on)}$ by a factor of 100 over silicon MOSFETs.

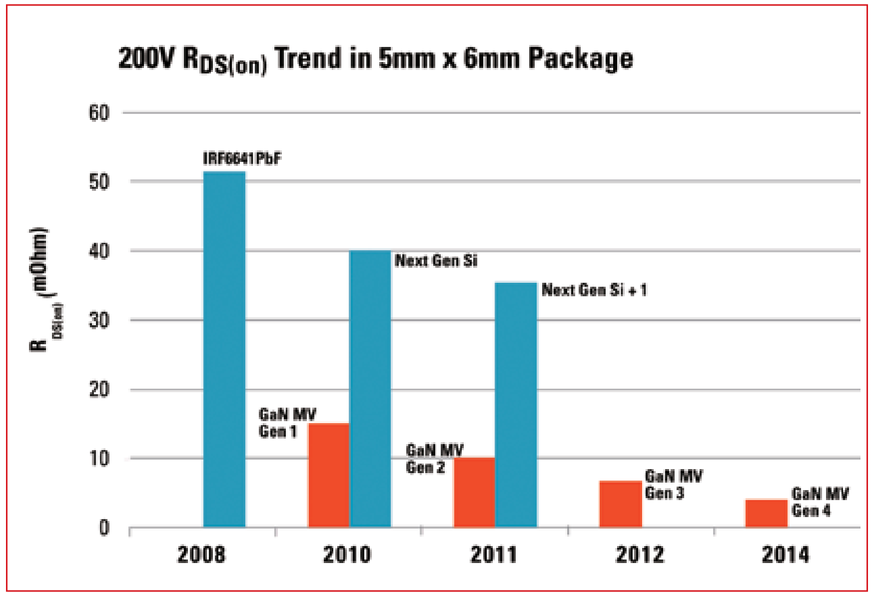


Figure 3: Device modeling and simulation shows that in next five years a 200V GaN-on-Si based HEMT in a 5 x 6mm package will offer 10x improvement in $R_{DS(on)}$ over today's state-of-the-art silicon MOSFETs.

GaN-on-Si HEMTs

Foreseeing a window of opportunity in power electronics, scientists and engineers at IR have developed a ground breaking GaN based power device technology platform that promises to deliver cost effective performance that is at least ten times better than existing silicon devices to enable dramatic reductions in energy consumption in the end applications.

In fact, over five years of device R&D, combined with 60 years of power device expertise, has resulted in a proprietary GaN-on-silicon epitaxial process and device design and fabrication technology platform. This novel platform is referred to as GaNpowIR, and it has the potential to spark a new paradigm in higher frequency, higher density, and higher

Power Conversion

efficiency power conversion solutions cost effectively.

However, accomplishing this hetero-epitaxial process has not been trivial, especially due to intrinsic mismatch in lattice constants and the thermal expansion coefficients between the substrate and the epitaxial films. Consequently, significant engineering efforts were made to resolve these problems. The result is a GaN technology platform that offers excellent epitaxial film uniformity, lower defect levels, higher device reliability and as well as a CMOS compatible device manufacturing process. This has allowed for high volume deposition of GaN based material on low cost silicon wafers costing about 100 times less than SiC wafers and offering larger diameter substrates (6-, 8- and 12-inch)..

IR's basic current GaN-on-Si based device structure is a high electron mobility transistor (HEMT), based on the presence of a two dimensional electron gas (2DEG) spontaneously formed by the intimacy of a thin layer of AlGaN on a high quality GaN surface as shown in Figure 1. It is obvious that the native nature of this device structure is a HFET with a high electron mobility channel and conducts in the absence of applied voltage (normally on). Several techniques have been developed to provide a built-in modification of the 2DEG under the gated region that permits normally off behavior.

Aside from providing high quality, reliable and a low-cost CMOS compatible device manufacturing process, the GaNpowIR technology platform also delivers dramatic improvements in three basic figures of merit (FOMs), namely specific on-resistance $R_{DS(on)}$, $R_{DS(on)}$*Qg and efficiency*density/cost.

A combination of high conduction electron density, high electron mobility and higher bandgap enables GaN to achieve significant reduction in the device specific on-resistance $R_{DS(on)}$ for a given reverse hold-off voltage. Fundamental physics shows that an improvement in $R_{DS(on)}$ by more than a factor of 10 can be achieved using GaN based power devices versus silicon MOSFETs in the 100 to 300V application range. In the 600 to 1200V application range, GaN based devices have the potential of improving $R_{DS(on)}$ by a factor of 100 over silicon MOSFETs as shown in the calculated material limit curves for (non-highly compensated) unipolar devices in Figure 2. In this figure, published measured results for FETs using the three materials, as well as

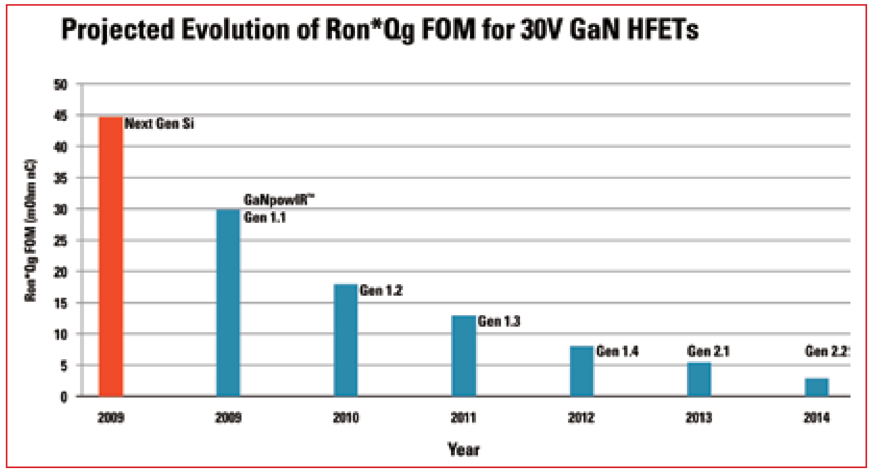


Figure 4: Continuous improvements projected for low voltage GaN based power devices promise an order of magnitude reduction in the RQ FOM within 5 years of introduction of the GaNpowIR platform in 2009.

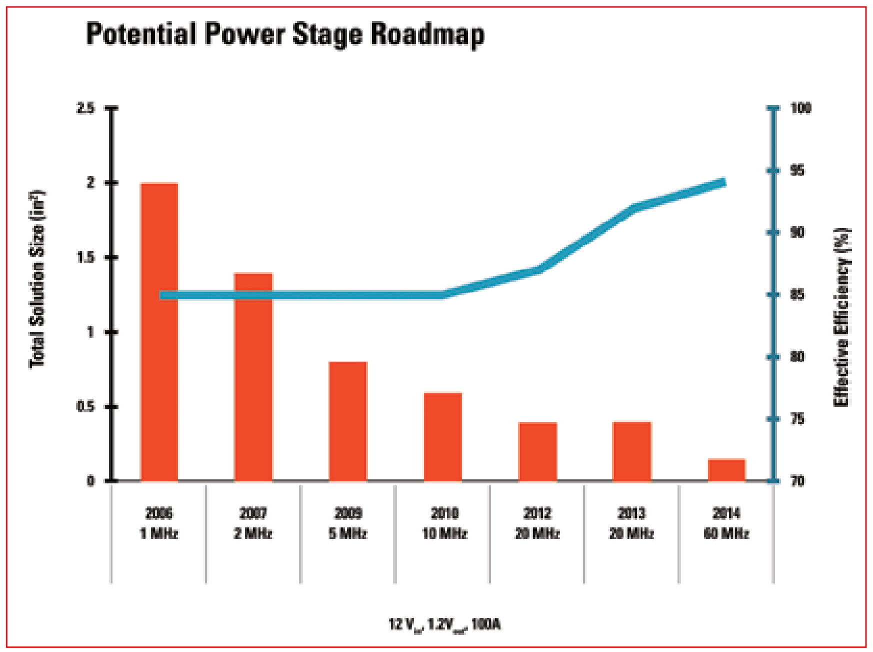


Figure 5: GaNpowIR technology platform has the potential to enable efficient power conversion to greater than 50 MHz in the near future, resulting in substantial improvement in power density of DC-DC converters without compromising power conversion efficiency.

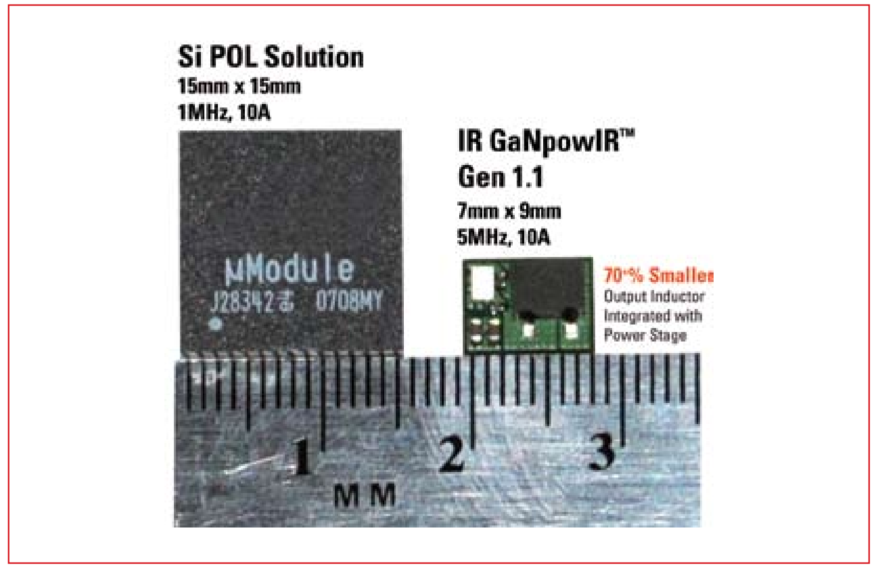


Figure 6: GaN-on-Si based 10A POL converter switches at 5MHz to deliver efficiency that is comparable to a commercially available silicon solution operating at 1MHz, but at less than one third the size.

highly compensated superjunction (SJ) and bipolar (IGBT) devices in silicon are included for reference. For comparison, results from early stage development of GaNpowIR technology based HEMTs (IR GaN) are presented in Figure 2.

Simulated results for a normally off switch function (Vt = 2.5V) based on 200V GaN-on-Si based HEMT in a 5 x 6mm package shows that with on going improvements in GaN power technology, it will achieve a 10x improvement in $R_{DS(on)}$ over today's state-of-the-art silicon MOSFETs in next five years. Figure 3 shows that by 2014, the $R_{DS(on)}$ for such a 200V switch in 5 x 6mm package will be less than 5mΩ.

Concurrently, GaN based power devices also achieve much lower gate capacitance to realize dramatic improvements in the device switching FOM $R_{DS(on)}$*Qg (RQ). Using device models based on early prototype fabricated devices, simulated results indicate that the first generation GaN-on-Si based power HEMTs are expected to represent about 33% improvement over state of the art silicon MOSFETs. Continuous improvements projected for GaN based devices promise an order of magnitude reduction in the RQ FOM within 5 years of introduction of the GaNpowIR platform in 2009 as depicted in Figure 4. As per this figure, R(on)*Qg for 30V GaNpowIR HEMTs is expected to be as low as 13 mΩ-nC by 2011 and by 2014, the R(on)*Qg for GaNpowIR is epxetced to be less than 5 mΩ-nC, an order of magnitude improvement over the state-of-the-art silicon MOSFETs available in 2009.

Correspondingly, enhancements in RQ FOM has propelled the operating frequency of converters based on the GaN-on-Si based power devices. Internal studies show that GaNpowIR technology platform is expected to enable efficient power conversion to greater than 50MHz in the near future. As a result, the size of DC-DC converters built with GaN based power devices will decrease significantly, without compromising power conversion efficiency. This impact is illustrated in Figure 5. As shown, current state of the art multi-phase silicon based solutions perform 12V to 1.2V conversion efficiently up to about 2 MHz per phase. By comparison, GaNpowIR technology platform will permit efficient power conversion to greater than 50MHz per phase. Switching at such higher frequencies will cut the external component count, as well as the undesired distance between the converter and the load to curb parasitic related power losses. The result will be an unprecedented achievement of high density, higher efficiency and lower system cost.

To demonstrate the distinct advantages of the new GaN-on-Si based power devices, several prototypes have been built. One such prototype is a low voltage point-of-load (POL) converter. Designed for a 12V input to 1.2V output at 10 A load current, this GaN based POL converter runs at 5 MHz to deliver efficiency that is comparable to a commercially available silicon solution running at 1MHz (Figure 6), but at less than one third the size. Both solutions integrate the controller/driver IC and output inductor within the power stage package.

First commercial GaN-on-Si based DC-DC converter modules are slated for release by the end of 2009. Initial products will include complete POL solutions for a broad range of input and output voltages. It is expected that in the near future, novel converter architectures and control schemes will be developed that will fully exploit the capabilities of GaN-on-Si based power devices.

Conclusions

By achieving dramatic improvements in power device FOM R(on)*Qg and power conversion application FOM efficiency*density/cost, GaN-on-Si based power technology platform promises to spark a new paradigm in high frequency, high density, highly efficient cost effective power conversion.

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Energy Efficiency

Knowledge is Power

Vendors use differing test conditions for their product specs

Eric Haber of Wolfson Microelectronics argues that a basic knowledge of systems and circuits is indispensable to correctly assess the power consumption of audio components. Consumers are looking for more and better functionality on their portable multimedia player (PMP) systems. System designers have responded by creating increasingly complex systems.

By Eric Haber, Product Architect, Wolfson Microelectronics

The challenge facing engineers is that - notwithstanding the increasing complexity of demands in terms of system performance - consumers still expect continuous improvements in battery life.

This means that power consumption is crucial to designers, and they will spend many hours scrutinising the claims made by different silicon vendors. Their task is not made any easier by the fact that there are many variables in play, and in many cases manufacturers do not provide like-for-like comparisons between products. Indeed, the area of audio input and output subsystems is especially tricky, since they include both analogue and digital circuitry, typically with several separate supply voltages.

Reading into data sheets

A closer inspection of the circuitry involved in audio subsystems helps in understanding the true meaning of power dissipation figures in manufacturers' data sheets. Figure 1 illustrates the main functional blocks involved in the creation of audio output for a portable system. Normally, the last few blocks in this chain – Digital Signal Enhancement, Digital-to-Analogue Conversion (DAC) and analogue mixing and amplification – are integrated into a single component, referred to as an "Audio DAC". Where data sheets specify "DAC power consumption", or, "DAC supply current", it's important to be sure whether or not this includes the power requirements of amplifiers and other sub-circuits associated with the DAC – if not, these need to be accounted for separately.

Likewise, quoted power consumption on data sheets for "playback to headphones" usually does not include on-chip enhancements such as limiting, 3-D signal enhancement and equalisation, all of which are frequently excluded from the power data by vendors to make their parts look better when compared with competitors. Some manufacturers even exclude the Digital Audio interface when specifying playback power consumption, which bears no resemblance to reality, as the interface must be powered up to receive audio data for playback.

Architecture choices

The fact that system architectures vary offers a further complication for designers. For instance, volume control may be affected via software on the CPU, in the digital part of the audio chip or using an analogue programmable-gain amplifier in the audio chip. As a rule of thumb, it's a good idea to identify the relevant functions for the system being designed, ascertain which physical component holds that function, and make sure that the power consumption for each function is being properly accounted for.

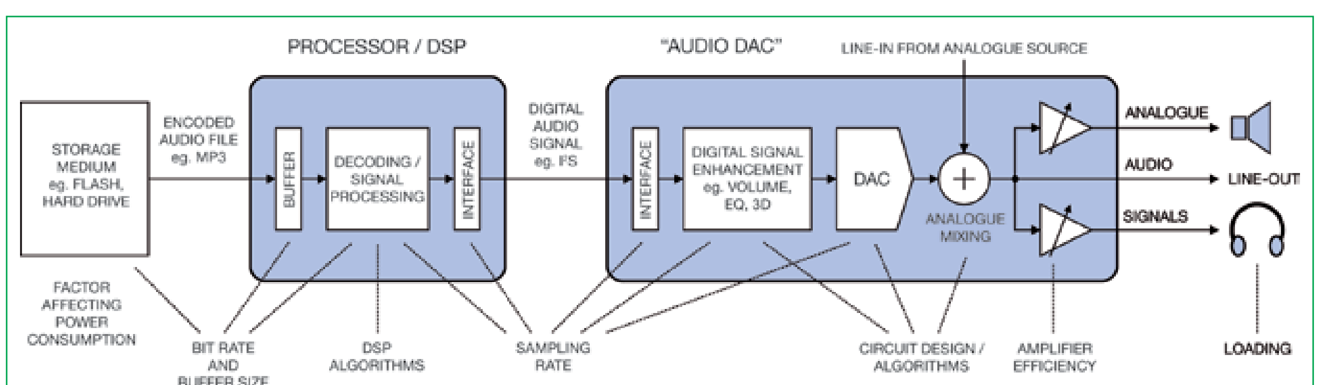

Figure 1: Example block diagram for audio playback, and factors affecting the power consumed in each block.

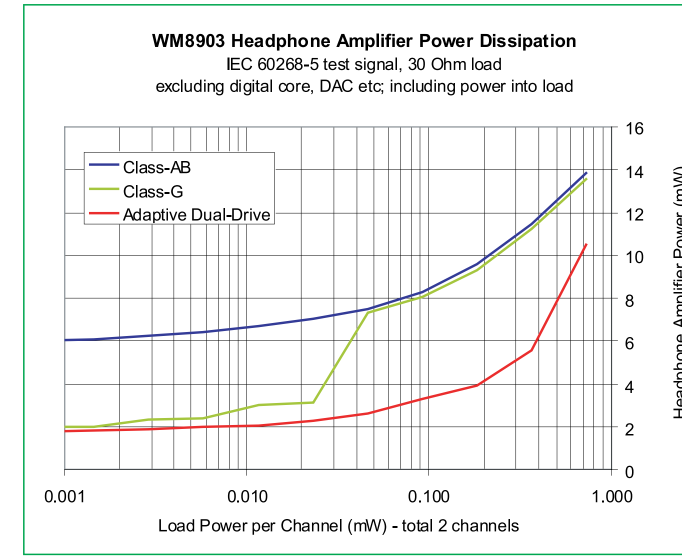

Figure 2: Efficiency of headphone amplifiers (example, using Wolfson's WM8903 audio codec).

Load and signal characteristics in the real world

There are other features of datasheets that often do not correspond to a real-world scenario. For instance, the power dissipated inside loudspeakers and headphones during playback accounts for a large percentage of overall power consumption, but these figures are not usually included in datasheets. More commonly, one will find power consumption specified in the "quiescent" (i.e. playing absolute silence) state, which is represented in the digital domain as a long series of zeros. In this state, voltage across the load is zero and no current flows through it. Whilst in a quiescent state, the audio IC itself consumes less power, which further reduces the headline power consumption – and sometimes, power consumption is even measured without connecting a load.

To get meaningful data, a load must be connected to the system. Typically in consumer electronics, its impedance is 8 Ohms for small loudspeakers and 16 or 32 Ohms for headphones. A realistic test signal must also be driven through all the relevant parts of the circuit and into the load.

Of course, the question of what constitutes a realistic test signal immediately arises. A 1kHz sine wave is easy to generate, which means that it is often used as a test signal – but this kind of signal does not reflect the mix of frequencies or the variations of amplitude over time that usually characterise music or speech. Perhaps the most useful kind of signal is provided by the IEC 60268-5 (formerly IEC 268-5) standard for loudspeakers. This standard uses so-called "pink" noise, which is a weighted mix of frequencies running right across the entire audio band. The "crest factor" – the difference between peak and long-term RMS amplitude – is well defined in "pink" noise, reflecting how real-world signals vary between louder and quieter passages.

Specifying signal amplitudes

Whatever test signal is used, its amplitude will dramatically affect power dissipation. This is yet another area where confusion can easily arise, since there are many different ways to specify signal amplitude. For example, "dBV" is relative to 1Vrms, whereas for "dBFS" the reference is "full-scale" – whatever that means for any given audio component. Decibel numbers using different references, or quoted without clearly specifying the reference, make it difficult to make meaningful comparisons. What ultimately matters is the power delivered to the load, so it makes sense to specify signal amplitude in terms of watts or milliwatts into a given load impedance.

Since the efficiency of any given amplifier varies with signal amplitude, it's worth considering the power consumption of amplifiers across the signal's entire dynamic range, as Figure Two shows. For instance, Class-G amplifiers use different supply voltages depending on the signal amplitude, and usually have a discontinuity around the switch-over points. In the example shown here, the amplifier's Class-G mode saves around two milliwatts compared to a traditional Class-AB circuit at low amplitudes, whereas for louder signals there is no saving. But a new Wolfson development, dubbed "Class-W", enables further savings compared to Class-G, and again the saving varies with amplitude, peaking at a signal level o 0.3mW into 30 Ohms. Very similar considerations apply for loudspeaker amplifiers, where Class-D technology is now considered the industry standard.

Sampling rates

Apart from amplifiers, there are other circuits in which power consumption is lower in the quiescent state than in real life. This situation also applies to analogue circuits such as mixers and programmable gain amplifiers as well as digital CMOS circuitry. In CMOS logic, power consumption is largely a function of how frequently bits toggle between the 0 and 1 states, so that a signal consisting only of zeros (i.e. quiescent) leads to an unrealistically low supply current. To deliver meaningful power data, all components should be processing a real, non-zero signal.

It's also important to consider the various sampling rates in digital audio signals. Many parts of digital and mixed-signal circuitry switch once per sample, which means that their average power consumption is directly proportional to the number of samples per second. This in turn means that when designers are comparing different audio DACs or ADCs, the supply currents for each unit should be specified at the same sampling rate. Further up the signal chain, power consumption in decoders can be affected by the encoding quality of the source audio file – in other words, the bit rate of lossy file formats such as MP3. Combined with the buffer size, this bit rate will determine how frequently data is retrieved from the storage medium. This is particularly important in the design of hard-disk based systems, where each disk access causes a large spike in battery current.

Master versus slave modes

Audio ICs such as DACs or ADCs can be configured as either master or slave devices. This is important, because in "master" mode, the audio IC will drive the digital audio interface and therefore require more current than in slave mode. It will therefore come as no surprise that power consumption is usually specified in slave mode.

Of course, this shouldn't be taken to imply that slave mode is always preferable – after all, if the audio IC isn't driving the interface, then the component on the other side has to do it, so that the power requirement is simply shifted around the system, rather than being eliminated. A further tip: even if power requirements are specified in master mode, watch out for the load capacitance specification, as this will determine how much extra current will be required. If the datasheet figures assume large, "worst-case" load capacitances, then the reality may be better than the specification given. On the other hand, vendors may also be using unrealistically low load capacitances to bring the headline power consumption figures down.

Some audio components have special clocking modes that will eliminate the need for a power-hungry low-jitter PLL (phase locked loop). Many Wolfson audio DACs and CODECs, for instance, have a "USB mode" in which audio clocks are generated directly from a 12MHz USB clock. In this case, the power saved by integrating the clocking normally far exceeds the power consumed in the audio interface.

Low voltage power supply

Apart from the most basic ICs, all of these circuits require more than one supply rail. Typically, there will be at least one analogue supply, a digital I/O supply for the audio and control interfaces and a separate digital core supply. The overall power consumption for any IC is calculated by adding together the power (voltage multiplied by current) required in each supply rail – which means that the most obvious way to save power is to use the lowest possible voltage for each supply.

In the case of Digital I/O voltage, this may be given by the other system components with which the audio IC needs to interface. On the other hand, it's possible to reduce the digital core voltage right down to its lower limit, which can normally be found under "Recommended Operating Conditions" in datasheets.

Ideally, datasheets would provide graphs of each supply current versus voltage in every possible scenario. Where such data is missing or incomplete, it's possible to make some educated guesses. For instance, current scales proportionally to voltage in CMOS logic. This means that a voltage reduction is doubly beneficial – with a 50% reduction in supply voltage resulting in a reduction of 75% in the power used on that rail. In analogue circuitry, things are somewhat more complex, since analogue circuits often contain constant-current sources. Typically, though, after halving an analogue supply voltage, the power consumed by that part of the IC (excluding any load) is somewhere between half and a quarter of its original value.

Conclusion: The real story on power consumption

Summing up, test conditions must be realistic and consistent if the performance of different IC units is going to be accurately and meaningfully compared. Factors to bear in mind include the power delivered to the load, the nature of the signal (e.g. "pink" noise), sampling rates and supply voltages. In addition, the functions being compared must reflect the desired use case: all the functions required must be enabled, and those not required must be disabled where possible. The digital interfaces of the audio ICs being compared should all run in master mode, or in slave mode, and load capacitances should be the same in each case. The master clock for each IC should also be the same: where a PLL is required to derive the audio clock, its power consumption should also be included in the calculation.

Different vendors will use differing test conditions for their audio ICs. But if a designer can be aware of the factors outlined above that most affect power consumption, then this will allow them to spot omissions and to extrapolate data from the test conditions given to the real-world scenarios for which they are designing their systems. This will give designers a clearer picture of audio IC power consumption, a picture which is often very different and far more meaningful than the "headline" specifications found on the front pages of datasheets.

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Energy Efficiency with HVDC Technology

Lighting the future of power transmission

Using HVDC Light underground cable, transmission systems are more compact, safe, and effective. They require much less maintenance, are environmentally friendly and out of sight.

By Anders Gustafsson, Marc Jeroense and Johan Karlstrand, ABB Power Systems, Raleigh, North Carolina

The global population today continues to grow, and resources are stretched. Growing populations need more land, not to mention adequate electrical, water and communication services. And these services must be provided in a way that complies with the now-compulsory environmental regulations.

For its part, the energy sector has been working hard to find safe and innovative ways of increasing power transmission in power corridors while keeping the environmental impact to a minimum.

In recent years, a couple of companies have developed breakthrough transmission capabilities that not only bring more power to the people, but do so in a safe and invisible way. Using this new high voltage direct current (HVDC) cable, transmission systems are more compact and effective, require low maintenance and are environmentally friendly.

Factbox Comparing different cable transmission systems

	HVAC XLPE Cables	HVDC Light® Cables	Overhead line
220 kV rating	200–500 MVA	100–300 MVA (150 kV)	300–800 MVA
400 kV rating	400–1,000 MVA	300–1,000 MVA (320 kV)	500–2,000 MVA
Width of affected land	1–2 m	0.5–1 m	40–60 m
MVA/m for 220–420 kV	200–500 MVA/m	200–1,000 MVA/m	7.5–33 MVA/m

Figure 1: Comparing different cable transmission systems.

The earth's resources are becoming more and more limited. Building the infrastructure to satisfy growing population demands is quickly becoming a critical issue. Whether they like it or not, energy, water and communication companies are now, more than ever, compelled to find ways of providing increased services using, in many cases, the same infrastructure in a more compact, effective and environmentally-friendly way.

The energy sector, for example, has been investigating ways of increasing power transmission in the already existing power corridors. Not only this but in the framework set by the European Commission in 2003, electrical trade between member countries must be increased. Because this is currently underdeveloped compared with other sectors of the economy, a larger number of inter-connectors must be built, either on land or at sea.

A DC transmission system improves transmission capability, has lower losses, is environmentally friendly and

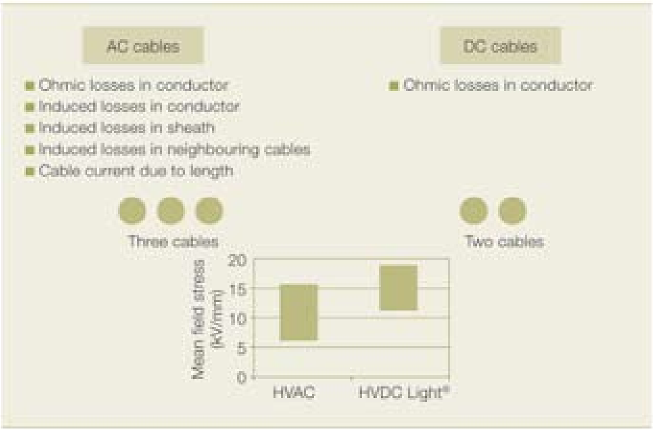

Figure 2: Comparison between HVAC and HVDC Light cables.

the transmission lengths are practically unlimited due to the elimination of capacitive currents.

In any case, to meet the demands of a growing population and tightening regulations, many service providers are faced with three very important questions:

- How can the power-per-square-meter of land usage be increased?

- How can the environmental effects with maintained or improved technology and/or reliability be reduced?

- How can the risks involved be handled?

Power transmission in the energy sector

Today, most electrical power is transmitted with conventional alternating current (AC) because it is relatively simple to transform one voltage level to another. In rural areas, overhead lines are normally used for transmission over long distances while power cables are adequate for urban areas.

Submarine AC cables are used for limited distances in seas and lakes. However, AC transmission systems have some technical limitations, such as reactive power generation/consumption and no power flow control. Compensation techniques, such as FACTS devices, are used to limit the effects of reactive power generation/consumption. Additionally, when compared with overhead lines, AC cables have higher capacitive charging currents, thereby limiting their ability to transmit power over long distances. There are also environmental concerns regarding the electrical and magnetic fields surrounding overhead lines and AC cables.

These limitations can be eliminated if direct current (DC) transmission is used. A DC transmission system improves transmission capability, has lower losses and the transmission lengths are practically unlimited due to the elimination of the capacitive currents.

Additionally, DC transmission is very environmentally friendly. However, since electrical power is generated as AC in a power station and delivered as AC to the consumers, a HVDC transmission needs AC to DC and DC to AC conversion at each end. Two main techniques, the conventional current source converter (LCC) and the voltage source converter (VSC), are used to do this.

The main advantage of 'HVDC Light' cables over their HVAC counterparts is their reduced weight and dimensions, which result in a higher power density.

HVDC Light® transmission on underground cables

The classical HVDC technique was first introduced in Sweden in 1954 by ASEA. In the 1990s, a relatively new power transmission technology called HVDC Light was developed. It is also known as "the invisible power transmission" since it is based on underground cables.

The main advantage of HVDC Light cables over their HVAC (high-voltage alternating current) counterparts is their reduced weight and dimensions, which result in a higher power density. In other words, the power that can be transported per kilogram of cable is higher for HVDC Light cables than for HVAC cables. The main reasons for this are:

- HVDC Light cables work at a higher electrical field stress, and because of this the cable insulation is thinner than that of HVAC cables.

- HVAC cable conductors must be dimensioned for skin effect losses, proximity effect losses, induced losses in screens and sheaths, and in the case of submarine cables, induced losses in armoring. HVDC Light cables have to be dimensioned only for their ohmic conductor losses.

Figure 3: HVDC Light Cables.

Special Report – Energy Efficiency

- An HVAC cable system needs three cables whereas a HVDC cable system only needs two.

Polymer HVDC Light cable systems have been developed, installed and are in service on voltage levels from 80kV to 150kV. These installed systems cover power ranges from 50MW to 350MW.

It is foreseen that the future demand for HVDC transmission and in particular HVDC cables will increase. The fact that long electrical power transmission can be built underground make these new HVDC systems very attractive. Currently, the traditional market and technical driving force behind the use of HVDC cable systems is long-distance submarine transmission, which is necessary especially if asynchronous networks need to be connected together. But the introduction of VSC and extruded polymer HVDC cables has created new market potential for HVDC Light systems.

For example, remote locations with weak networks can now be easily connected to, as can off-shore wind power and oil and gas platforms. "Undergrounding" has been identified as a strong market driver. The forces behind this include new and demanding North American and European standards, more difficult and time consuming "permission processes" for overhead lines, and increasing public opinion that solutions with higher aesthetic values are needed.

Higher Reliability

The world's first commercial HVDC Light cable system was installed in Sweden in 1999. A major wind park on the southern tip of Gotland Island was connected to the city of Visby, also located on Gotland, by an 80kV, 50MW connection. Since then, many other projects have been realized, including the Estlink project, a 150kV, 350MW link. In less than a decade, almost 1,500km of HVDC Light cables have been installed, with another 400km on the way.

On top of this, approximately 500 cable joints are now in service. This can be compared to the more than 1,700km of mass impregnated cables installed by ABB since 1953.

Figure 4: HVDC Light cable laying with minimum environmental intrusion.

Light Installation

The relatively low weight, small dimensions – which enable a reduced number of joints – and robustness of HVDC Light cables have a positive influence on installation costs, which constitute a significant part of the total investment cost. This, combined with newly developed land installation equipment, means that the cost ratios between overhead line systems and those based on HVDC polymer cables are – depending on the circuit length and conditions –comparatively low.

Nowadays, installation is aided by mechanized cable-laying machines with wheel cutters and automated backfilling devices. Existing infrastructures often have defined soil compositions and installation is easier if boulders, etc., can be avoided. In one project in Australia, HVDC Light cables were laid at a speed of one to three kilometers per day. This type of speed is possible only with HVDC Light technology and lean HVAC XLPE cable designs.

These light cables can be installed on land or at sea. Their relatively low weight and dimensions strongly influence the amount of cable that can be reeled up on one drum, or the amount that can be transported on a cable installation vessel.

Environmental effects

Besides the economical benefits of using less land for transmission systems in existing infrastructures, the environmental impact of using HVDC Light is also reduced. For example, an overhead line system routed through a forest results in a loss of CO_2 uptake because trees convert carbon dioxide from the atmosphere into carbon stored in the wood. In fact, a 400 kV line through a forest represents a loss of approximately 42 tons of CO_2 per km per year.

The earth's magnetic field originates from large convective DC currents in its interior. This natural magnetic field varies from between 30 to 60 μTesla for different latitudes on the earth's surface. The same type of magnetic field is produced by an HVDC Light cable, and is not considered unhealthy to the human body.

A DC cable will generate a magnetic field of between 5 and 10 μTesla one meter above the ground surface. This will then be superposed to the natural magnetic field of the earth, which is much the same as saying that the magnetic effect from a DC cable corresponds to traveling from the south to the north of the earth. This is not considered dangerous from a magnetic point of view.

Safety

The laying and installing of cables along roads or other infrastructures is generally easier than in the countryside. Cable positions and locations can be defined according to the systems used to route roads or railways.

National road and railway administrations normally have very good systems for doing this. In Sweden all roads have fixed coordinates in a GPS system, which means that other services like electrical and fiber cables can be positioned and logged in the same system. Hence, the risk for third-party damage is reduced.

Additionally, an HVDC Light system will reduce the short-circuit current to zero approximately 15–20 times faster than conventional AC lines and this will have a positive effect on the personal risks involved.

Conclusion

The most obvious advantage of using HVDC Light cables for electrical transmission is that cables that are laid underground make the electrical energy transport invisible. This, together with the other advantages of using DC cables, such as environmental and safety-related features as well as the ability to transfer electricity over long distances, means that a more comfortable electrical transmission system is now easier to obtain.

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Designing For Energy Saving

Single-chip quad high-side switch with minimized power dissipation

Here follows a new quad high-side switch specifically designed to minimize total power dissipation. The block diagram, main features and a typical application description are reported, together with power dissipation improvements with respect to the present technology and best in class on the market.

By Giuseppe Di Stefano and Michelangelo Marchese, STMicroelectronics, Italy

This article presents a single-chip quad high-side switch able to drive any type of load with one side connected to ground. The device, the VNI4140K, integrates on chip four low-voltage MOSFET channels (80mΩ maximum $R_{DS(on)}$ at 25°C), with protection and diagnostic systems. The device is housed in the JEDEC standard PSSO-24 lead power package. The VNI4140K uses STMicroelectronics' VIPower® technology; this is a proprietary smart-power technology that allows the integration on the same chip of both the control part and the power stage.

The VNI4140K is compliant with IEC 61131-2 (programmable logic controller international standard); nevertheless it can also be used as a smart-power solid-state relay in any other application with 36V maximum operating voltage.

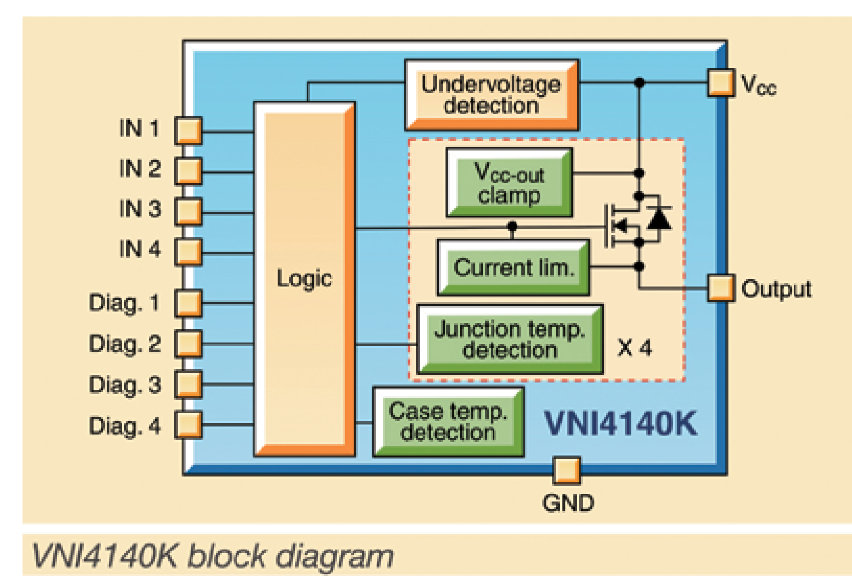

Figure1: VNI4140K block diagram.

Technical Description at Block Level General

It can be seen from the block diagram in Figure 1 that each channel is fully protected. Junction over-temperature protection (thermally independent for each channel), current limitation (typically 1A), and an inductive clamp (typically –45V) are built on silicon. As a result, each channel is self protected against load short-circuit and overload, and is able to manage inductive loads up to 2H. In addition, undervoltage and loss-of-ground protection are added at chip level. The case over-temperature protection implements a double thermal protection integrated on chip, to avoid high temperature on the PCB where the part is assembled. The input blocks of the device are TTL/CMOS compatible, they are designed to minimize input switching times, and to allow the direct connection of an opto-coupler with a dark current of 10μA maximum.

Figure 1 shows the basic protection blocks which equip each output channel of the VNI4140K. The current limitation is a must for each high-side switch used in industrial automation, because it is required by IEC 61131 (programmable controllers international standard). The junction shut-down temperature for each channel has a minimum value of 150°C; it protects the channel against a generic overload. The clamping chain at –45V performs the demagnetization of inductive loads.

The status pins are able to directly drive a light emitting diode (LED). All pins are ESD protected according to the human body model up to 2kV.

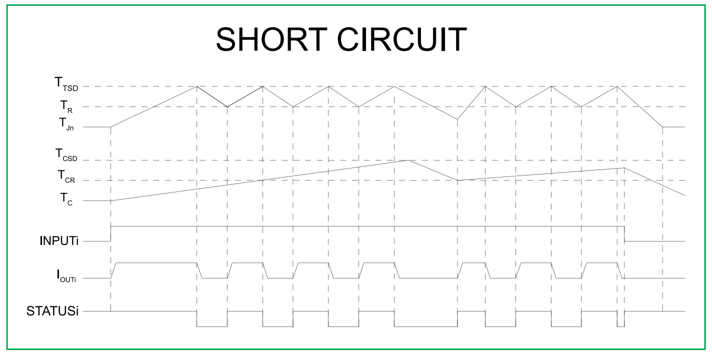

Figure2: VNI4140K waveforms in short circuit.

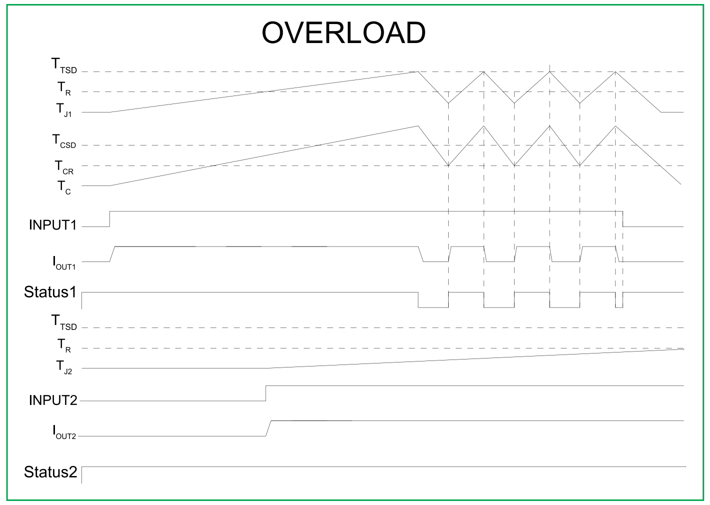

Figure3: VNI4140K overload condition.

Case Temperature Detection and Protection

As already mentioned, the VNI4140K device has a double thermal protection integrated. Together with the junction temperature detection (T_{TSD}) and protection included on each channel, the device also integrates case temperature detection (T_{CSD}) and protection, related to the whole device dissipation. This additional protection avoids PCB degradation in the case of a large number of channels in overload conditions, which would lead to a rapid increase in case temperature.

In overload condition, in fact, a channel turns off and back on automatically, so maintaining the channel junction temperature between T_{TSD} (junction thermal shut-down temperature) and T_R (junction reset temperature). This overload condition increases the case temperature. When the case temperature reaches T_{CSD} (case thermal shut-down temperature) and the junction temperature reaches T_{TSD}, the overload channel is turned off and restarts again only when the case temperature has decreased down to T_{CR} (case reset temperature). What is important to highlight is that the T_{CSD} acts only on the overload channel; non-overloaded channels continue to operate normally. Over-temperature waveforms during short circuit and overload are shown in Figures 2 and 3.

Application Description General

A typical application circuit of the device is shown in Figure 4; it represents the output stage of a programmable logic controller designed for industrial automation or process control. In order to protect the device in high-side configuration from the harsh industrial conditions of power supply lines, opto-coupler diodes are usually used to separate the application control circuits from the power supply, both on the inputs and the status pins.

A Transil diode protects the high-side switch (HSS) against both positive and negative surge pulses to make the device compliant with IEC 61000-4-5.

An electrolytic capacitor must be placed on the bus line (Vcc) in order to filter the bus inductance effect, so stabilizing the supply voltage and avoiding undervoltage shut-down. The size of the electrolytic capacitor is selected based on the slope of the output current, the impedance of the complex power supply cables, as well as the maximum allowed voltage drop across the device. A low ESR capacitor is suggested, as close as possible to the device, in order to filter the power supply line for electromagnetic compatibility concerns.

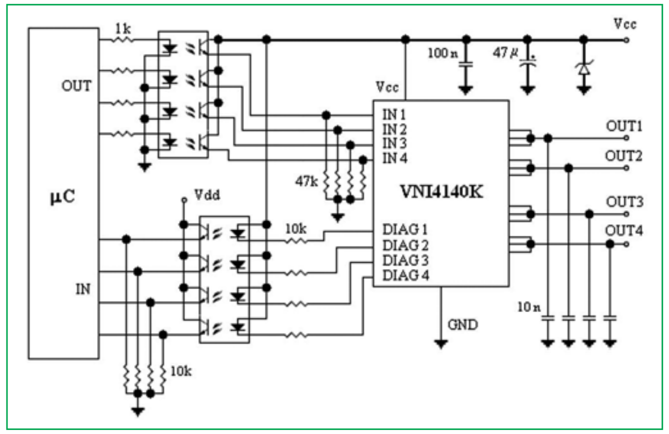

Figure4: VNI4140K typical application circuit.

To comply with IEC 61000-4-6 (current injection test), a 10 nF capacitor is added to the output pins.

Reference Board

Based on the typical application described in 3.1 (PLC - programmable logic controllers), a reference board has been developed to test the device functionalities inside an industrial environment, while driving loads such as lamps, valves, or relays. This tool also allows the evaluation of device embedded self-protections, power handling capabilities, operation and diagnostic feedback, thermal behavior and conformity to inherent IEC standards. The board is shown in Figure 6.

Figure5: PSSO24 power package.

Figure6: VNI4140K reference demo board.

Driving Inductive Loads

The toughest loads to be driven in factory automation/process control are inductive ones; it is common to drive a 1.15 Henry nominal load, and loads up to 2 Henry. The associated energy to manage such inductive loads during demagnetization is considerable, involving sensitive power dissipation and a very high junction temperature: the VNI4140K was specifically designed to drive properly such big loads limiting the temperature increase.

Power Dissipation

Energy saving was the main issue of the VNI4140K design. By using the latest generation of VIPower® technology, total power dissipation and maximum junction temperature of the power stage have been decreased considerably. We can separate total power losses into:

1) Conduction losses
2) Switching losses

Conduction Losses

During the conduction phase, losses are due to the supply current (Is) and to the power channels. Concerning Is, looking at the VNI4140K datasheet, we note that this parameter (in on state) has a maximum guaranteed value of 4mA (all four channels on). Hence supply current losses are:

$$P_{IS} = V_{CC} \cdot I_S = 24V \cdot 4mA = 96mW \quad (1)$$

Losses in the power MOSFET are calculated considering the worst case of $R_{DS(on)}$ at 150°C junction temperature, nominal output current of 0.5A and 0.5Hz switching frequency (for 4 channels). A typical value of $R_{DS(on)}$ at 150°C is 160mΩ. Hence power MOSFET losses are:

$$P_{MOS} = R_{dS(on)} \cdot (I_{OUT})^2 \cdot f \cdot 4 = 160m\Omega \cdot (0.5^2) \cdot 0.5HZ \cdot 4 = 80mW \quad (2)$$

Switching Losses

During the switching phase, losses (the 4 channels turning off the inductive loads at the same time) are due to inductance discharges (1.15 Henry):

$$E_{Off} = \frac{V_{Clamp}}{R_{Load}} \cdot \left[\frac{L \cdot V_{CC}}{R_{Load}} - \left(V_{Clamp} - V_{CC}\right) \cdot t_{off} \right] = 149.5mJ$$

$$P_{off} = E_{off} \cdot f \cdot 4 = 149.5mJ \cdot 0.5 \cdot 4 = 299mW \quad (3)$$

So that total losses are:

$$P = P_{IS} + P_{MOS} + P_{off} = 0.475W \quad (4)$$

Comparing total losses before calculating them with an actual quad of the preceding VIPower® technology generation and with the equivalent competitive devices, we get an outstanding energy saving due to reduced power losses. With respect to the preceding VIPower® generation total power dissipation is decreased by 42.5%; while comparing with best-in-class equivalent devices of the competition, total power dissipation is decreased in the range of 10%. Reduced total power losses, together with optimal values set for output current limitation, make the VNI4140K the unrivalled solution for protection classification (DIN EN 60529) IP65 (or greater) sockets.

Conclusion

A smart monolithic quad high-side switch specifically intended for industrial applications has been developed. The device includes features to protect the device and limit junction and case temperature levels. The typical application circuit has been analyzed, suggesting external components to add to be compliant with the fundamental IEC rules. Analysis of the energy saving benefits of the device shows its outstanding behavior with respect to the preceding intelligent power-switch generation and similar best-in-class devices on the market.

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Special Report – Energy Efficiency

PSDNA Green Power ENERGY EFFICIENCY

Designing for Energy Efficiency at the Component Level

Tools to understand inductor losses in DC-DC converters

To design for high energy efficiency, the power converter designer must have a comprehensive understanding of energy flow. Articles about new system level and converter level improvements are seemingly published every day. These articles describe developments in digital power control, new power management units, and lower loss switching devices, yet it is also crucial for the designer to understand power efficiency at the component level. If the selection of passive components is not understood and optimized, the benefits from the other improvements may be reduced or even entirely offset.

By Len Crane, Director - Technical Marketing, Coilcraft, Cary, Illinois, USA

One of the most important components in the dc-dc converter power path is the inductor. When choosing an inductor for the best efficiency it is important to have tools to present a clear picture of both core and winding loss mechanisms.

Inductor Losses

The specifications typically listed on the inductor data sheet are the inductance, the saturation current and the DCR. Clearly the DCR is the most important and most direct measure of how power will be dissipated in the inductor by power loss $P_L = I^2 \times$ DCR. Using the DCR this way it is straightforward to determine how the inductor affects the overall efficiency of the converter. If efficiency were the only parameter of concern the selection procedure would be simply to choose an inductor with a low DCR that achieves the desired I^2R loss. However, choosing low DCR for efficiency gain normally involves a compromise between efficiency, saturation current, cost, and physical size.

Consider the tradeoff between physical size and DCR. This can be relatively straightforward, with lower DCR usually requiring a larger part. On the other hand, premium core materials may be used that allow lower turn count and therefore, lower DCR. Choice of a premium material may dictate a premium price.

Another possible tradeoff is to lower the DCR and keep the same physical size inductor at the expense of a lower saturation current rating. A small amount of inductor saturation can be tolerated in the operation of many converters; however, this can lead to unforeseen consequences. By the basic nature of inductor operation V= L (di/dt), if an inductor is driven into saturation so that the effective inductance is lowered, the slope of the current (di/dt) increases, causing higher ripple current, and in turn, causing higher conduction losses.

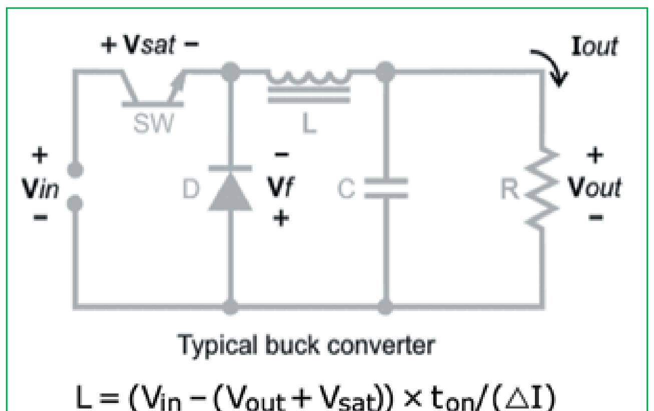


Figure 1: Typical Buck Converter Inductance Calculation.

Part number	Mounting	Other *	L (µH)	DCR (Ohms)	I sat (A)	I rms (A)	L (mm)	W (mm)	H (mm)	Price @ 1,000
MLC1555-302	SM	S	3.0	0.0041	14.0	12.2	13.80	13.20	5.60	$1.07
SER1052-322	SM	S	3.2	0.0060	8.5	15.0	10.60	10.60	5.20	$1.01
MSS1048-332	SM	S	3.3	0.0104	7.6	7.22	10.50	10.30	5.10	$0.44
MSS1260T-332	SM	S	3.3	0.0126	13.12	7.0	12.30	12.30	6.20	$0.68

Figure 2: Inductor choices.

	Coilcraft Part Number	I^2R Dissipation	% Power
Inductor 1	MLC1555-302	0.10	0.6
Inductor 2	SER1052-322	0.15	0.9
Inductor 3	MSS1048-332	00.26	1.6
Inductor 4	MSS1260T-332	.32	1.9

The losses caused by higher peak-peak ripple current are generally due to frequency dependent, ac loss mechanisms, not the DCR. There are several ac loss mechanisms to be considered, including both winding loss and core loss. The winding loss can include proximity effects as well as skin effect, with skin effect generally being the bigger concern, and certainly the easier to predict. Skin effect can be predicted based on the wire size and switching frequency. Proximity effect is dependent on winding configuration and is much more difficult to model. Fortunately skin effect serves well as a predictor of ac winding loss in a wide variety of applications.

Magnetic losses outside the core can include eddy current loss in the region of the air gap when fringing flux intersects the windings or other nearby conductors. However most magnetic loss is usually captured by what is generally referred to as the Steinmetz equation: Core Loss $= k \times B^x \times f^y$, where k, x, and y are characteristics of the specific core material. The result of this equation is the loss generically described as "core loss". It is important to note that the Steinmetz coefficients are empirically derived by ferrite and iron powder core suppliers based on sine wave measurements and therefore do not represent an exact model for core performance in dc-dc converters. There have been models proposed to refine the calculation for different wave shapes, yet this model remains a valuable tool, is an excellent predictor of core loss in the majority of practical applications, and the coefficients in this form are available for a wide range of core materials.

Given the number of parameters to be considered and their interdependent nature, it is infeasible to conceive that one calculation can determine the optimal inductor. The best tool for selecting the right component is one that allows the user to easily view and compare the options.

Example 1 – Point-of-Load Buck Converter

As an example, assume the following 16.5 Watt buck converter design requirement.

V_{in} = 6 - 16Vdc
I_{out} = 5A
V_{out} = 3.3Vdc
F = 500kHz

The first step is to calculate the inductor value based on the pertinent variation of V= L (di/dt), as shown in Figure 1.

Step 1,2,3 Enter the operating conditions *(all fields required)*

Frequency	IL rms max	ΔIL peak-peak
500 kHz	5.00 Amps	2.00 Amps

Calculate

Results *(estimated)*

	Inductor 1	Inductor 2	Inductor 3	Inductor 4
	MLC1555-302	SER1052-322	MSS1048-332	MSS1260T-332
	$1.07 each at 1,000 qty.	$1.01 each at 1,000 qty.	$0.44 each at 1,000 qty.	$0.68 each at 1,000 qty.
Total inductor loss	317 mW	170 mW	467 mW	475 mW
Inductor core loss	216 mW	20 mW	206 mW	124 mW
DCR loss	102 mW	150 mW	260 mW	350 mW
AC winding loss	0 mW	0 mW	0 mW	1 mW
Temperature rise	9 °C	5 °C	34 °C	28 °C

Figure 3: Output from Coilcraft Inductor Core and Winding Loss Calculator.

The voltages in this equation are fixed by the design requirement and the ton is determined once a switching frequency is chosen. The only degree of freedom and typically the only choice the designer must make in this calculation is how much ripple current to allow. This decision will be based on the desired ripple voltage and the type of output filter capacitor, but will affect the inductor in a couple ways. First, the peak current determines the saturation rating of the inductor and the peak-peak ripple has a direct effect on the ac inductor loss. For the example, we choose to allow the peak-peak ripple current to be 40% of the output current in the inductance calculation, and solve for the worst case V-T combination at $V_{in(min)}$ and $t_{on(max)}$:

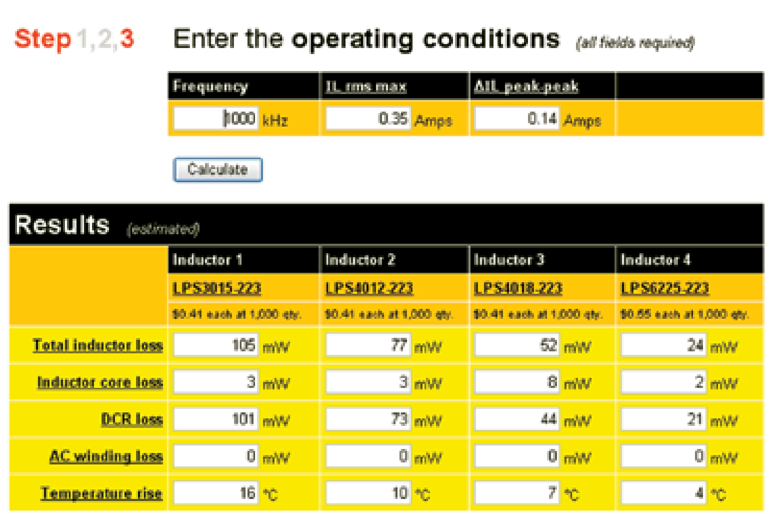
$$L = (V_{in} - (V_{out} + V_{sat})) \times t_{on}/(\Delta I)$$
$$L = (16V - (3.3V + 0.7Vv))\ 0.5 \times 10^{-6}/(2A) = 3 \times 10^{-6}\ H$$
$$L = 3\mu H$$

The average current is the same 5A as the load current and the peak of the ripple current is 6 A (the load current plus one half the peak-peak ripple). Searching the Coilcraft Power Inductor Finder, shown in Figure 2, results in choices with DCR ranging from 4.1mΩ to 12.6mΩ.

Using the 5 A load current and the DCR values it is easy to calculate the power dissipated in each inductor choice.

The winning component seems quite clear if the choice is to be made strictly on the basis of DCR loss, but this does not consider the ac losses, which can be analyzed by the Coilcraft Core and Winding Loss Calculator. This tool uses the average current to calculate the DCR loss as above, but also uses the frequency and the ripple current to calculate the frequency dependent core loss and winding loss due to skin effect.

New information is provided by these results in Figure 3. While Inductors 3 and 4 with the highest DCR still have the highest power loss, the lowest DCR part, inductor 1, is no longer the most efficient. What was not apparent from just looking at the DCR is that inductor 2 has a superior, low loss core compared to inductor 1. While inductor 1 would have been chosen based on DCR it would not be the lowest loss, most efficient choice. The addition of the ac loss information helps indicate the best inductor choice for highest efficiency.



	Inductor 1	Inductor 2	Inductor 3	Inductor 4
	LPS3015-223	LPS4012-223	LPS4018-223	LPS6225-223
	$0.41 each at 1,000 qty.	$0.41 each at 1,000 qty.	$0.41 each at 1,000 qty.	$0.55 each at 1,000 qty.
Total inductor loss	105 mW	77 mW	52 mW	24 mW
Inductor core loss	3 mW	3 mW	8 mW	2 mW
DCR loss	101 mW	73 mW	44 mW	21 mW
AC winding loss	0 mW	0 mW	0 mW	0 mW
Temperature rise	16 °C	10 °C	7 °C	4 °C

Figure 4: Core and winding loss for LED driver inductor.

	Coilcraft Part Number	DCR	Size (mm)
Inductor 1	LPS3015-223	830 mΩ	3 × 3 × 1.5
Inductor 2	LPS4012-223	600 mΩ	4 × 4 × 1.2
Inductor 3	LPS4018-223	360 mΩ	4 × 4 × 1.8
Inductor 4	LPS6225-223	175 mΩ	6.2 × 6.2 × 2.5

Example 2 – White LED Driver

Assume another buck regulator, this time to drive a single white LED with a 350mA drive current and a forward voltage of 3.4Volts. Assuming a switching frequency of 1MHz we calculate a standard value of 22µH to achieve a 40% ripple current and a range of inductor choices.

The Coilcraft Core and Winding Loss Calculator results are shown in Figure 4. In this case the core loss follows the DCR and size of the part as expected. It is left to the user to judge the size versus performance tradeoff best for the application.

These examples demonstrate that the consideration of frequency dependent core and winding loss information are necessary to make the correct inductor choice, which can be done with on-line tools available today. With such a side-by-side comparison, the user can select the most efficient power inductor and can easily make rapid comparisons of the benefits of various choices. The user can easily compare the cost and size as well as the performance.

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The Age of the 100% Efficient Power Supply

PFC design for energy efficiency

In the mid 1980s the power supply industry embarked on a fundamental transformation that has changed the way in which off-line power supplies are designed and manufactured today. Without fully knowing the follow-on impact, power supply designers have introduced power factor correction (PFC) to off-line, switch-mode power conversion. The newly developed PFC front-ends have changed the input characteristics of the power supply from a highly non-linear peak rectification to emulating resistive input impedance. The importance of this transformation – how the power supply looks at its input from the source – has had a remarkable effect on the utilization and efficiency of the power grid.

By Laszlo Balogh, Technical Fellow, Fairchild Semiconductor, South Portland, Maine, USA

The ever increasing number of electronic gadgets constantly plugged into the wall at home and in the workplace creates an unprecedented demand for electricity. More importantly, our modern marvels have changed the characteristics of the load powered from the 120V or 230V AC network. While incandescent light bulbs and older electronic equipment looked more like a resistive load, the new devices like computers, standby power sources for all remote controlled apparatus, battery chargers – so many of them are invisible parts of our everyday life – present a huge problem for the utility companies. These new devices employ switch-mode power converters for their small size compared to more conventional techniques. Their input stage is a peak rectifier circuit converting the AC source to a DC voltage and providing energy storage. Peak rectifiers draw current only around the peak of the AC line voltage.

The results are low conduction angle of the input current and large magnitude of harmonic components at the odd multiples of the line frequency. A power factor (PF) of 0.5 to 0.7 is typical for off-line power supplies utilizing peak rectification. The power factor is an important indicator of the efficient use of the input power source. By definition power factor is the ratio of the real power delivered and used by the load (in Watts) and the apparent power needed to be generated at the power plant (in VA units) to supply the load.

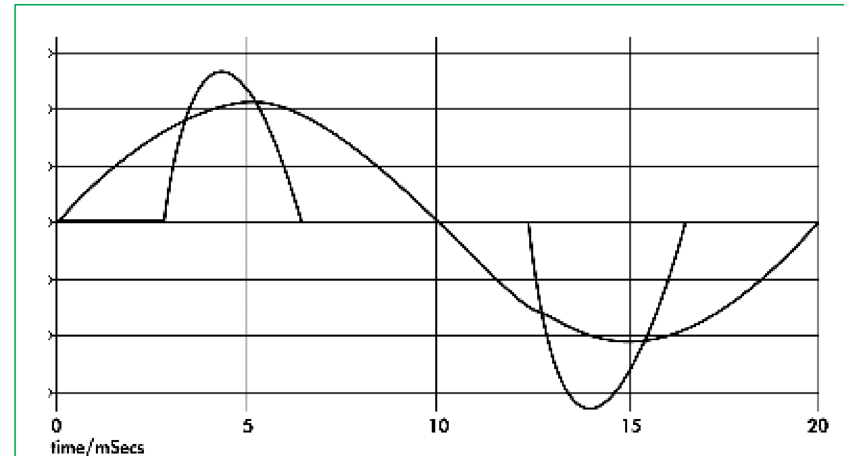

Figure 1: Typical line voltage and current waveforms using peak rectifier input.

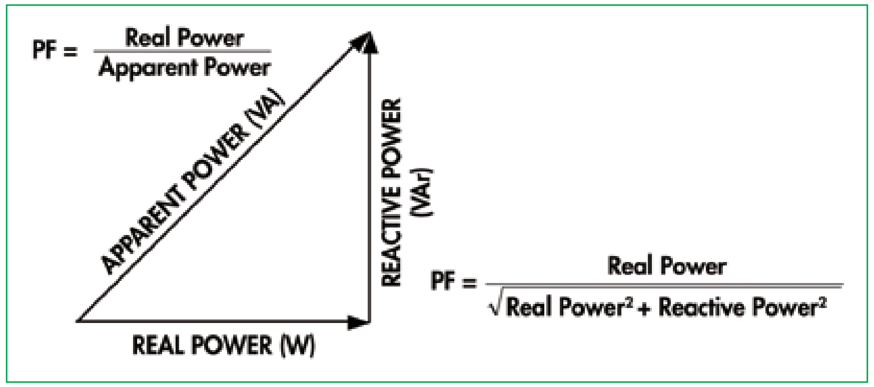

Figure 2: Relationship of Real, Reactive and Apparent power.

A power factor of 0.7 implies that in order to use 100W of real power by the load an additional 100VAR of reactive power must be provided by the generator. The reactive power is not being used but causes additional stress and losses in the power distribution network. The fact that poor power factor escalates the demand for electricity generation has long been recognized and addressed by the utility companies. Capacitive or inductive loads are constantly being switched into and out of the grid to correct for low power factor. Furthermore, some providers impose penalty on users whose power factor falls below 0.95.

An additional practical benefit from improved PF is the capability of drawing more power from standard installations as the RMS value of the input current is significantly reduced by using power factor correction. The usual 120V AC household feed protected by a 15A breaker can deliver 1.8kW for a power factor corrected load while the same source can provide only about 1.3kW to 1.5KW depending on waveform and PF of the load current for equipments employing an input stage with peak rectification.

In the mid 1980s several factors came together to inspire witty power supply engineers to tackle the power factor issue in the power supply itself. The most significant one was that the energy demand in many application areas utilizing the smaller and more efficient switch-mode power supplies just sky rocketed. This trend was primarily visible in telecommunication and computing but in time it proliferated to industrial, lighting and later to consumer applications as well. This large quantity of equipment posed a measurable degradation on the power factor at the utility side and introduced large third and seventh harmonic currents to the grid. Both of these challenges needed to be addressed.

Pioneers of this time built the first power factor corrected supplies using passive components to improve the characteristics of the input current wave shape. But these passive circuits turned out to be bulky considering the significant size reduction offered by switched mode power conversion. The field opened up for further innovation and this was the dawn of switch-mode power factor correctors.

From the onset of this trend the boost converter was the most popular converter topology for the task at hand. The boost topology shown in Figure 3 is a very simple power stage. It only requires an inductor, a suitable switching transistor and a rectifier diode and can be easily positioned between the output of the rectifier bridge and the energy storage capacitor, already present in the power supplies. Its implementation required very minimal changes of the existing designs.

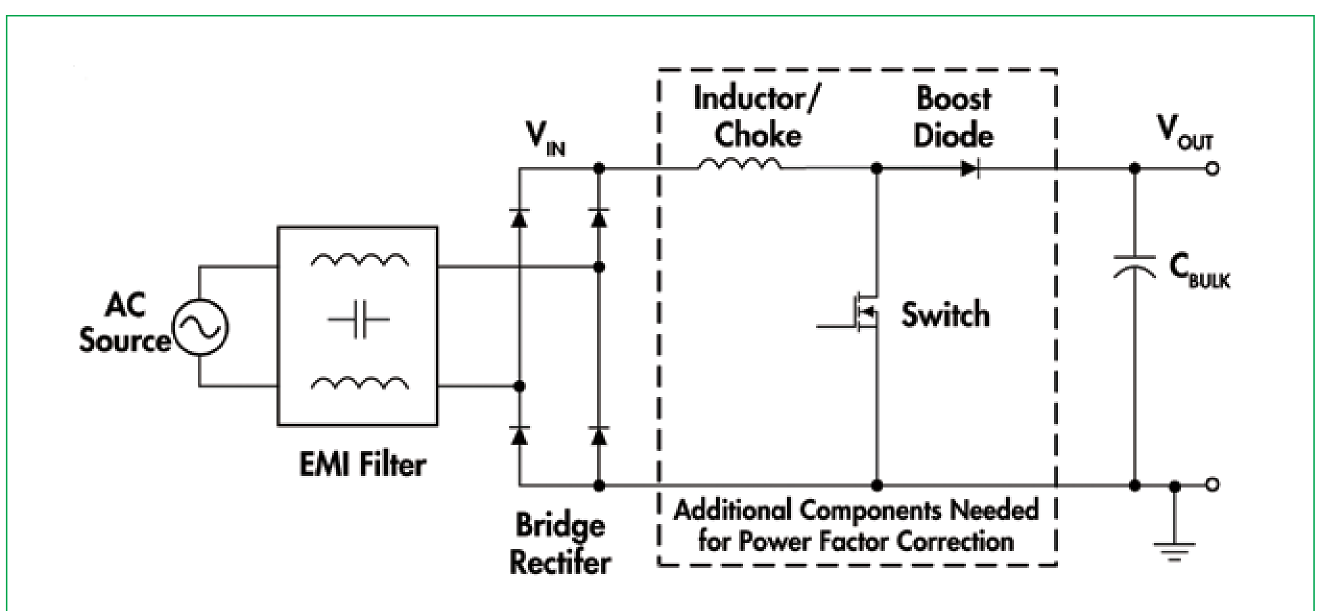

Figure 3: Simplified power supply input schematic with boost power factor corrector.

The reason the boost converter dominates power factor correction rests in its capability to draw controlled current from any input voltage, which is below its regulated output voltage level. This attribute is especially desirable to emulate resistive input impedance, i.e., to produce perfect unity power factor.

In order to approach unity power factor, the boost converter has to be appropriately controlled. The input current should follow the shape of the input voltage waveform as it would do if a resistor was connected to the mains. This requires a dedicated controller that has not been readily available in the market.

Similar to many emerging technologies the first PFC controllers were implemented using discrete components, an oscillator, operational amplifiers and comparators. The circuit seemed rather complex and still couldn't address all the challenges of the optimal control algorithm. It wasn't until the introduction of the UC3854 in 1990, the first integrated PWM controller dedicated to power factor corrector applications, that the control bottleneck had been satisfactorily addressed. The UC3854 can be considered the enabling piece of the puzzle which led to mainstream use of PFC converters.

This controller operates the boost converter in continuous inductor current (CCM) and uses average current mode control to make the input current follow the input voltage waveform. The reference for the current loop is derived by multiplying the instantaneous input voltage and the output of the error amplifier. This ensures the resistive input impedance for the converter and high power factor. To prevent the converter from processing excessive output power at high input voltages the UC3854 also implements a squarer and divider circuit. This method guarantees constant voltage loop gain, independent from input voltage variations. Integrating these essential functions with the usual protection and housekeeping circuits created the industry standard for PFC controllers. Later in the 1990s several similar controllers were introduced into the market with slight improvements and minor changes to the basic control algorithm of the UC3854. The availability of good controllers from multiple vendors allowed the PFC market to flourish.

As the market matured and migrated to many application areas, demand grew for simpler implementations. After the war of the UC3854 clones, new control techniques and thus new ICs emerged. Low power, cost-sensitive applications called for a different breed of controllers. In order to achieve acceptable efficiency at lower power levels the boost converter was run on the verge of continuous and discontinuous inductor current mode. This technique eliminates the major loss mechanism encountered in CCM operation; namely, the reverse recovery losses of the boost rectifier diode due to its forced commutation. A new family of boundary conduction mode (BCM) power factor control ICs hit the market to serve the new requirements of the power supply industry.

Generally, the BCM PFC controllers are no frills, 8-pin devices, often providing only the bare minimum in functionality at a low cost. They take advantage of the fact that boundary conduction mode operation works well with one of the simplest control method, constant on-time voltage mode control. There is no need for additional current loop and frequently the input voltage is not even monitored.

Recently, considerable effort has been made to further improve the efficiency of the power factor corrector circuits, which brought changes to the power stage designs. The two most noteworthy developments on the PFC field are to employ interleaving and to consider the long known but rarely used bridgeless boost topology.

The concept of interleaving proved its usefulness extensively in low voltage, processor power supplies. However, it is a universal principle that

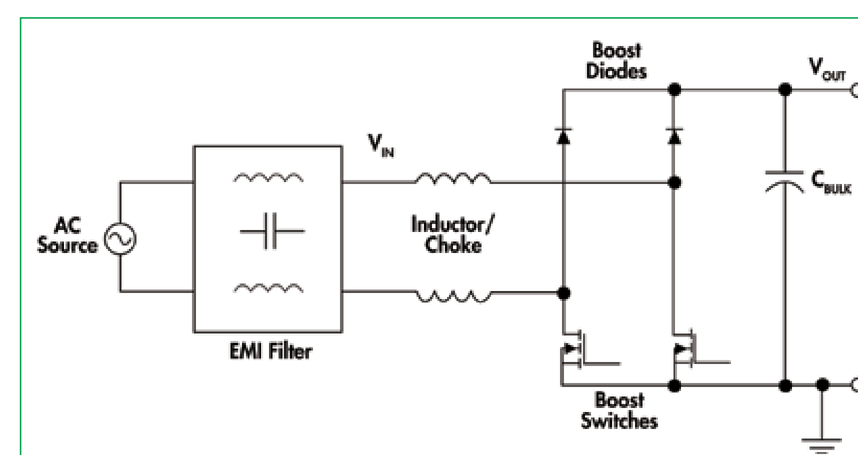

Figure 4: One potential bridgeless PFC implementation (simplified).

is equally applicable to any power conversion task. Interleaving allows the designer to achieve higher power levels using smaller, more efficient modules operated parallel, 180 degrees out of phase. The benefits of this technique is ripple current cancellation of the boost inductor ripple currents that allow smaller, more efficient EMI filters in the PFC supplies and easier thermal management due to spreading the power dissipation among more devices. The cooler operating temperatures have additional positive effect on efficiency considering the positive temperature coefficient of many resistive components in the power supply.

The bridgeless boost power factor corrector tackles the efficiency challenge by reducing the number of series connected semiconductors in the high current path of the converter.

Traditionally, two of the diodes in the input rectifier bridge and either the MOSFET switch or the rectifier diode of the boost power stage carries the inductor current at any given moment. As shown in Figure 5 the input bridge is absent in the bridgeless PFC hence the name of the solution. Its function is combined with the switch and rectifier function of the boost circuit. In this solution the high current of the inductor goes through only two semiconductor devices between the input AC source and the DC output voltage of the power factor corrector. The obvious benefit is reduced voltage drop in the high current path and therefore better efficiency. This topology presents some challenges to the designer because the semiconductors are much more exposed to nasty line transients often present in industrial and rural installations. Furthermore, sensing of the input or the output voltage can be troublesome from a control point of view as those voltages are not referenced to the same ground in the bridgeless boost converter. Similar difficulty can be encountered interfacing the gate drive of the boost switches to the controller's output signal in certain variations of the topology. At the time of writing this article there is no dedicated controller for the bridgeless PFC converter that could overcome the aforementioned obstacles of the control circuit.

As all power supply engineers know, controllers can do just so much to improve efficiency. Ultimately, the converter's efficiency is determined by its power stage design, more specifically by the characteristics of the power components. Today, the PFC market is a 500 million dollar opportunity with an expected annual growth rate of 16% percent, outpacing the average growth of the general power supply industry. It is natural that power MOSFETs and suitable rectifier diodes for power factor applications enjoy considerable attention from discrete semiconductor vendors.

Similar to the evolution of topologies and controllers the power semi-conductors used in today's solutions are far more optimized compared to the ones twenty years ago. When examining power MOSFET technologies, the devices continue to evolve offering lower RDSON values and better Figure of Merit (FOM). Higher cell density offers lower resistance that allows the efficiency of the power converters to be raised. Faster switching and lower switching losses became possible by lowering the MOSFET capacitances. Further improvements focus on reliability by enhancing avalanche capabilities and avert dv/dt induced parasitic turn-on in the devices.

The boost rectifier diodes for high voltage power factor applications went through a similar evolution. Designers can choose among several families of high performance, ultra-fast diodes and ultimately use SiC devices for top notch results. For these devices, forward voltage drop and reverse recovery characteristics are the key parameters to be carefully optimized for the specific applications.

The progress made in device technology and topology development has led to a steady increase in the efficiency of the PFC solutions ever since the first power factor correctors had been introduced. Today, when energy conservation is becoming the focus of our society, power factor correction is imperative to reduce the carbon footprint of our homes and work environments. Exemplary efficiency in state of the art PFC converters peaks above 98% and provides close to unity power factor to eliminate additional losses associated with harmonic currents and reactive power in the distribution network and at the power plants.

To estimate the true cost of reactive power in the utility grid is rather difficult but it is clear that the quest for "greener," more efficient usage of electricity is to a great extent assisted by the better power factor of the load. The efficiency of the power delivery system in the United States is estimated around 93%. If our effort in power factor correction can reduce reactive power flow and increase the efficiency of the grid, the net effect of active power factor correction could be viewed as an "apparent" efficiency over hundred percent.

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Energy Efficient Chargers

No-load dissipation reduced to 30mW

New controller IC from Power Integrations reduces cell phone charger component count by 30% and shrinks no-load power dissipation to a miniscule 30mW.

By Silvestro Fimiani, Product Marketing Manager, Power Integrations Inc.

Recent world events and relentless increases in energy prices are putting ever more focus on energy consumption and the efficiency of electrical appliances in the home. The growing use of portable electronic appliances –media players, PDAs, cell phones, etc. – has multiplied the number of External Power Supplies (EPS) or battery chargers occupying power sockets in the home. The total electricity consumed by EPS has become significant in relation to total domestic electricity consumption, attracting the attention of regulatory authorities.

Organizations including the European Code of Conduct and ENERGY STAR continue to tighten requirements for efficiency and no-load power consumption. The five major cell phone manufacturers (Nokia, Samsung, Sony Ericsson, Motorola and LG Electronics) have taken it a step further by instituting the cell phone charger Star Rating System. To achieve the coveted five-star rating, chargers cannot exceed 0.03W (30mW) power consumption in no-load mode – just one-tenth of the limit currently permitted under ENERGY STAR EPS Specification Version 2.0. Ultra-low no-load consumption is becoming an industry "must have" and is seen as a means of demonstrating good corporate citizenship and attracting eco-minded consumers, rather than something being solely driven by government.

For the other key energy consumption parameter, operating efficiency, the ENERGY STAR specification sets a minimum for external supplies in the range from 1W to 50W according to a logarithmic formula based on rated power. For 1W supplies, a minimum efficiency of 62% is required, going up to 87% efficiency for 50W supplies. For a 5V / 500mA (2.5W) supply, the minimum required efficiency is 65%.

Tightening specifications are placing new challenges on the electronics designer. Not only must an EPS consume a minimum of power under no-load conditions and operate at near theoretical efficiency, but it must also provide good load and line regulation within all component tolerances and over the full temperature range, meet EMI standards, and be manufactured at a competitive cost.

To help meet these stringent requirements, Power Integrations Inc (PI) recently added the new LinkSwitchâ-II product, designed specifically for EPS/charger applications, to its line of integrated switching ICs. The device provides a constant voltage/constant current (CV/CC) characteristic suitable for both battery charging and LED driving applications. LinkSwitch-II uniquely uses a winding in the transformer for both feedback and to provide a low-voltage power feed. This eliminates the current sense resistor, along with many other components, and enables the complete EPS to operate with a power dissipation of only 30mW under no-load conditions.

A cell phone EPS is typically used to charge a phone for just 1 hour a day, but it is often left plugged into the power outlet with no load for the remaining 23 hours of the day. Many cell phone manufacturers are therefore developing EPS with no-load performance significantly better

Power Consumption Parameters	*ENERGY STAR EPS v2.0*	*PI 2.75W CC/CV Charger*
Efficiency	*64%*	*74%*
No-load dissipation	*300 mW*	*30 mW*
No-load annual consumption	*2.52 kWh*	*0.27 kWh*
Total Annual power consumption	*4.09 kWh*	*1.63 kWh*
Energy saved per year		*2.46 kWh*

Table 1: Energy consumption of PI 2.75 W charger versus ENERGY STAR (input 230V AC, active duty cycle / no load 1hr / 23Hr).

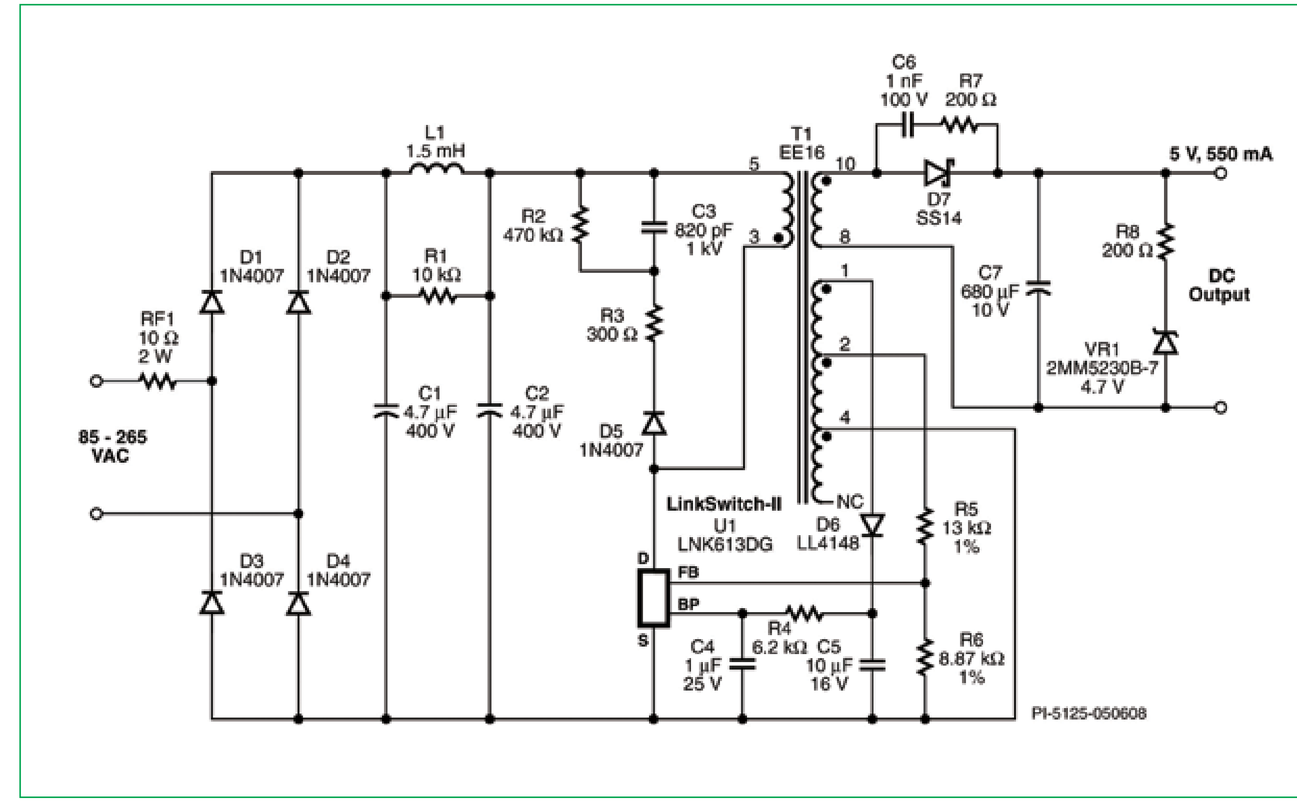


Figure 1: 2.75W CV/CC universal input charger power supply.

than the ENERGY STAR specification requires. Although the no-load figure is very low in relation to the operating power delivered, the total energy consumption accumulates and becomes quite significant. The LinkSwitch-II device can deliver considerable energy savings over and above ENERGY STAR with an active efficiency of 74% for a 2.75W supply. Such a circuit is detailed in Figure 1 and described in Power Integrations' Design Idea DI-157. The importance of no-load dissipation is illustrated in Table 1, where the performance of the PI 2.75W design is compared with a supply just meeting ENERGY STAR EPS v2.0.

Table 1 shows that 2.52kWh out of the total 2.46kWh annual energy saving arises from the no-load performance of the PI power supply. The function of the power supply shown in Figure 1 and how its energy saving performance is achieved are described below.

The LinkSwitch-II controller U1 is key to this design. The device incorporates a 700V power MOSFET, a novel On/Off control state machine, a high-voltage switched-current source for self biasing, frequency jittering, cycle-by-cycle current limit and hysteretic thermal shutdown circuitry onto a monolithic IC. It dramatically simplifies low-power CV/CC charger designs by eliminating a costly optocoupler and secondary control circuitry in an isolated design. The device uses a revolutionary control technique to provide ±5% output voltage and ± 10% current regulation, compensating for transformer and internal parameter tolerances along with input voltage variations.

In the CV region, the output voltage is regulated by using on-off control. Output voltage is maintained by skipping switching cycles. Regulation is maintained by adjusting the ratio of enabled and disabled cycles. This also optimizes converter efficiency over the entire load range. At light loads (trickle charge), the current limit is reduced to decrease the transformer flux density, which reduces audible noise and switching losses. As the load current increases, the current limit is increased and fewer cycles are skipped.

At the point where no switching cycles are skipped (maximum power point), the controller within the LinkSwitch-II transitions into CC mode. A further increase in the load current demand causes the output voltage to drop. This drop in output voltage is reflected on the FB pin voltage. In response to the reduction of voltage at the FB pin, the switching frequency is linearly reduced to achieve constant output current.

At the AC power supply input, the fusible, flameproof wire-wound resistor RF1 provides safety protection against catastrophic failure and limits inrush current on startup. The rectified voltage is smoothed by the π filter

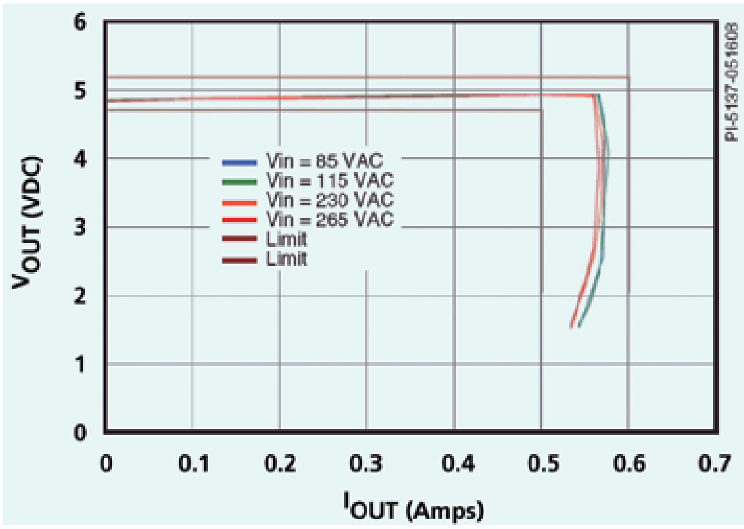


Figure 2: Typical CV/CC characteristic over line at 25°C.

formed by L1, C1, and C2 which also attenuates conducted differential-mode EMI.

The RCD-R clamp formed by D5, R2, R3, and C3 limits leakage inductance drain voltage spikes. Resistor R3 has a relatively large value to prevent ringing on the drain voltage waveform caused by the leakage inductance. It prevents excessive ringing during turn-off events, thereby reducing conducted EMI. The EMI is further reduced by Power Integrations' transformer E-shield™ technology, a winding between the main windings and the core, shielding the core from capacitive coupling. In T1, this is the winding between Terminal 4 and NC.

In this design, the transformer is the component likely to exhibit the worst manufacturing tolerances. However, if the primary magnetizing inductance is either too high or low, the converter will automatically compensate for this by adjusting the oscillator frequency. Since this controller is designed to operate in discontinuous-conduction mode, the output power is directly proportional to the set primary inductance and its tolerance can be completely compensated with adjustments to the switching frequency.

Diode D7 rectifies the secondary and C7 filters it. A 40V Schottky barrier diode is used for D7 for higher efficiency. If a lower efficiency is acceptable, a 1 A PN junction diode can be used for lower cost. The combination of C6 and R7 limits transient voltage spikes across D7 and reduces conducted and radiated EMI. The EMI filtering and screening incorporated throughout the design enables EN55022 class B to be met with a wide margin.

Resistor R8 and Zener diode VR1 form an output preload to ensure the output voltage at no-load is kept within acceptable limits. The Zener diode is incorporated to limit battery self discharge, but may be omitted if this is not a requirement. Feedback resistors R5 and R6 set both the maximum operating frequency and the output voltage in the CV region.

D6, R4 and C5 form an optional bias supply for U1. This provides a low-voltage power feed to U1, enabling the no-load consumption figure of 30 mW for the EPS to be achieved. If these components are omitted, U1 draws its power from the high-voltage primary side, in which case the no-load dissipation increases to 200 mW, still well within the ENERGY STAR EPS v2.0 specification. If ultra-low no-load dissipation is not a requirement, then the designer has the option of omitting the bias circuit and saving cost.

C4 acts as decoupling for U1 and controls the output cable compensation function. This compensation provides a constant output voltage at the end of the cable over the entire load range in CV mode. As the converter load increases from no-load to the peak power point (transition point between CV and CC), the voltage drop introduced across the output cable is compensated by increasing the FB pin reference voltage. The controller determines the output load, and therefore the correct degree of compensation, based on the output of the state machine. A value of 1μF corresponds to compensation for a 0.3Ω, 24AWG USB output cable. (A 10μF capacitor compensates 0.49Ω, 26 AWG USB output cables.)

Figure 2 illustrates the tight control of output voltage and current at 25° C for the full range of input voltages. The output tolerances for LinkSwitch-II shown in Figure 2 are specified over a junction temperature range of 0°C to 100°C for the P/G package.

LinkSwitch-II has set a new benchmark for performance, efficiency and cost of low-power external power supplies. The range of control and protection features within LinkSwitch-II eliminates the difficulties commonly associated with switching power supply design and assures consistent performance in high-volume manufacturing. Reference design kits and applications support can be found at the company's website.

www.powerint.com

Only time will tell

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

We are now exposed to a financial and an environmental disaster, both of which can, in the end, be resolved by good engineering and great engineers. Although traditionally seen as left brain individuals, the creativity demonstrated over decades clearly shows the huge talent within our community. Solar, wind, wave and other viable forms of non-fossil energy have been pioneered by engineers. Now comes the task of getting industry and governments to fund the much needed accelerated deployment of these humanity-improving engineering marvels.

IMS Research reported at the end of last year that the global photovoltaic inverter market is set to double in size, exceeding $2 billion for the first time. According to the latest analysis, the PV inverter market grew by an astounding 110% in the first nine months of 2008. Europe continues to drive this growth and accounted for 80% of all global revenues, due to exceptional performances in Spain and Italy as well as higher than expected demand from Germany.

California's mercury news reported that despite the turbulent economy, solar energy remains a growth industry in California. The amount of electricity generated in the state by solar energy soared in 2008, and applications for rebates under the state's Million Solar Roofs program reached record levels in the last five months of the year.

Experts attribute the surge in solar sales to a big increase in the federal tax credit, an ongoing state rebate and new innovative financing programs, as well as to mounting consumer concerns over global warming. The growth comes despite a U.S. economy suffering from a battered stock market, severe declines in house and car sales, and growing unemployment.

An estimated 150 megawatts or more of new solar panels were installed in California in 2008, up from 81 megawatts in 2007. (In California, one megawatt is enough electricity for 750 houses.)

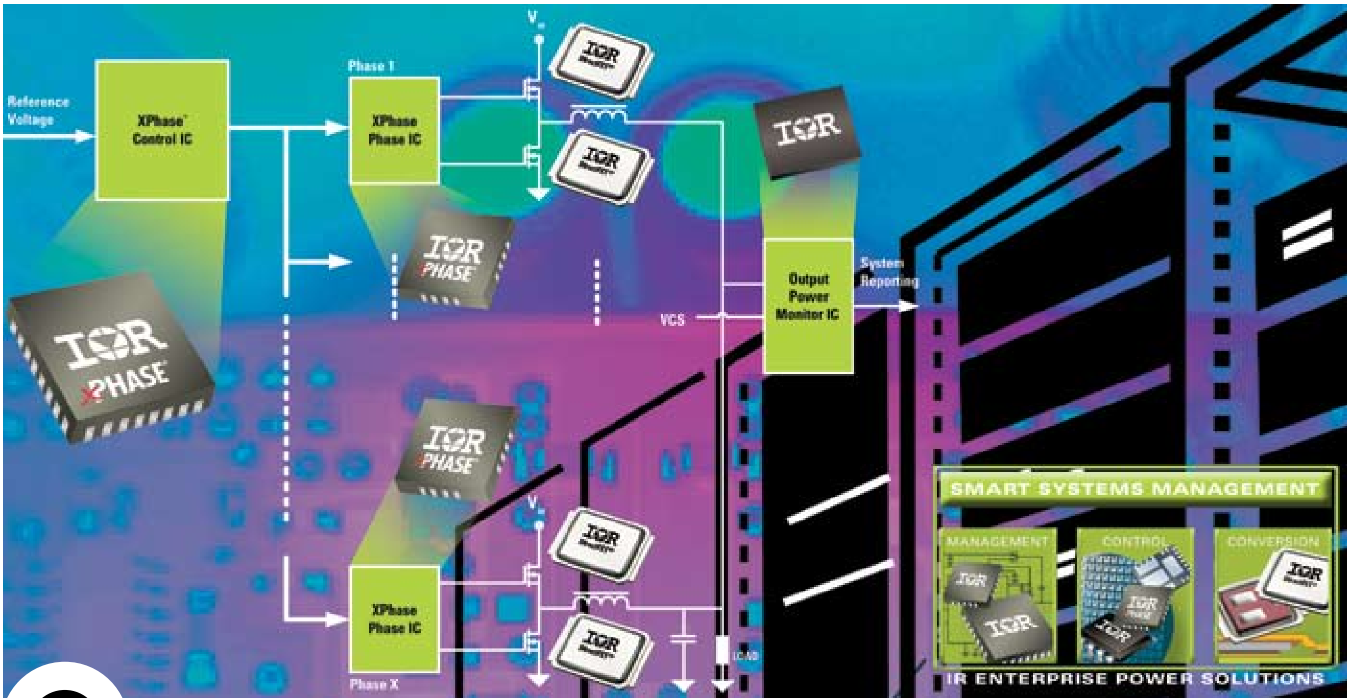
California has more than half of the solar capacity in the United States, and that the state ranks as the world's No. 4 solar entity after Germany, Spain and Japan.

Solar's growth here is "somewhat surprising, as we expected the economic downtown might have some dampening effect," said Damon Franz, an energy analyst with the California Public Utilities Commission.

Sales increased because consumers now see solar as a safe economic bet, and a hedge against rising energy prices, said Lyndon Rive, chief executive of Solar City, a solar installer based in Foster City, US.

It seems to me that the only way to accelerate the adoption of alternatives such as solar power and energy efficient lighting is to make it attractive and affordable. This is where respective government bodies such as in Germany and California have really made an impact in weaning off the dependence on fossil fuels and encourage consumers to use less wasteful technologies. For other regions only time will tell.

www.powersystemsdesign.com/greenpage.htm



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IRF6797MPBF	DirectFET MX	25	20	1.1	1.8	45

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