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ENERGY EFFICIENCY

Special Reports - Lighting Systems & Digital Power

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Volume 1, Issue 3

PSDNA Green Power ENERGY EFFICIENCY

Make it Happen

Welcome to this special double-feature issue of PSD North America. In this issue we bring two specialized sections of topical importance to power engineers. These features cover the ever pervasive Digital Power arena where the options now opened up to engineers have never been greater, and in addition, Lighting Systems where efforts to make more efficient and cost effective illumination for a greener world are relentless. All this is put together with the 'real world' in mind. Companies need to make a profit to enable future growth and investment, and in these difficult times this is a real economic challenge. The 'green shoots' appear in the mass-media long before they hit reality.

Many companies in our industry still continue to find it difficult to make headway and fear for the future - with the net result that many of our colleagues are suffering the inevitable downsizing. Not a desirable or dignified approach to the current economic difficulties, or indeed a confidence builder for the current captains of industry.

In 2008 China surpassed the United States to become the world's second largest auto-making nation and is set to displace Japan in 2009 as the planet's largest car producer, according to iSuppli Corp. China manufactured 9.3 million cars in 2008, while the United States built 8.7 million. In 2009, China will build 8.7 million autos, compared to 7.6 million for Japan.

But despite the current downturn, opportunities for continued growth in the medical imaging equipment market have been highlighted in the first edition of InMedica's report, "Medical Imaging Production Yearbook". Forecast to exceed $22 billion by 2012, the combined market for ultrasound, X-ray, MRI and CT imaging equipment is expected to continue to expand in an environment where restrictions in healthcare spending and reductions in reimbursement are ever-increasing. Technologies predicted to have the greatest impact in the medical imaging equipment market over the next few years are those which allow changes to clinical pathways that will eliminate unnecessary diagnostic procedures, dramatically reduce the cost of healthcare and increase diagnostic accuracy for patients.

I am convinced though, that in spite of the negativity in today's industry, media and workplace, we will get through it. Time will tell, but I believe that the ever-innovating power industry with its huge resource of engineering talent is still extremely well placed for a sustained recovery - when we all help forward-looking firms make it happen.

Enjoy this double-feature issue, keep the great technology reports and feedback coming and check out our fun-strip, Dilbert, at the back of the magazine.

All the best!

Cliff Keys

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ABB Wins Multi $M Orders

ABB has won an order worth $400 million from Kuwait's Ministry of Electricity and Water for three new substations to improve the country's electrical transmission grid.

ABB will design, supply, install, test and commission the substations, which will increase transmission voltage from 300 kilovolt (kV) to 400kV. The higher voltage will help strengthen the grid's reliability and increase its capacity to meet rising demand for electricity.

ABB gas-insulated switchgear.

Key components include gas-insulated switchgear, 12 large power transformers (400kV, 765MVA), low-voltage auxiliary systems and network protection and control equipment. The project is scheduled for completion in 2011.

"Our technologies and global presence enable the expansion and strengthening of power infrastructure around the world," said Peter Leupp, head of ABB's Power Systems division. "These substations will reinforce the transmission network and boost capacity in Kuwait, to help meet the region's growing demand, increase energy efficiency and improve the quality of power."

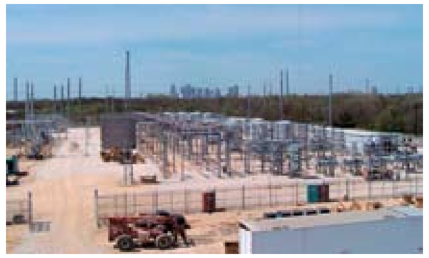
Increasing the transmission voltage will enable Kuwait's grid to be connected to neighboring GCC (Gulf Cooperation Council) countries, already operating at 400kV. The first substation at this voltage in Kuwait was also built by ABB as part of the GCC initiative to interlink Gulf states.

Substations facilitate efficient transmission and distribution of electricity, and include equipment for the protection and control of electrical power. ABB has delivered around 10,000 substations worldwide, at voltages of up to 800kV.

$20 Million US Power Order from Oncor

ABB has won an order worth $20 million from Oncor to supply a Static VAr Compensator (SVC) unit to support the transmission grid in north Texas. The order was booked in the first quarter and the turnkey project is scheduled for completion by the end of 2010.

The SVC unit will be installed at the Renner substation in the northern part of the state. ABB has won three similar orders from Oncor in the past, most recently in 2008 for a project in the vicinity of Renner. The first two SVC units, delivered to the Parkdale substation in the Dallas-Fort Worth area, are scheduled to begin operations in mid-2009. The Parkdale installation is the world's largest cluster of SVC technology.



Parkdale substation in the Dallas-Fort Worth area.

SVC devices provide fast-acting reactive power compensation in high-voltage electricity networks, which enhances stability by countering fluctuations in the voltage and current of an electric grid, and by allowing more power to flow through the network. The technology is part of ABB's family of Flexible AC Transmission Systems (FACTS) solutions that increase the capacity of existing transmission networks and improve their reliability.

"This is an innovative 'no wires' solution designed to improve energy efficiency, help maintain an uninterrupted flow of electricity and enhance grid reliability," said Per Haugland, head of the Grid Systems business within ABB's Power Systems division. "It will also facilitate future integration of wind power and other renewables, as grids get smarter."

"The robust design and flexibility of Static VAr Compensators will allow Oncor to continue to reliably operate the transmission grid in North Texas with less dependence on local generation," said Oncor senior vice president Jim Greer. "ABB worked hard to develop an electrical power solution that will keep pace with the North Texas area's ever increasing power demands, while enabling the improvement of the local environment."

Oncor serves more than seven million customers in Texas and operates the largest distribution and transmission system in the state, with some 164,000 kilometers of distribution and 22,500 kilometers of transmission lines.

www.abb.com

Philips Lumileds Joins California Lighting Technology Center Affiliate Program

Philips Lumileds announced that it has joined the California Lighting Technology Center as an affiliate member. As a member of the CLTC, Philips Lumileds is working with luminaire manufacturers to develop market ready LUXEON LED based applications that meet the energy efficiency and lighting quality levels required to meet EnergyStar® and similar regional and national guidelines.

"Our affiliation with the CLTC supports the development of specification and architectural grade solutions using our LUXEON Rebel and LUXEON K2 power LEDs," said Jay Shuler, Regional Marketing Manager for The Americas at Philips Lumileds. "By working with the CLTC, our customers will gain access to new opportunities with state agencies, utilities and businesses eager to adopt solid state lighting solutions."

CLTC, established through a joint effort of the California Energy Commission (CEC) and University of California at Davis, conducts both cooperative and independent activities with lighting manufacturers, electrical utilities and the design and engineering professional communities. These valuable partnerships facilitate the commercialization of products developed at CLTC in accordance with CLTC's mission to bring viable research-based projects to the commercial marketplace in two years or less.

www.philipslumileds.com

Solyndra Completes Commercial Rooftop Solar System in Livermore, California

Solyndra Inc., a manufacturer of proprietary photovoltaic (PV) systems designed to optimize solar electricity production on commercial rooftops, announced the completion and full operation of a 132 kWp system by SPG Solar, Inc., on the rooftop of Cinema West's Livermore Cinemas in Livermore, CA. This project is one of many major commercial installations that have been completed or are underway with Solyndra PV systems in the US and Europe.

Solyndra's PV system design allows maximum coverage and easy installation on commercial low-slope rooftops. There is no need for roof-penetrating mounts or ballast to hold panels in place and, as a result, the installation took less than 4 days. According to Dave Corkill, Owner of Livermore Cinemas, "No other system could offset as much power – the installation was over before we knew it."

132 kWp system by SPG Solar, Inc., on the rooftop of Cinema West's Livermore Cinemas in Livermore, CA.

The Livermore project involved covering a complex roof shape with many areas not aligned in the north/south direction. Whereas conventional PV panels would have needed to be tilted facing southward to avoid significant energy loss, the orientation of Solyndra panels has minimal impact on overall energy yield. "The Solyndra system allowed us to maximize the available roof space, minimize labor and installation costs and increase power production – which allowed us to optimize our client's investment in solar," adds Ted Walsh, Director of Commercial Development, SPG Solar, Inc.

"The efficiency of installation saved us time and money, and we were able to pass those savings onto Cinema West. Solyndra's PV system is emerging as a truly innovative and excellent solution for rooftop solar applications," says Dan Thompson, Founder, President & CEO, SPG Solar, Inc.

"We are very pleased to announce this project by SPG Solar," said Dr. Kelly Truman, Solyndra's Vice President of Marketing, Sales and Business Development. "Solyndra's products passed smoothly through permitting and commissioning, helping a great partner quickly meet their business needs."

www.solyndra.com

National Semiconductor Acquires Act Solar

National Semiconductor

National Semiconductor has acquired Act Solar, Inc. a privately held solar energy company that provides power optimization solutions for commercial and utility-scale solar installations.

With the acquisition of Act Solar, National expands its portfolio of power optimization technologies along with the acquisition of new diagnostics and panel monitoring capabilities for solar arrays.

"National Semiconductor is applying its 'PowerWise' capabilities to drive new energy generation and efficiency initiatives in the solar panel marketplace," said Mike Polacek, senior vice president of National's Key Market Segments. "Now with Act Solar we can further improve the performance and efficiency of solar systems, at the same time providing monitoring capabilities not available before. This will make solar installations more efficient and ultimately reduces the cost of solar energy for everyone."

National's SolarMagic™ technology enhances the efficiency and output of solar arrays when the panels are affected by mismatch issues including shade, debris, different panel types, and panel aging.
Recent internal testing showed that National's SolarMagic power optimizers recovered 57% of power lost due to shade, thereby enhancing the solar installation's output and efficiency. SolarMagic power optimizers begin shipping this spring.

Act Solar now becomes part of the SolarMagic family. Its products improve array performance by 6 to 11% using patent-pending technology, complementing central inverters by dynamically re-circulating small amounts of energy as needed. The balance of the array is maintained, assuring maximum power output. The technology utilizes a revolutionary technique for power tracking, which works by injecting energy into the string as opposed to traditional DC-DC voltage converting approaches. Early field tests and historical modeling have shown that this solution can cumulatively deliver 40 to 80% more power over the operating life of a solar panel installation.

www.national.com www.actsolar.com

Exclusive Distribution Agreement

AMS Technologies AG, based in Martinsried near Munich has announced an exclusive distribution agreement with San Diego based C3 Semiconductors LLC. The agreement entitles the Pan European distributor to sell C3 Semis semiconductor products throughout Europe.

C3 Semiconductors LLC is a manufacturer of a wide array of discrete semiconductors such as Triacs, SCR's, rectifiers in TO220, TO218, Dpack, D2pack package sizes. Also power modules, IGBT modules and solid state relays are available. The products are used for solutions in a variety

of applications including lighting, motor control, automation and high power control.

C3 Semis was formed to bring a new focus to the semiconductor industry, providing the flexibility to fulfill specific customers' requirements. Due to its expertise C3 Semis is able to construct different circuits in a number of diverse packages and configurations or with special characteristics.

C3 Semis products will be shown at **PCIM 2009** (12th to 14th May, Nuremberg, Germany) at **AMS booth # 12-512**.

www.ams.de

Energy-Efficient Ballast

Up to 45% cost saving

Fluorescent lighting is still the dominant light source in the commercial sector. With the increasing need to conserve energy and the financial drive to contain costs, a product which maximizes power efficiency in this lighting sector has a broad appeal.

American Ballast, a global commercial and residential power solutions company, has developed a line of NEMA approved high-efficiency, multi-voltage ballasts. Providing up to 45% energy costs savings in a wide range of applications including general, decorative, retail and indirect lighting, the energy-efficient electronic ballasts are designed for retrofits installations or new construction.

The electronic ballasts feature Instant Start technology with parallel circuit configuration and are engineered to out-perform other instant start ballasts as well as rapid start ballasts in short-cycle and frequently switched applications. The high-efficiency ballast series has exceptional power quality with a power factor of >98% and a THD of 10%. The ballast series also features silent, flicker-free operation and anti-striation control creates an even level of light output. The lumen output for these NEMA approved ballasts is 0.87. The minimum lamp starting temperature is -18°C.

The NEMA Premium Electronic Ballast Program provides the method for identifying the most efficient T8 fluorescent ballasts available in the market and identifies models that are consistent with the Consortium for Energy Efficiency (CEE) specifications for high performance lamps and ballasts, tested in accordance with ANSI C82 Standards. Qualifying products have a special mark to help lighting professionals and end users identify the market's highest performing electronic ballast products that will help support energy-efficient objectives.

American Ballast's NEMA approved multi-voltage ballasts operate one, two, three, or four T8 lamps at an installer-simplicity universal input voltage of 108-305 volts. The electronic ballasts also feature parallel lamp operation, which enables lamps to continue operating normally in the event of a single lamp failure. The high-efficiency ballasts can utilize the same wiring and mounting footprint as conventional ballasts, negating the need for any expensive electrical work.

"Our new NEMA approved high-efficiency electronic ballasts use less input watts than standard efficiency electronic ballast and consume less energy than Rapid-start ballasts," said Eric Hsieh, American Ballast's R&D Director. "The high-efficiency series allows our customers to experience maximum light output combined with minimum power usage."

With a NEMA certification, customers are guaranteed a high-performance T8 ballast that meets FCC rules and regulations, ANSI requirements and complies with all applicable state and federal efficiency standards, as well as meeting RoHS standards.

Through its extensive burn-in, full-functional and advanced-life testing procedures, American Ballast confidently offers a five year warranty on the ballast product family. All American Ballast lighting solutions are UL and CuL listed.

For more information about the NEMA approved high-efficiency ballast series, visit American Ballast at:

www.americanballast.com

Burgeoning LED Lighting Market Needs Efficient Power Supplies

By Doug Bailey, VP Marketing, Power Integrations, Inc., San Jose, CA

The use of LED technology for lighting applications is accelerating. LEDs last much longer than other illumination technologies, consume significantly less power, and are much more controllable, enabling the right amount of light to be delivered where it is required. In the long run, the cost of ownership of LED lighting is likely to beat current fluorescent solutions, not only due to energy savings, but also because of significantly-reduced maintenance costs.

For indoor LED lighting applications, much of the focus has been centered on replacement bulbs. Initial LED light bulbs were cumbersome and compromised, but today there are some very attractive industrial designs available from manufacturers in the U.S. and worldwide. These are mostly characterized by a large-finned aluminum heatsink body, with the LEDs behind an optical spreader/diffuser and the power supply crammed into small space inside the traditional screw fitting connector. High-brightness white LEDs are much more efficient and rugged than incandescents, so it is important that designers drive these safe, clean, and efficient light sources with similarly effective power supplies.

Accurate constant-current performance is an important parameter for LED driver designs to ensure a consistent light output, small size, and low heat generation. Power Integrations' LinkSwitch®-II AC/DC switch-mode power conversion ICs with primary-side control can be configured in a tapped-buck topology and are perfect solutions for the small space inside the screw fitting of a light bulb replacement up to about 8W. LinkSwitch technology offers a high level of integration and low external component count. It is also highly efficient, avoiding the thermal management challenge inherent in LED light bulb form factors. LinkSwitch-II also has low EMI due to frequency jitter, aiding physical design by eliminating large common-mode chokes and reducing the size of X-capacitors.

There is a growing enthusiasm in municipalities as far afield as Qingdao (China) and Annapolis (Maryland) for the installation of LED street lighting. Following positive trials, many cities are now introducing policies to replace traditional street lights with LED products. Los Angeles will replace its 140,000 existing street light fixtures with LED units; improving LA's lighting quality while reducing electricity use and cost. LED fixtures last two to three times longer than traditional products and are more resistant to damage, delivering significant maintenance cost savings.

We can expect explosive growth in LED street lighting and widespread adoption in a very short time. It seems reasonable to predict an almost complete worldwide switch to LED street light installation this decade. The HiperPLC® power supply controller IC, Power Integrations' first high-power product, is targeted at the latest generations of high-brightness LED street lights. The device saves costs by combining the PFC and LLC controllers into a single IC. It is ideal for LED street lighting, as it combines excellent power factor correction, greater than 90% efficiency, and small size and an improvement in overall operating life.

Visit the Power Integrations LED lighting microsite at:

www.powerint.com/en/applications/led-lighting

From CFL's to Liquid LEDs

Reported by Shane Walker, Research Analyst, Consumer Electronics Group, IMS Research

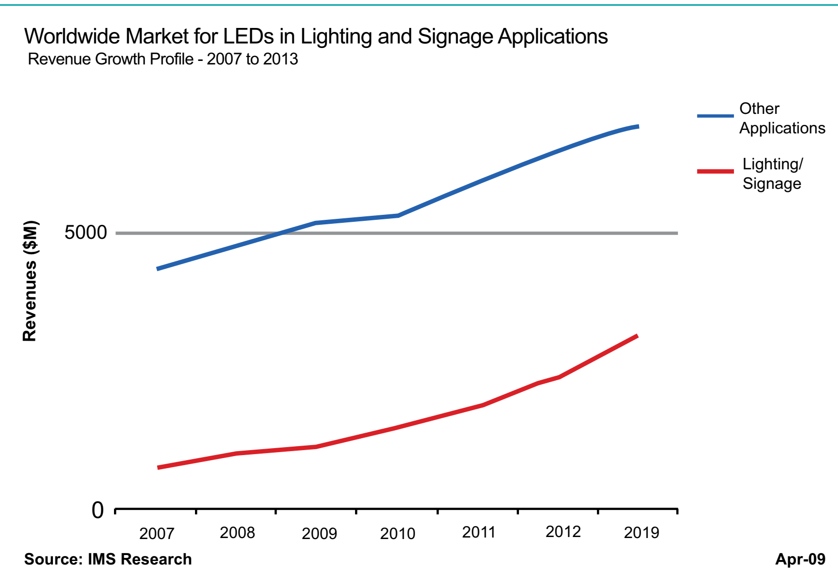
With an 11% market contraction forecast in 2009, it appears that the lighting industry is not immune to the global economic downturn. However, there is a bright spot within the forecast for companies delivering LEDs. While LED lighting is a small part of the overall lighting industry at present, the growth potential is enormous.

Major LED suppliers such as Nichia, Osram, Lumileds and Cree are all well aware that, while LEDs in backlighting applications are worth more dollars at present, indoor and outdoor illumination applications will represent the largest market in a few years as LEDs become brighter and more efficient. Many of these LED applications will also require or benefit from dedicated LED driver

ICs. However many LED driver IC manufacturers remain focused on mobile handset and other consumer applications, where the revenue is currently much larger.

In the near term, we expect to see heightened awareness of a new non-IC LED known as a liquid LED. These bulbs are poised as a possible replacement for interior lighting — a market that has not traditionally been seen as viable by LED manufacturers due to cost and overall lighting quality as compared to incandescent and fluorescent bulbs.

Liquid LEDs address the key challenges of high power LED lighting including heat dissipation and light decay, extensive beam angle and high luminance, security and certification, and compatibility with existing standard light fixtures.



The Liquid Immersed Thermal Management Solution (LITMS) from Liquidleds of Taiwan is designed to replace higher wattage incandescent lamps and lower wattage CFLs for residential applications. What is interesting about the technology is that heat is dissipated at the junction by filling an AC LED bulb with liquid, extending lamp life to approximately 35,000 hours. A thermal conductor in the liquid transfers heat from the LED module through the liquid and to the light cover. The LED light penetrates through the liquid creating wide angle uniform illumination. We tested the bulb in an interior setting and found that a 4W bulb doesn't quite supplant a general service "A" bulb or a CFL, but that a 10W bulb most likely would do the job. In addition, these bulbs do not require a driver as do typical DC LEDs and are therefore dimmable. Currently, the 2W, 4W and 5W bulbs have sold primarily into the Western European markets of Germany, Poland, and France and a 10W bulb is on the way. Distributor costs have yet to be fully disclosed; however, based on information that we have received, price estimates for these bulbs fall between US$10 to US$20 each. This would bring estimated consumer costs back to a reasonable (or semi-reasonable) level, as compared to other LEDs which are still US$95 at retail.

Why would anyone be interested in switching? Let's remember that incandescent lighting converts heat to light at approximately 5% efficiency with an average lamp lifetime of 2,000 hours. While there have been some advances in the technology, such as double filament bulbs, little has been accomplished in terms of overall energy efficiency. Then there are fluorescent or compact fluorescent lamps, which operate at approximately 25% efficiency with an average lamp life of 6,000 to 10,000 hours. Self-contained electronic ballasts with dimming control ICs are allowing fluorescents to compete with incandescent lamps as they will operate similarly in 3-way lamp sockets. However, a principle drawback to fluorescent lighting continues to be the mercury used to create the UV light. Other than dimming capability, recent advances in CFLs include removable ballasts which allow for the separation of the expensive ballast portion of the lamp for reuse.

While it is unlikely that there will be a fundamental shift to LED or Liquidled lighting for residential applications in the near future, it is clear that the energy savings to be had from their use will increasingly improve their standing.

www.imsresearch.com

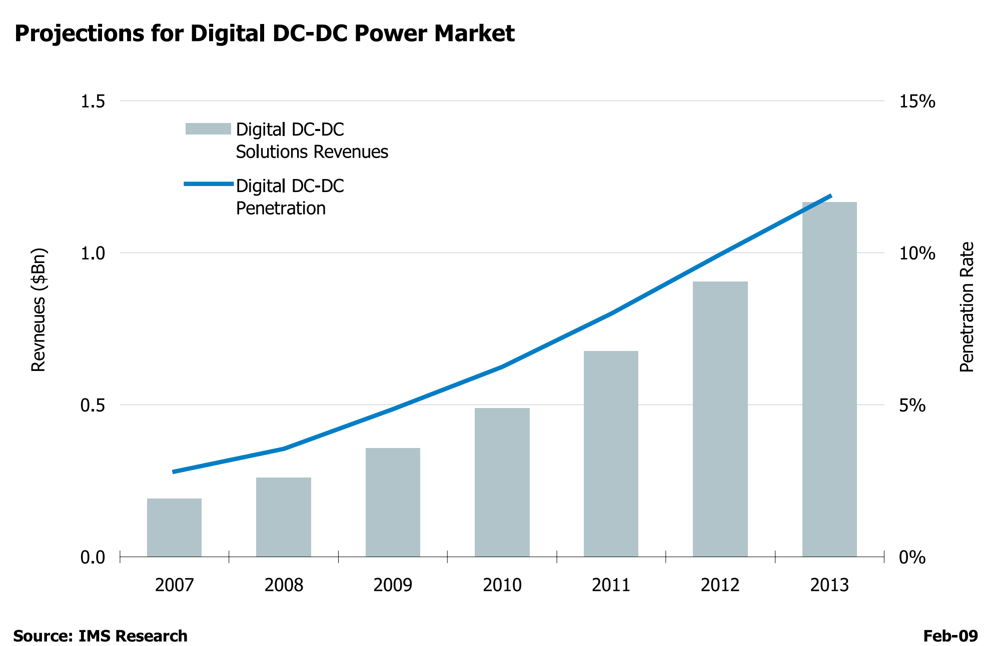
Digital Power to Grow Significantly

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

The topic of digital power has divided the power industry over the past few years into two camps: those that think it will never take off, and those that believe it will revolutionize the industry. Increasingly, the consensus appears to be that it will gain significant adoption, but the questions remain – when will this be, and why hasn't it happened already? After all digital power as a concept has been around for many years.

Digital solutions have been proven to work in power designs for sub-systems such as rectifiers, inverters and UPS; yet adoption of digital power for DC-DC conversion remains relatively limited, despite a number of obvious benefits. Whilst most users are not interested in whether a digital or analogue control loop is used, they may be convinced to switch to digital to reap the benefits of reduced component count, better control capability and improved efficiency.

Enhanced functionality now appears to be the main marketing angle used by suppliers active in the digital power field and is probably the most significant benefit of digital power, particularly in applications where there is a need for real time power system diagnostics and adaptive control under different loads or operation modes. Digital power can also reduce the overall cost of new designs, by allowing companies to use the same design platform across multiple topologies and customising designs through the use of software.



Whilst there are some clear benefits of employing digital products in power designs, penetration of these products to date remains low. IMS Research's latest reports on the Global Market for AC-DC & DC-DC Power Supplies and the Global Market for Power Management ICs found that in 2008, just 3.6% of DC-DC solutions revenues were from digital products (Figure 1). In order for digital power to really take off on a large scale, a number of issues need to be overcome.

Firstly, prices of digital power products will need to fall further in order to gain wide scale adoption. Whilst prices are often described as 'comparable' to analog solutions, this is typically only true for specific designs with a large number of voltage rails and only when comparing the overall design cost rather than just comparing component costs. It is inevitable that prices of digital products will fall further as more suppliers enter the market and volumes rise; however, the customer will need to be persuaded on the basis that overall system costs will be lower.

Demand for digital power will need to be generated in new, high volume applications. To date, most demand has come from high-current designs in applications such as routers, servers and storage and switching equipment. The acceptance of digital power over analog in one or more high-volume application would help raise acceptance of the technology, further reduce prices and drive mass adoption.

Finally, one of the most critical restraints on digital power adoption is the reluctance of designers to switch – the 'inertia to change'. Digital designs will require power supply designers, often traditional analog engineers, to learn new design techniques and take into account new layout considerations. Some designers may have difficulties with software design and will prefer to continue using "old fashioned" analog techniques. This obstacle is in part being addressed by a number of power IC vendors that are providing much greater design support for customers and in some cases taking care of the entire design process.

IMS Research projects that penetration of digital products in DC/DC solutions will continue to grow significantly, reaching nearly 12% by 2013, implying that revenues of digital DC-DC solutions will increase by some 35% per year on average over the next five years. Whilst one can debate whether this forecast is too aggressive or too conservative, what seems unarguable is that the future for digital power is very positive.

www.imsresearch.com

Frequency Response of Switching Power Supplies – Part 3

Injecting signals into the power supply

In this article, Dr. Ridley continues the topic of frequency response of switching power supplies. Previous articles showed how a frequency response analyzer pulls out a single test frequency from a broad range of noise and signal. This third article shows how an analyzer can be connected to measure the essential transfer functions of a power supply and its components.

By Dr. Ray Ridley, Ridley Engineering

Measurement of Passive Components

As mentioned in previous articles in this magazine[1-3], all passive power components should be characterized across the frequency range over which they are required to function. This includes dc measurements for magnetic components, out to 30MHz, the limit of conducted EMI measurements.

Figure 1 shows the test setup for high impedance measurements (greater than 1ohm), typically used to characterize magnetics. This is used to measure magnetizing inductances, leakage inductance, resonances, and winding capacitances. Details of

such measurements are given in[1-2]. Power magnetics are usually custom and should be measured to confirm performance. Off-the-shelf parts should also be measured since they are usually inadequately specified by vendors.

Figure 2 shows the test setup for low impedance measurements, down to as low as 1mOhm. This setup is used to characterize power capacitors, and will show capacitor values, resonant frequencies, and equivalent series resistances. All of these quantities can have significant variation depending on the type of capacitor used, temperature, bias point, and batch sample. Most manufacturers do not provide enough accurate data to properly design a power supply, making this an essential measurement for any power capacitor[3].

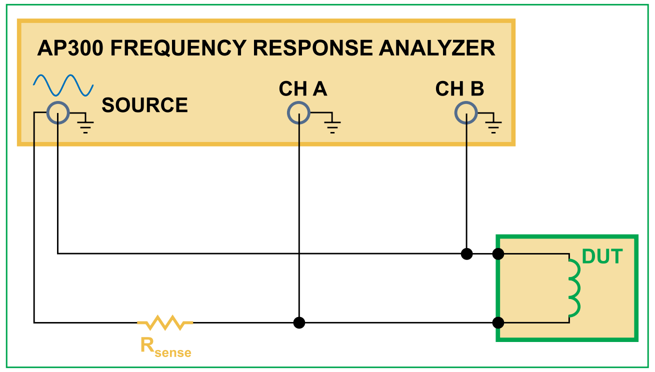


Figure 1: Setup for high impedance measurements, usually used to characterize magnetics and small capacitances.

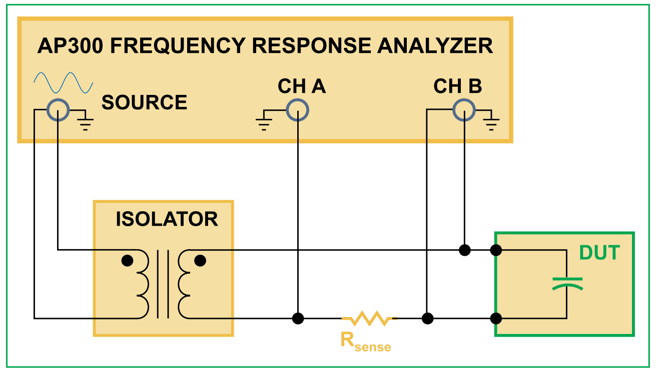


Figure 2: Setup for low impedance measurements, usually used to characterize power capacitors.

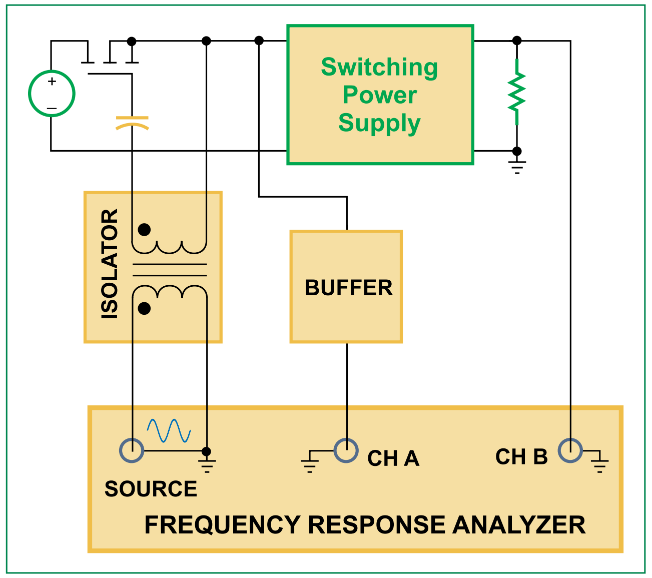


Figure 3: Setup for input-output conducted noise, or audiosusceptibility, measurement.

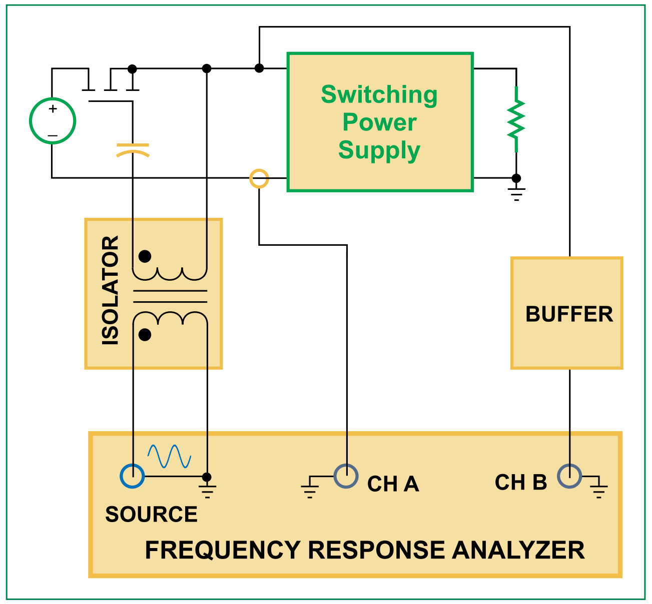


Figure 4: Setup for input impedance measurement.

Audiosusceptibility Measurement

In the aerospace industry, it is usually a requirement to measure the input bus to output voltage transfer function, also referred to as audiosusceptibility. This involves the inconvenient process of modulating the input voltage with the frequency response analyzer. More elaborate electronic power sources may have the capability of producing this perturbation, but we usually have to build a circuit to do customized injection, tailored to the specific input voltage and current levels of the converter.

Figure 3 shows a method to inject into the input rail of a power supply. A series-pass FET is used, and its gate is modulated via an isolation transformer. In setting up this test, make sure the FET is rated for the full input voltage, and properly heatsinked for the full input current.

Since the input voltage of a power system is typically higher than the allowable range of a frequency response analyzer, it is common to buffer the signal measured at the input voltage. This can be done with a high-voltage differential probe, or using an oscilloscope with a Signal Out feature.

Input Impedance Measurement

The same injection technique as used for audiosusceptibility allows the measurement of input impedance, as shown in Fig. 4. Input impedance is a requirement for most aerospace power systems, and very useful for any large scale systems where power supplies are connected together and system interactions are crucial.

For input impedance, the analyzer measures the perturbation of the input voltage and the perturbation of the input current, using a suitable current transducer.

Output Impedance Measurement

Two setups are available for measuring output impedance of a

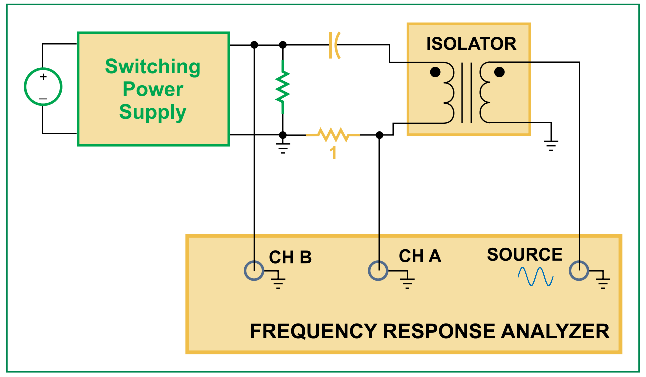


Figure 5: Setup for output impedance measurement for low power outputs.

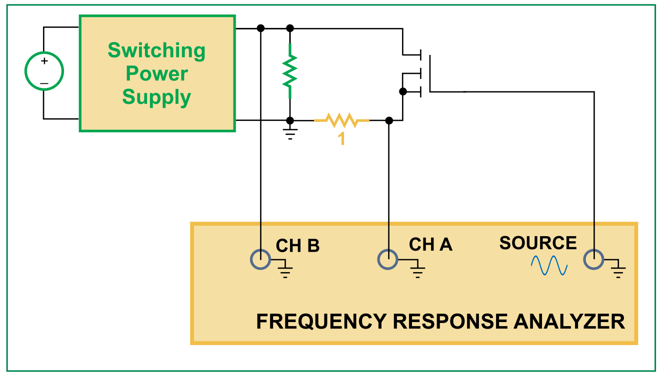


Figure 6: Setup for output impedance measurement for high power outputs.



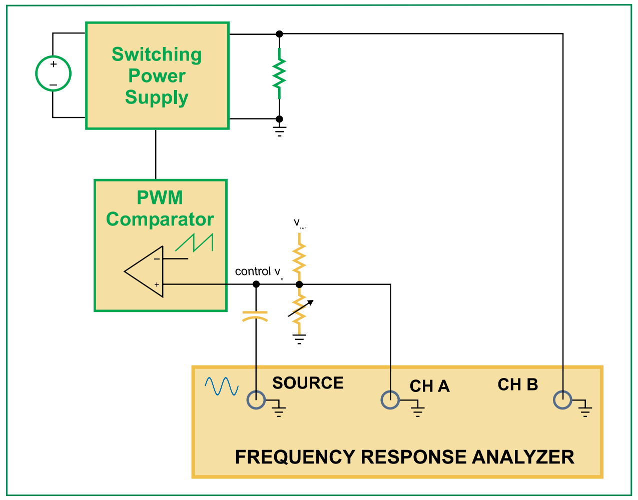



Figure 7: Setup for output impedance measurement for low power outputs.

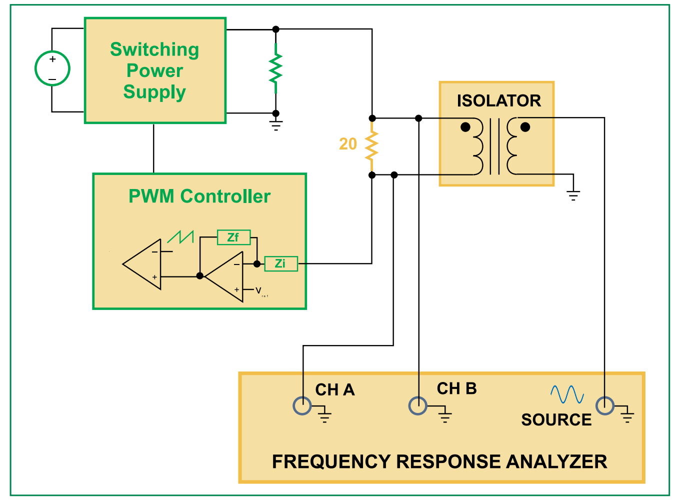


Figure 8: Setup for output impedance measurement for low power outputs.

power supply. In the first, shown in Fig. 5, a passive circuit is used via a coupling transformer, and DC blocking capacitor. This test setup can only generate a small current into the output of the power supply due to the limited drive capability of the frequency response analyzer. It is typically useful down to around 10mOhm output impedance.

For higher current power supply measurement, a higher drive current is needed, and this can be achieved as shown in Fig. 6.

Control-to-Output Measurement

Before closing a control loop around a switching power supply, the characteristics of the power stage must be measured. These can be highly variable depending on load, input voltage, and component parasitics, making measurement essential.

It is a common industry practice to set the duty cycle of the PWM controller using a potentiometer which adjusts the control voltage as shown in Fig. 7. The control voltage can then be modulated by ac-coupling to the source of the frequency response analyzer. Care must be taken to keep the power supply operating in its small-signal region at all times, so the proper sized signal must be injected.

Loop Gain Measurement

Once the power stage has been measured, the feedback compensation is designed, and the loop is closed around the system. A very special technique is then used to inject the test signal into the closed loop system, as shown in Fig. 8.

The test voltage is injected differentially across a 20-ohm resistor via a transformer isolator as shown. With this technique, the loop is kept closed in order to regulate the output voltage, but the voltage impressed across the resistor allows the measurement of the open loop gain. In effect, we are electronically breaking the loop, forcing a difference between the loop input and output signals on either side of the resistor. The next article in this series will discuss this in more detail.

Loop measurement is a very powerful design and diagnostic tool. It allows the compensation design to be verified and adjusted for any nonidealities that may arise in the system. It is also a very sensitive measure of almost all of the components in the power system, and can be used to verify that all of the components are correct.

Summary

This article has provided eight of the most common frequency response test circuits used for characterizing power supplies. All of these tests are useful for ensuring the design of a rugged system, and should be a part of the complete documentation package. For many commercial power supplies, the measurement of audiosusceptibility and input impedance is omitted due to the difficulty of signal injection, but these are also essential for more complex power systems, and a requirment for most aerospace systems.

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www.ridleyengineering.com

The Challenges of PoE+

Standardized PSE module simplifies switch design

The IEEE is close to completing the PoE+ standard and network equipment makers are rushing to upgrade their designs, but making the transition can be challenging. A new industry-standard PSE module makes the job a lot easier, reduces time-to-market, and simplifies testing.

By Alison Steer, Product Marketing Manager,
Mixed Signal Products for Linear Technology Corp., Milpitas, CA.

PoE+ is nearly here

The Power over Ethernet (PoE) market has grown tremendously over the past few years. PoE has become almost ubiquitous, with millions of PoE-enabled switches installed all over the world.

The primary application of PoE is still to remotely power IP telephones and wireless access points. Engineers have dreamed of using PoE for many other applications, but too often these dreams have been frustrated by the small amount of available power. Under the original IEEE 802.3af standard, a Powered Device (PD) could only draw up to 12.95W.

The IEEE is about to improve the situation with the eagerly anticipated 802.3at revision (sometimes called PoE+) that is nearing completion. This latest revision will increase the power limit, allowing a PD to draw up to 25.5W, and will open the door to a host of high volume applications such as Pan-Zoom-Tilt (PZT) cameras, multimedia kiosks, industrial controllers, and laptop battery chargers.

Making the transition to PoE+

The challenge now is for Power Sourcing Equipment (PSE) manufacturers to get those high-power PoE+ ports into the field rapidly. High-power PDs won't become commonplace until high-power PSE ports are widely available.

Upgrading an existing PSE design for PoE+ requires:

• Improved Ethernet magnetics that can take more bias current without increased bit error rates at full gigabit line rate.

• New PSE controller chips with higher cutoff current thresholds.

• Depending on which controller chip is used, larger MOSFETs with larger Safe Operating Areas (SOA) may be needed.

• Larger main power supply.

• Miscellaneous components such as connectors, fuses, common-mode chokes, transient voltage suppressor diodes, current-sense resistors, and EMI filters may need to be upgraded for higher currents.

These components are already available and vendors have tried to make their new PoE+ magnetics and chips simple drop-in replacements for 802.3af components as much as practical. But unfortunately, upgrading a PSE design for PoE+ will rarely be as simple as changing the bill of materials; usually, significant PCB layout changes are needed.

Figure 1: 12-Port PSE-ICM, COURTESY OF Tyco Elecronics.

For example, designs that use discrete Ethernet magnetics may need layout changes. The traces that carry gigabit Ethernet data and power from the RJ45 connectors to the transformers must have controlled impedances, but also must be heavy enough to carry the increased current. Many existing designs use single-ended 50Ω traces on inner layers which are typically 6 mils wide in 0.5 oz. (14g.) copper; some designs use closely coupled differential traces where the widths are even narrower. While these layouts may have worked at 400mA for 802.3af, there could be a serious risk of overheating at 600mA for 802.3at. Therefore, a PoE+ switch may need to route these traces on the outer layers where 50Ω line widths are typically 8 to 10 mils. What is more, surface layers are typically 1.5 oz. (42g.), after plating.

But the list of headaches for the switch designer is even longer: the increased heat dissipation may require additional or stronger fans; the whole industry is under pressure to make network equipment more energy efficient; and the upgraded PSE design will have to repeat qualification and certification testing. All of the above mentioned tasks can put a significant burden on switch designers who, in many cases, are already overburdened.

One solution is to use a multi-port PSE module. There have been some module assemblies available for 802.3af PSE in the form of DIMM cards, or power supplies with PSE port circuitry built in. But these types of modules leave the designer some significant challenges because they don't include the Ethernet magnetics or RJ45 connectors. The Ethernet signals must be carefully routed from the connectors through the magnetics to the PHY chips, and power must be routed from the transformer center-taps to the PSE port circuits. As mentioned above, this can be tricky: maintaining controlled impedances, maintaining clearances for high potential (hipot), and making the traces heavy enough to carry maximum current under worst-case thermal conditions is not trivial.

PSE Integrated connector modules

Probably the most elegant approach is to put all of the PSE circuitry and Ethernet magnetics inside a ganged connector assembly. This really simplifies the task of laying out a board because all of the Ethernet signal pins are on the PHY side of the transformers; they don't carry DC currents, so you don't have to worry about the ohms per square of the traces, and you don't have to worry about maintaining clearances for hipot. Just route these signals directly to the PHY chips as normal impedance-controlled traces.

Some PSE modules like this have been available for 802.3af switches but one of their main drawbacks has been a lack of standardization. Each vendor has a specific footprint and electrical characteristics. Once you pick a vendor you're locked into their design.

But that's changed now, thanks to PoETec. PoETec is a consortium of leading manufacturers of network equipment and components, dedicated to advancing and promoting PoE technology. PoETec has developed, and will soon publish a specification for the industry's first standardized PSE module, which they call the PSE Integrated Connector Module (PSE-ICM). The specification defines all aspects of the PSE-ICM characteristics including footprint, signal functions, and the internal register set. So a PSE design that uses one brand of PSE-ICM can simply drop in another brand without changing the board layout or the system software.

Figure 1 shows a 12-port PSE-ICM from one vendor. At the time of this writing, two PoETec member companies (Molex and Tyco Electronics) are shipping PSE-ICMs and two more companies are about to start shipping. Presently, there are 12-port and 8-port PSE-ICMs available; 16-port PSE-ICMs may be coming in the near future. There are also versions with

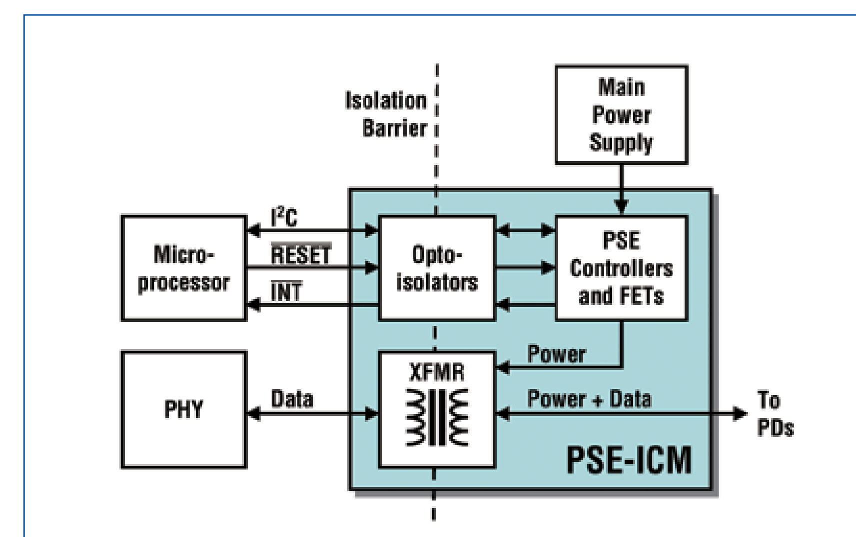

Figure 2: Block Diagram.

COVER STORY

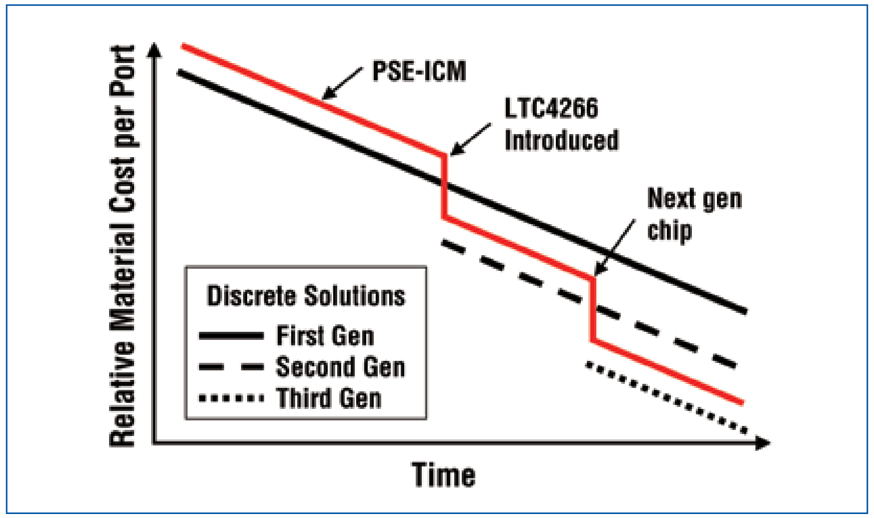

Figure 3: PSE Cost vs. Time.

and without LEDs. Passive modules without the PSE circuitry, just the magnetics, are also available.

Figure 2 shows a simplified block diagram of a 12-port PSE-ICM. It includes an isolated I^2C interface for control and monitoring of PSE functions. Also included, but not shown, are common-mode chokes and terminations. All that's needed is the main power supply and an external microprocessor to run the power management software. The PSE-ICM can also be configured for AUTO mode in which standalone operation is achieved. In this mode, the external microprocessor is not required.

The PSE-ICMs were made practical by some pretty advanced technology, and probably couldn't have been built at a reasonable cost just a year ago. One key enabling technology is the new LTC4266 quad PSE controller chip from Linear Technology Corp. The LTC4266 has the smallest package (5x7mm QFN) and lowest power dissipation of any quad PSE controller in the industry: just 165mW/port at 600mA, including current-sense resistors and MOSFET on-resistance. What is more, the LTC4266 has a unique non-linear foldback feature that protects the module from short circuit faults; without this feature, larger MOSFETs with bigger Safe Operating Area (SOA) would be needed to support the higher current levels reliably.

PSE-ICM advantages

These days, switch designers face many tough engineering challenges. All of the digital and software tasks are difficult enough, without having to worry about analog issues. For example, hipot, EMI, UL certification, lightning surge protection, and heat dissipation are several areas where problems often crop up near the end of a project, when it's most costly and time-consuming to fix them. In fact, these are probably the most common reasons why products miss their launch dates.

The primary advantage of the PSE-ICM is that it's already been through all these tests. Therefore it not only reduces the switch designer's workload, but also reduces the risks of last minute problems. Of course, it's still possible for a switch to fail hipot or EMI because of layout issues outside the PSE-ICM, but the chances of that happening are reduced.

The PSE-ICM also reduces risk because there are multiple sources. This not only creates price-competition, but reduces the risk of late delivery that sometimes occurs when using sole sources for components.

Poor technical support can also lead to project delays and cost overruns. Suppose you're testing a new PSE prototype and one of the MOSFETs overheats. Was the failure due to a bad MOSFET or a bad controller chip? The two vendors will likely point their fingers at each other, while your project slips further behind schedule. But with the PSE-ICM there is no finger pointing; if one PSE-ICM brand seems unreliable, you can simply switch to one of the others with no changes to your board layout or software.

The cost issue

Of course cost is king in the network equipment industry. Some designers may take one look at the PSE-ICM and say it's too expensive, but a smart designer won't be so hasty. The real objective is to reduce overall costs; that's rarely as simple as picking the cheapest parts.

Figure 3 shows a qualitative cost comparison between a discrete design – where the designer places all the PSE components (controller chips, FETs, magnetics, etc.) on the main board – and a design that uses the PSE-ICM.

The graph is intended to illustrate three points:
- The costs of both alternatives decrease over time.
- There are sudden drops in cost when new technologies are introduced.
- The material cost of the discrete approach will always be slightly lower.

Think about the second bullet. One of the advantages of the PSE-ICM is it allows you to more easily keep up with advancing technology and take advantage of the savings. For example, when a new chip that reduces cost is introduced, it may be difficult to use that chip in the discrete design because a new PCB layout would be needed. But when that chip is incorporated into a new PSE-ICM, you can just drop it on your board because the PSE-ICM footprint hasn't changed.

Now think about the third bullet. The discrete approach has a slightly lower material cost, but the PSE-ICM offers a lot of added value that makes up the difference.

For example:
- Shorter time to market. Some products have market windows only 8 to 12 months before they're obsolete. If the launch of such a product were delayed just 2 months, due to PCB layout problems for example, then the overall revenue from that product would be severely reduced. The PSE-ICM can greatly reduce the risk of these delays, and that has economic value that should be counted.

- Lower assembly and test costs. The PSE-ICM obviously reduces assembly cost, but its benefit of reducing test costs should not be overlooked. A designer who goes with the discrete approach must develop test setups and software sufficient to catch all the defects that might occur during the assembly process: at a minimum one would need to verify basic functions such as detection, classification, and disconnect sensing. All these functions are pre-tested in the PSE-ICM; the only testing required would be to verify there are no bent pins or bad solder joints when the PSE-ICM is stuffed on the board. You get almost complete coverage just by running Ethernet traffic on all the ports and verifying the PSE-ICM acknowledges when it is addressed via the I2C bus.

- Lower configuration management costs. For example, PSE-ICMs are available without the PSE electronics in the same footprint. This means a switch maker can design two products (a PoE-enabled switch, and a switch without PoE) that use the same main board; the only difference being which type of PSE-ICM is stuffed.

Conclusions

As the new IEEE 802.3at standard nears completion, many companies are preparing to launch their new PoE+ products. In this environment, where designers have a long list of technical challenges and a wave of competing products is imminent, shortening the design cycle time can be critical for success.

The PSE-ICM can greatly reduce time to market, but offers many other advantages described in this article. The two main drawbacks of previous modules were lack of standardization and high cost, but both of these are addressed by the new PoETec industry standard: Multiple sources are already on line, with more coming. The new PSE-ICMs are already lower cost than their predecessors, and over time competition and technological advances will drive costs down even further.

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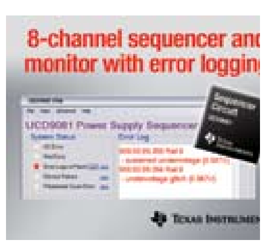

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Capacitance values range from 0.33μF to 20μF and voltage ratings are 50 to 500 VDC. Lead time is stock or four to six weeks.

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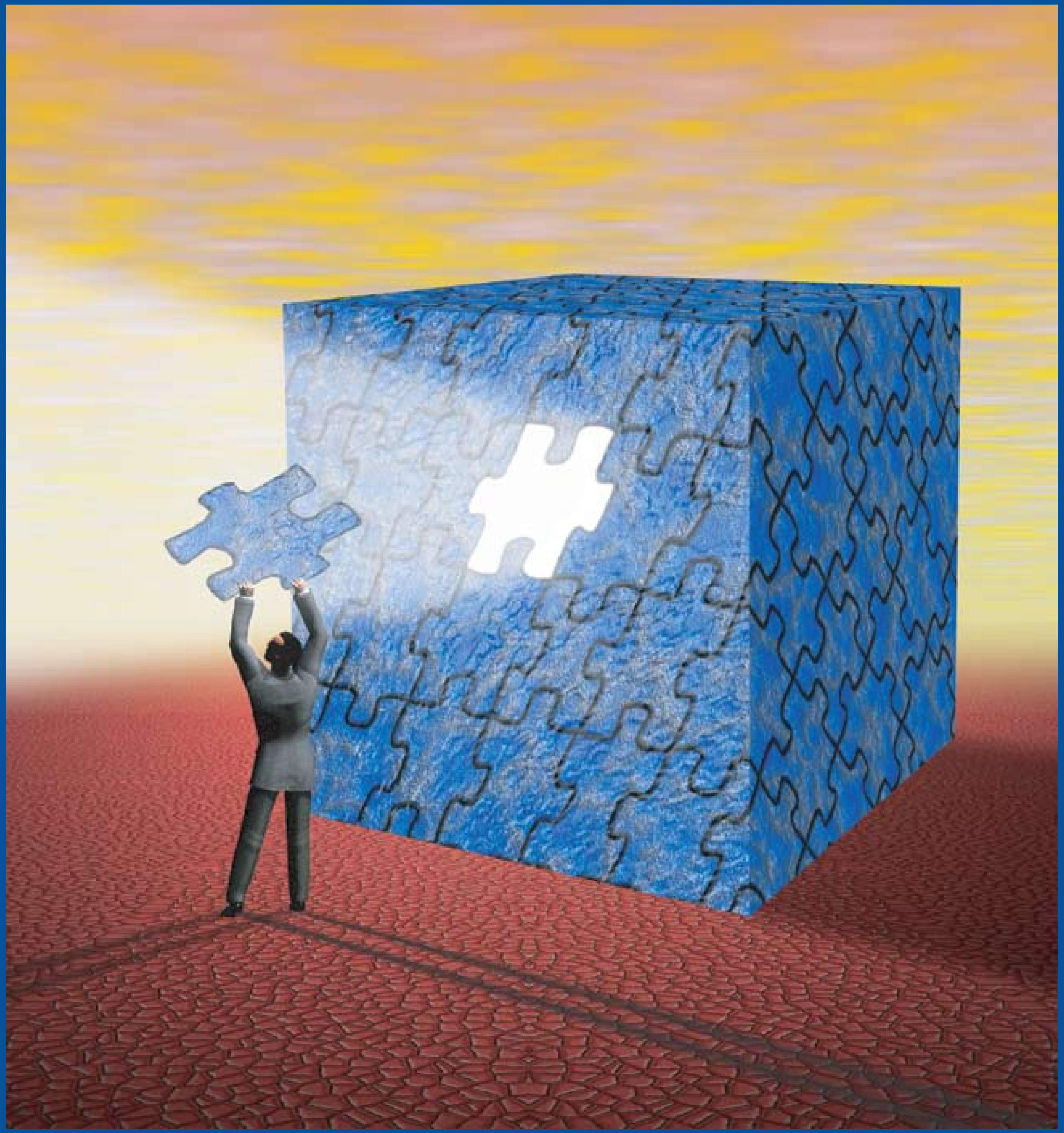

New LED Applications are Unfamiliar Territory

Tools help designers with inductor selection

New LED developments are making many new lighting applications possible, but some designers must now confront challenges in areas outside their traditional expertise.

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

A product we are all familiar with as consumers, the traditional incandescent flashlight, usually has a very basic circuit design: batteries, a light bulb, an on-off switch, and a way to connect them all. By contrast, opening one of the new LED flashlights now on store shelves reveals a much greater electronic complexity. They use a variety of driver circuits with a wide array of components. It is easy to imagine that flashlight designers have always required a large measure of specialized expertise to produce ruggedized items for uses like sporting and police, fire and rescue applications. But they didn't necessarily need to be experienced with dc-dc converters, let alone components like the power inductors that make up a typical dc-dc converter bill of material.

As the range of new LED lighting applications grows, it is also easy to imagine this scenario repeating itself for a variety of lighting products. It is incumbent on established power component manufacturers to help these new industries adapt existing dc-dc converter expertise into their designs – and do it in ways that achieve the performance and energy efficiency promised by new lighting applications. This article examines the ways an experienced engineer can quickly and easily access existing dc-dc converter expertise including magnetic component detail.

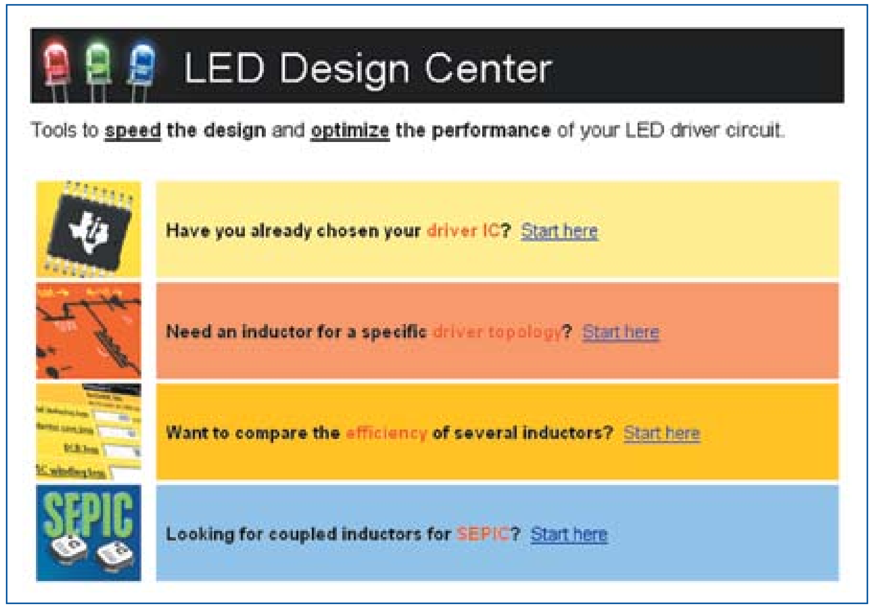

Figure 1: Coilcraft LED Design Center options.

Coilcraft has created several tools to guide the user in the selection of inductors. These tools are available in the new LED Design Center as shown in Figure 1. The tools are arranged to provide the user a choice of starting points.

Starting from the driver IC

The list of LED driver circuit ICs is long and includes all the well known names such as Allegro Micro, Austria Microsystems, Durel, Fairchild, Freescale, Linear Technology, Maxim, National Semiconductor, NXP, ON Semiconductor, STMicroelectronics and Texas Instruments. Documentation from IC companies typically includes not only the technical specifications for their products but also design examples and application hints. Often complete ready-to-use evaluation or demonstration kits are made available.

In addition to the usual reference design information, companies have implemented special LED design centers as a way to gather the information related specifically to lighting applications. National Semiconductor, for example, offers the on-line WEBENCH LED Designer as part of its renowned WEBENCH Designer tool set. Texas Instruments' web offerings for Power Management Products feature an LED Driver, Lighting & Display Solutions section, and Linear Technologies lists an LED Driver ICs page. These are just examples of the lengths the driver IC makers are going to support the fledgling LED lighting market.

The Coilcraft LED Design Centers collects information on LED driver ICs and connects the user to the appropriate inductors with its Inductor Matching Tool. This tool starts by helping the user select from a list of the IC companies, driver ICs, and specific application of interest as shown in Figure 2.

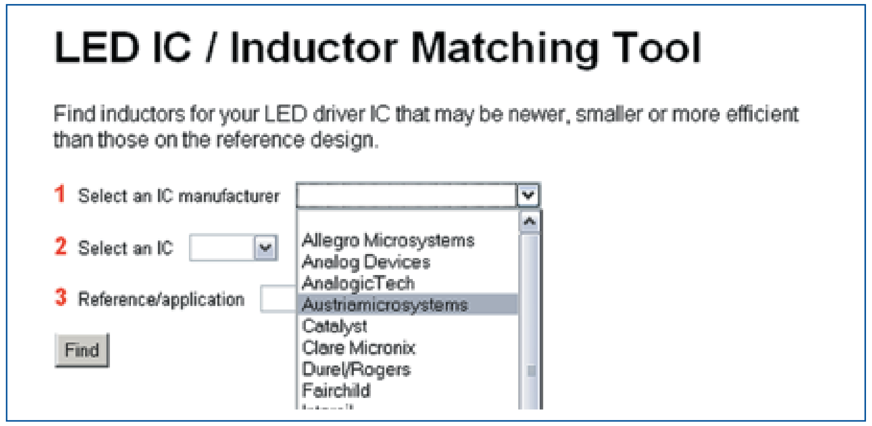

Figure 2: LED driver IC and inductor matching tool.

From the selected information, the tool provides the appropriate inductor information for the application. Figure 3 shows a typical result which features a summary of the inductor parameters and a live link to the complete inductor specification. Because the inductors listed as solutions are pulled from a live database of active part numbers, this tool is more powerful than a simple cross-reference list to the inductors listed in the IC reference design. This feature provides the user with an always up-to-date list of the available inductors, not limited to those inductors identified by the reference design at the time of publication.

Starting with the LED

As the heart of the application, the properties of the LED device itself and the operating requirements are necessarily the starting point for most designs. For example, the basic

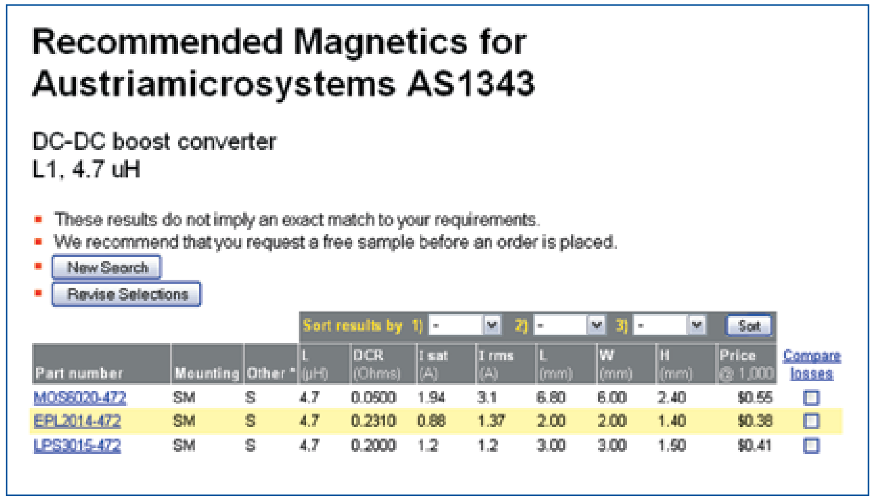

Figure 3: Inductor solutions found by IC/Inductor matching tool.

Company	Part Number	Vf	Io	Color	Reference
Avago	ASMT-MW00	3.6	0.35	Cool white	www.avagotech.com
Cree	XRCWHT-L1-0000-00601	3.5	0.35	Cool white	www.cree.com
Everlight	EHP-AX08B/CT01H-P01	3.5	0.35	Cool white	www.everlight.com
Lite-on	LOPL-E011WA	3.8	0.35	white	www.us.liteon.com
Osram	LW-W5SM	3.2	0.35	White	www.osram-os.com
Philips Lumileds	LXK2-PW12-S00	3.42	0.35	White	www.philipslumileds.com
Seoul Semiconductor	W10190	3.5	0.35	Cool white	www.seoulsemicon.com

Table 1: Typical white LEDs

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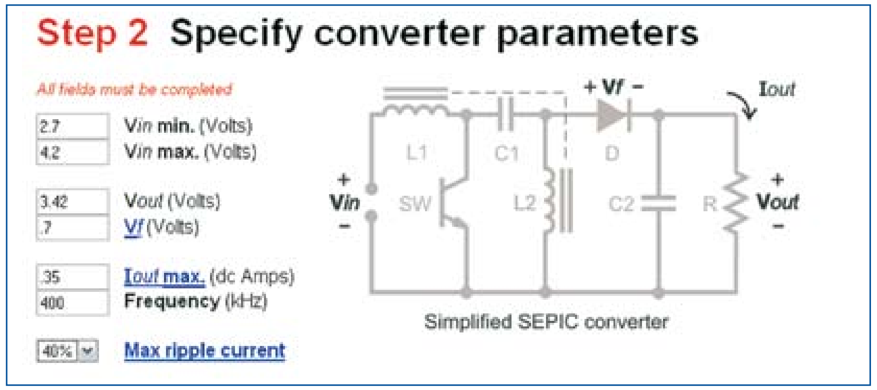

Figure 4: SEPIC input screen.

Step 3 Review inductor requirements

Inductor 1		Inductor 2			
11.50	L min. (µH)	11.50	L min. (µH)	0.50	Duty cycle (min)
0.58	Isat (A)	0.44	Isat (A)	0.60	Duty cycle (max)
0.49	Irms (A)	0.35	Irms (A)		

Figure 5: Coupled inductor results.

Step 4 Suitable coupled inductors

- Your minimum requirements: Inductance 11.50 uH Isat 0.58 A Irms 0.49 A
- Click on a part number to view the complete data sheet.
- We recommend that you request free evaluation samples for testing.
- New Search

Sort results 1) - 2) - 3) - Sort

Part number	Mounting	Other *	L (µH)	DCR (Ohms)	I sat (A)	I rms (A)	L (mm)	W (mm)	H (mm)	Price @ 1,000	Compare losses
MSD1278-123	SM	S,C	12.0	0.0620	9.6	3.5	12.30	12.30	8.05	$0.64	☐
MSD1260-123	SM	S,C	12.0	0.0740	6.86	3.12	12.30	12.30	6.00	$0.58	☐
MSD7342-123	SM	S,C	12.0	0.1200	2.7	1.61	7.50	7.50	4.60	$0.57	☐

Figure 6: Standard coupled inductors.

operating parameters like those shown in Table 1 are easily found from the LED data sheets.

Most web sites from these manufacturers provide a variety of helpful application tips, including lists of technology partners to facilitate the integration of different areas of expertise.

Starting with choice of driver circuit topology

Using the LED specifications provided by the manufacturers, and depending on the available input voltages and the number of LEDs to be driven, the engineer might prefer to specify the driver topology: buck, boost, buck-boost or SEPIC. The Coilcraft LED Design Center can quickly identify the correct inductor for each of those.

For example, this tool can be used in the selection of coupled inductors for SEPIC converters to drive the white LEDs shown in Table 1. Typically these white LEDs are specified for driving with forward currents of 350 mA, which can be supplied from a single Li-ion battery, the typical power source of handheld devices. The basic requirements for driving a single one of these might be as follows.

Fsw = 400kHz / Vin = 2.7 to 4.2Vdc / Vo = 3.42Vdc / Io = 35mA

The challenge with this design is to operate from as wide a voltage range as possible in order to maximize the battery life per charge. During charging, the Li-ion cell voltage is greater than the output voltage, while at the end of the charge cycle the cell voltage will be less than the desired output. Therefore, neither a buck nor boost regulator will be sufficient for this purpose and so the increasingly popular SEPIC topology is chosen.

The Coilcraft LED Design Center includes coupled inductor selection for SEPIC converters as shown in Figure 4. The SEPIC input screen requests the input/output specifications, the switching frequency and asks the user to select the allowed ripple current.

For a SEPIC coupled inductor the requirements for each winding must be calculated separately to determine the expected peak and average current, which may differ between L1 and L2 depending on the operating conditions. The Coilcraft tool calculates both L1 and L2 requirements and presents the results as shown in figure 5.

The list of standard parts that meet this requirement is then returned (as shown in Figure 6), and the user is allowed to choose, the most suitable inductor for the application, depending on the parameters of most interest.

It is always helpful to offer tools that serve a wide range of experience and expertise, and it is especially important in a developing space that may draw from previously unrelated industries and applications. In the broad field of LED lighting applications, such a variety is being offered by an increasing number of LED, IC, and passive component suppliers.

www.COILCRAFT.com

HB-LED Lighting Solutions

Illuminating the way forward

The continuing evolution of LED-based lighting solutions has been driven by market factors such as increasing optical efficiency, better color performance, maximized product life, reduction of maintenance costs, and reduced environmental impacts.

By Troy Wu, Director, R&D Division, Everlight Electronics, Taipei, Taiwan

In order to provide lighting customers with the best service for their new LED lighting and luminaire products, Everlight Electronics has invested more than five years in developing high power LED emitters, and is likely to be one of the industry's most important high power LED suppliers. Besides high power LED emitters, Everlight also develops complete LED light engine solutions which integrate the capabilities of LED selections, mechanical designs, optical design, thermal management, LED driver design and assembly, to reduce customer design time and costs.

High power LEDs

High power LED emitters are core components for LED lighting fixtures as their optical efficiency is a key factor to determine the performance of LED lighting fixtures. Currently, the company can offer high power LEDs with 90lm/W at 1W operation, and expects to provide 100lm/W at 1W operation in the second quarter of 2009.

Lumens per package is a key index of high power LED packaging which strongly influences the total cost of LED lighting fixtures. Figure 1 shows the roadmap of lumen output per LED packaging of Everlight high power

Power Consumption	2008	2009	2010
5W	CC: 300lm WW: 250lm	CC: 360lm WW: 300lm	CC: 400lm WW: 330lm
3W	CC: 200lm WW: 160lm	CC: 250lm WW: 210lm	CC: 300lm WW: 250lm
1W	CC: 90lm WW: 70lm; CC: 750lm WW: 60lm	CC: 110lm WW: 90lm; CC: 100lm WW: 85lm	CC: 150lm WW: 130lm; CC: 150lm WW: 110lm
0.5W	CC: 40lm WW: 30lm	CC: 55lm WW: 48lm	CC: 70lm WW: 60lm

(CC: Cool white, 6500K / WW: Warm white, 3000K)

Figure 1: The lumen output of Everlight high power LED packages.

Figure 2: The concept of Everlight LED light engine solution.

Figure 3: SL-Dolphin street light.

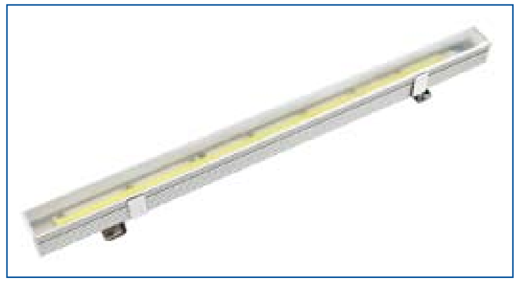

Figure 5: E-Skyline MI750.

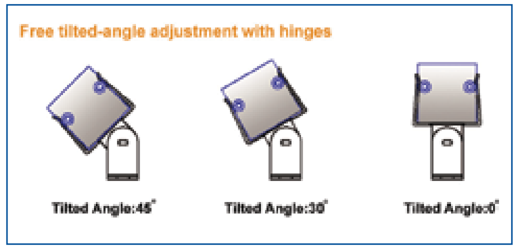

Figure 6: Mounting hinge for E-Skyline MI750.

LEDs. For example, 0.5W LEDs that achieve 40lm at 6500K today are expected to achieve 55lm in 2009 and 70lm in 2010. The expected figures for 1, 3 and 5W LEDs with 90, 200 and 300lm respectively at 6500K today are expected to offer 110, 250 and 360lm in 2009 and 150, 300, 400 lm in 2010.

LED lighting modules

In order to provide convenient LED lighting solutions and reduce costs, Everlight proposes and offers LED light engine solutions which integrate the capabilities of LED selections, mechanical designs, optical design, thermal management, LED driver design and assembly. This means one-stop shopping for LED lighting customers from LED to a complete module that saves both design time and development costs. Figure 2 shows the concept of Everlight LED light engine solutions.

LED light engine reference models

Several standard LED light engine models have been developed based on indoor or outdoor applications. Two examples serve as reference designs and illustrate Everlight's light engine concept: the SL-Dolphin street light and the E-Skyline MI750 high efficiency linear luminaire.

Dolphin Street lamp

Figure 3 shows the photo of an SL-Dolphin street light. Currently 60W, 90W, 120W are available for pole heights up to 8m. The life time of the LED module is L70>35,000hours, a 3 year warranty is available. The Dolphin street lamp is designed for IP65 water and dust proof. The light distribution of SL-Dolphin follows street lighting regulations. As an alternative to choosing the complete SL-Dolphin fixture, customers can select the light source of the Dolphin assembly, called Phoenix (Fig. 4), for their own lighting fixture housing design. The Phoenix can also perform IP65 water and dust proof and L70>35.000 hours with a suitable heat dissipation design based on the metal housing.

Figure 4: Designers can select the Dolphin light source, Phoenix, for their own lighting fixture housing design.

E-Skyline MI750

Figure 5 shows the photo of the linear lighting fixture E-Skyline MI750. This is a high quality, high efficiency linear luminaire suitable for indoor decoration lighting and general lighting applications. There are 3 types of beam angle available: 15°, 60° and 120°. The power consumption of E-skyline MI750 is 6W and an excellent thermal management design can keep the surface cool enough (under 50°C) when is operated. The on-board driver design allows for a serial connection of 10 E-Skyline fixtures with only one 60W/24VDC power supply that can easily be bought from the electric shop next door, thereby reducing the power supply costs. A tilt angle adjustable hinge is designed to mount E-Skylines as shown in Figure 6.

The future of the lighting systems industry promises steady growth as regions around the world adopt more efficient and environmentally friendly technologies. Regulation plays its part, but it will be the economic factors together with the quality of electronic and mechanical innovations that designers and manufacturers can deliver, that will differentiate companies in this market.

www.everlight.com

Taking a Dim View

Solutions to simplify dimming of fluorescent lamps

There is much in the news these days about LED lighting and the circuits developed to drive then. Fluorescent lamps however, are still widely used and are energy efficient. The drawbacks in the past have been the difficulties associated with adjusting the light output from these lamps. This article looks at the requirements for dimming fluorescent lamps and highlights how a new generation of control ICs can simplify future designs.

By Tom Ribarich, Director of Lighting Design, International Rectifier

Designers employ a variety of techniques to provide users with the ability to dim fluorescent lamps. Common approaches include DALI (digitally addressable lighting interface), triac-based wall dimmers, power line communication, 1VDC-10VDC interfaces and even wireless control. These all, however, require additional wiring at the electronic ballast during installation. Now new IC technologies are set to remove the need for this additional wiring and, therefore, speed, simplify and reduce the cost of dimmable fluorescent designs.

Driving and Dimming Fluorescent Lamps

Fluorescent lamps require a current to preheat the filaments, a high voltage for ignition, and a high-frequency AC current during operation. An electronic ballast circuit must first perform a low-frequency AC-to-DC conversion at the input, followed by a high-frequency DC-to-AC conversion at the output.

Figure 1 shows a block diagram of a ballast for such a lamp, including a dimming circuit that combines a dimming reference signal, a lamp current sensing and feedback signal, and a summing circuit for closed-loop lamp current control.

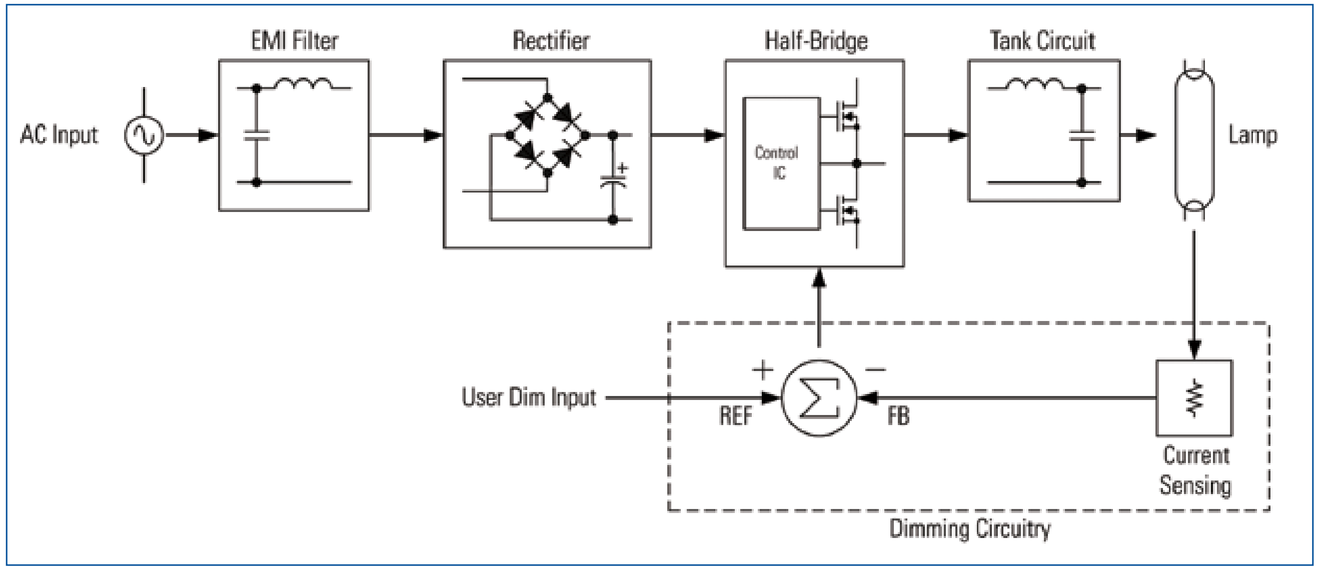

Figure 1: Dimming electronic ballast block diagram.

Special Report – Lighting Systems

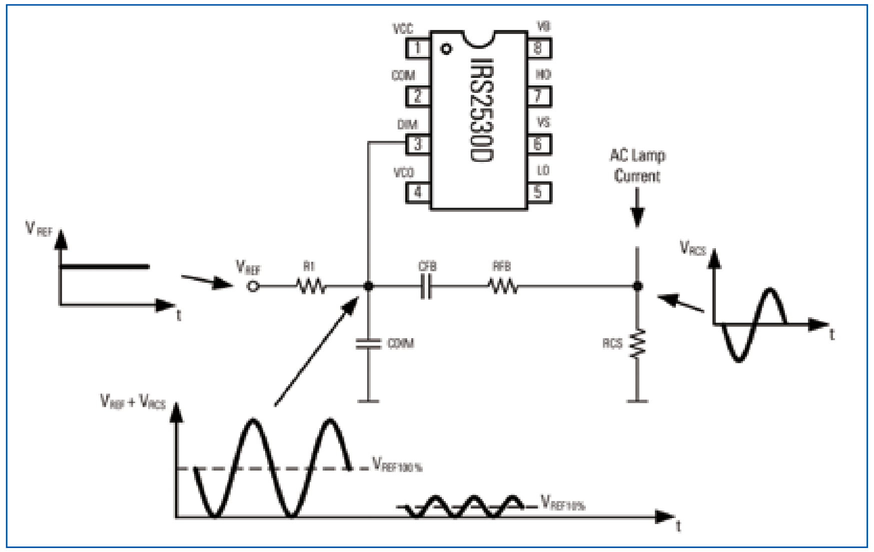

Figure 2: IRS2530D AC+DC dimming control method.

After passing through an EMI filter to block switching noise, the AC mains voltage is full-wave rectified and then peak-charges a capacitor to produce a smooth DC bus voltage. The DC bus voltage is then converted into a high-frequency, 50% duty-cycle, AC square-wave voltage using a standard half-bridge switching circuit. The high-frequency AC square-wave voltage then drives the resonant tank circuit to produce a filtered sinusoidal current and voltage at the lamp.

During operation the resonant tank, which is a series-LC circuit with a high Q-factor during the pre-ignition phase, becomes a series-L, parallel-RC circuit with a Q-factor somewhere between a high and low value depending on the lamp dimming level. When the CFL is first turned on, the control IC sweeps the half-bridge frequency from the maximum frequency towards the resonance frequency of the high-Q ballast output stage. The lamp filaments are preheated as the frequency decreases and the lamp voltage and load current increase. As the frequency decreases the voltage rises and the lamp ignites when lamp ignition voltage threshold is reached. Lamp current is then controlled to maintain the correct power and brightness level.

Increasing the frequency of the half-bridge reduces resonant tank circuit gain, leading to decreased lamp current and, therefore, lamp dimming. The closed-loop feedback circuit measures the lamp current and continuously adjusts the half-bridge frequency to regulate it to the dimming reference level.

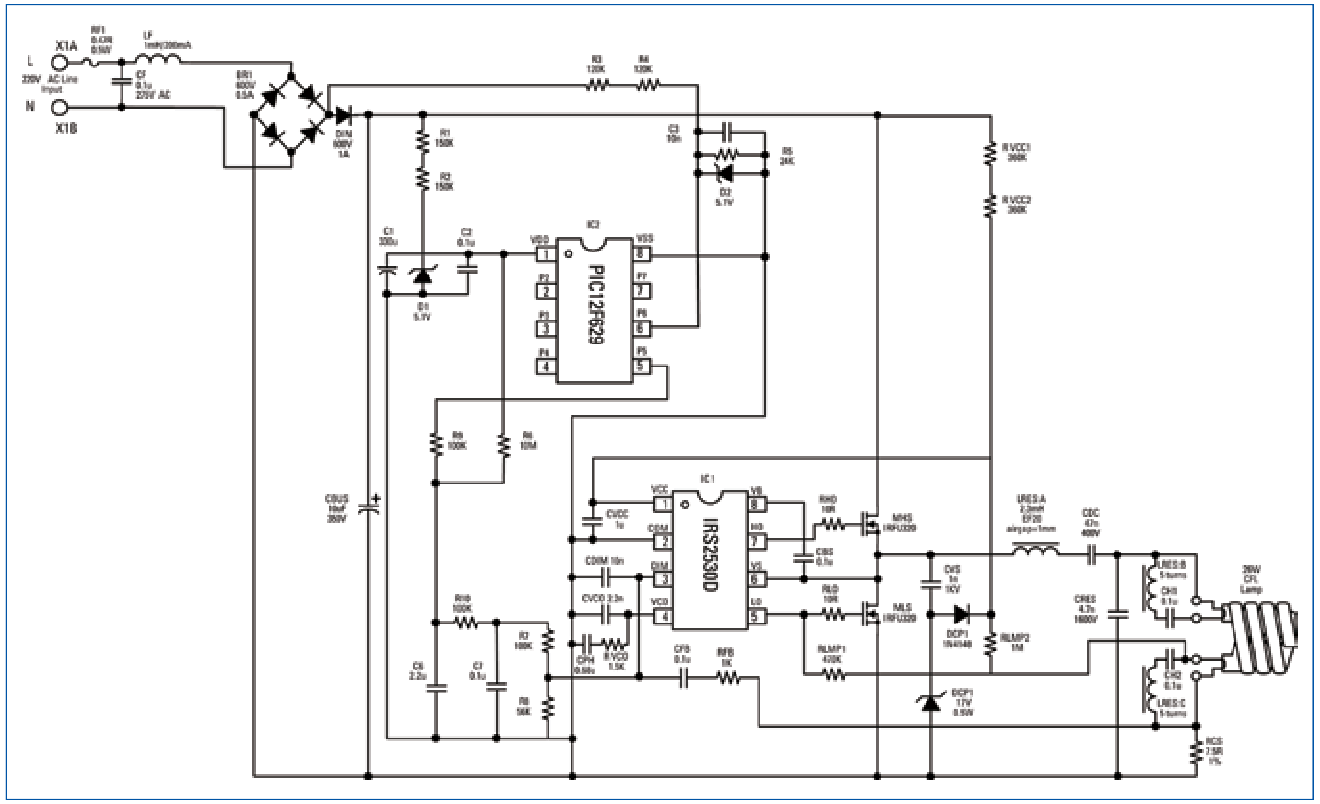

Figure 3: Schematic of quad-level dimming circuit.

Control IC

Choice of control IC for a dimming application is clearly important and International Rectifier's IRS2530D provides a good example of the current state of play. This device incorporates all of the functions to preheat and ignite the lamp, and a variety of protection against fault conditions such as open filament failures, lamp non-strike and mains brown-out.

Figure 2 shows how the AC lamp current measurement across the sensing resistor RCS is coupled onto the DC dimming reference through a feedback capacitor CFB and resistor RFB. This allows the dimming function to be realized by combining the AC lamp current measurement with the DC reference voltage at a single node. The IC's feedback circuit continuously adjusts the half-bridge frequency so as to regulate the valley of the AC+DC signal to COM as the DC dimming level is increased or decreased. This causes lamp current to increase or decrease for dimming.

Quad-Level Dimming

Now let's consider how a device such as the IRS2530D can be used to implement a four-level dimming design that will help to reduce the problem of additional ballast wiring mentioned earlier.

Figure 3 shows a schematic of the quad-level switch dim ballast design that combines an EMI filter, a full-bridge rectifier and smoothing DC bus capacitor, the IRS2530D "*DIM8™*" dimming control IC, a switching half-bridge and resonant tank circuit to preheat, ignite and run the lamp. In this design a microcontroller is used to set and store the dimming level, and a pulse detection circuit to detect when the AC input voltage turns on and off.

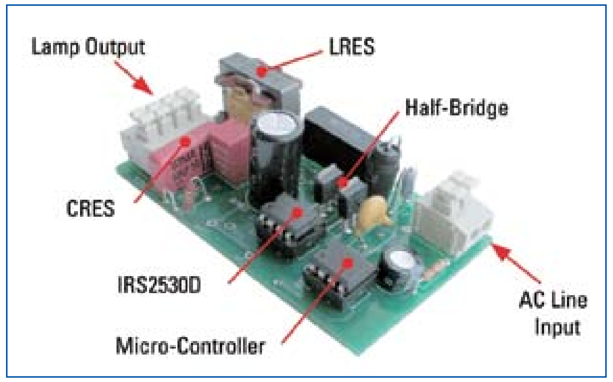

Figure 4: Quad-level fluorescent dimmer reference design.

The lamp arc current is detected through RCS after ignition and coupled onto a DC reference voltage to provide an AC signal with a DC offset at the DIM pin of the IRS2530D. During DIM mode, the IRS2530D adjusts the oscillator frequency in order to maintain the amplitude of this feedback signal and control the lamp current for dimming. The frequency of the HO and LO gate driver outputs is set by the voltage at the VCO pin of the IRS2530D and the Capacitor CPH is used to program the frequency sweep time for preheat and ignition of the lamp.

At turn-on, the voltage at the VCO pin will ramp up from 0V causing the frequency to decrease from the maximum frequency down to the minimum frequency. As the frequency continues to fall towards the resonance frequency of the tank circuit, the lamp voltage increases until the lamp ignites. The lamp arc current begins to flow and a feedback signal is produced at the current sense resistor RCS. If ignition fails then the IRS2530D will shut down, going into a low VCC current fault mode.

The DC dimming reference at the DIM pin is derived from an RC-filtered square wave voltage generated by the microcontroller. This microcontroller controls the four dim levels by using a fixed frequency signal at four separate duty-cycle modes of 100%, 66%, 33% and 10%. Highest brightness level is achieved with the highest duty cycle.

Pin 6 of the control IC is connected to the AC line input voltage through a fast delay circuit, which is used to detect fast on/off cycles of the AC line input. When the AC line is switched off the IC - which can continue to run for more than one second after removal of the AC line thanks to the VDD supply capacitor - detects this and starts a timer. Restoring power within one second reduces the output square-wave duty-cycle and, therefore, the dimming by one step (unless the dimming level is already at minimum then it cycles back to maximum). If the AC line is removed for more than one second, the dimming level will not change. After the supply capacitor has discharged below the minimum operating voltage of the control IC the microcontroller will shut off.

Summary

Implementing a ballast circuit based on the IRS2530D dimming control IC, a microcontroller and a pulse detection circuit as described above provides an elegant solution for delivering four different levels of brightness by sensing the on/off switching of the AC mains voltage. The IC itself incorporates complete ballast control, dimming feedback loop and fault protection, simplifying overall design and leaving the engineer free to concentrate on other aspects of the design.

To help designers evaluate and implement quad-level dimming solutions as described here, International rectifier is offering a complete reference design (Figure 4) based on a two-layer PCB with small form factor that is suitable for driving a 26W fluorescent lamp.

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Backlighting for Optimized Color

RGB LED driver solution

In order to obtain the best color display in mid-size TFT screens, such as in the popular 7-inch photo frames, RGB LED backlight provides an ideal solution. Using RGB LED backlighting, it is possible to obtain a better NTSC color gamut range, realistic to the human eye. This article discusses the RGB LED driver circuit and outlines a complete RGB LED solution.

By Man Lau, Senior Application Engineer, National Semiconductor, Hong Kong

Since the LCD display is unable to emit light by itself, it must rely on backlight for projecting the colorful images onto the screen. Traditionally, CCFL has been widely used as a light source, but there is now a powerful move towards the use of LEDs with more and more electronic products offering built-in LCD displays illuminated by LED backlights.

Simple, low-end products use white LEDs while higher quality models use RGB LEDs. The white LED is basically a blue LED with a coating of phosphorus which enables the blue light to be converted into red, green and blue lights. If the lights are mixed in the correct proportions, they will be seen by the human eye as white light. Although the circuit design for white LED applications is simple, the color gamut is much more limited than that offered by RGB LEDs.

Basically, white LEDs and CCFL do not differ greatly in terms of color gamut. However, since LEDs offer the added advantages of higher performance, longer life and simpler circuit design, they have a competitive edge over CCFL and hence have a wider variety of applications. Handheld products are a typical example.

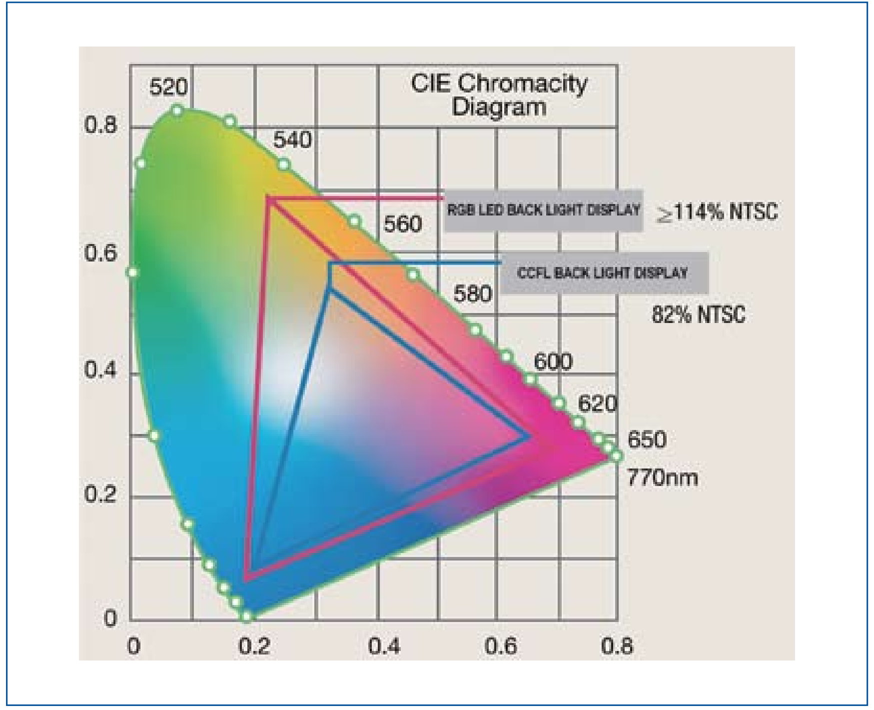

Figure 1: Color gamut of NTSC.

Figure 1 shows the color gamut of CCFL and RGB LED backlighting systems. The advantages of RGB LED backlighting are obvious, especially when it comes to applications that are demanding in terms of color accuracy, such as electronic photo frames, which require a full-range color gamut.

Color correction is another important feature. The inherent nature of RGB LEDs enables the user to exercise control over many aspects of the LEDs. The fine shades of a wide range of colors can be easily adjusted making design much more straightforward as individual preferences can be accommodated.

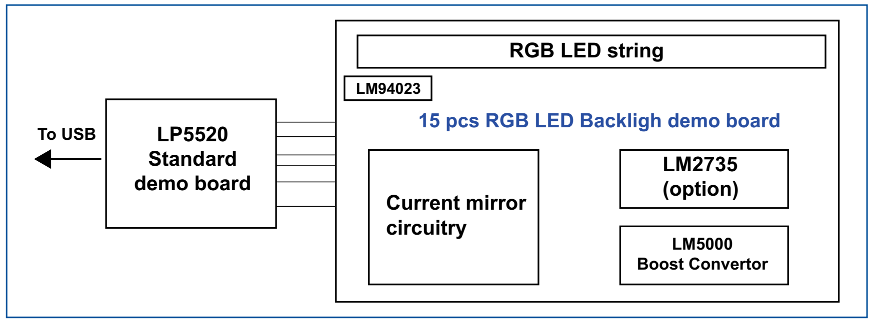

Figure 2: Block diagram of the expanded LP5520 RGB LED driver circuit.

Reference design

National Semiconductor's LP5520 is an RGB LED driver for backlighting systems of small LCDs. Capable of driving four to 4 ~ 5 RGB LEDs, it is able to meet the backlighting needs of a typical small-size LCD display. Details of the specifications of the LP5520 driver are provided in the data sheet. A typical medium-size photo frame is normally 7-inch in size. For a display of this size, its backlighting system requires more than 15 RGB LEDs. In order to take full advantage of the color correction capability and driving power of the LP5520 driver, its typical circuit design has been modified. For example, the LM5000 or LM2735 DC-DC step-up converter and current mirror circuitry are added for higher number of LED application, which enables the entire circuit to drive 15 RGB LEDs. This ensures that the driving current flowing through various strings of RGB LEDs and the driving current provided by LP5520 will remain steady and constant, with no difference between them. Figure 2 is the block diagram of the demonstration circuit.

The LM94023 is an analog temperature sensor. It sends all temperature data back to the LP5520 driver. After receiving the temperature data, the LP5520 driver checks with the EEPROM for the corrected, temperature-compensated PWM values and based on the compensated values, drive the R, G and B LEDs respectively. This will then ensure that the RGB LEDs emit truly white lights.

Calibration of RGB LEDs

In order to emit truly white light, all RGB LEDs must undergo precise calibration. The RGB LED can only emit white light when the intensity of the red, green and blue lights (primary colors) is at the correct level. The intensity of light of each color will vary with the change of temperature while their respective wavelengths, especially that of red light, will also vary with temperature changes. In order to maintain the same light intensity throughout, white balance should be compensated very accurately.

The LP5520 driver allows the respective changes in intensity and wavelength to be compensated according to the values provided by the typical intensity versus temperature function of the RGB LED. Throughout the process of correction, the PWM value determines the intensity of light of a particular color.

Since all LEDs undergo adjustments during production, any slight difference between various parts can be ignored and because room temperature is in the center of the temperature range, the sample performs best at this temperature. As the temperature moves towards the two extremes, the difference in color will be more apparent. Figure 3 shows the block diagram of the correction circuit.

Specific correction steps:

1) Switch to the Manual Operation Mode of the circuit and set the LED current. The LED of each color may have a different current and this means

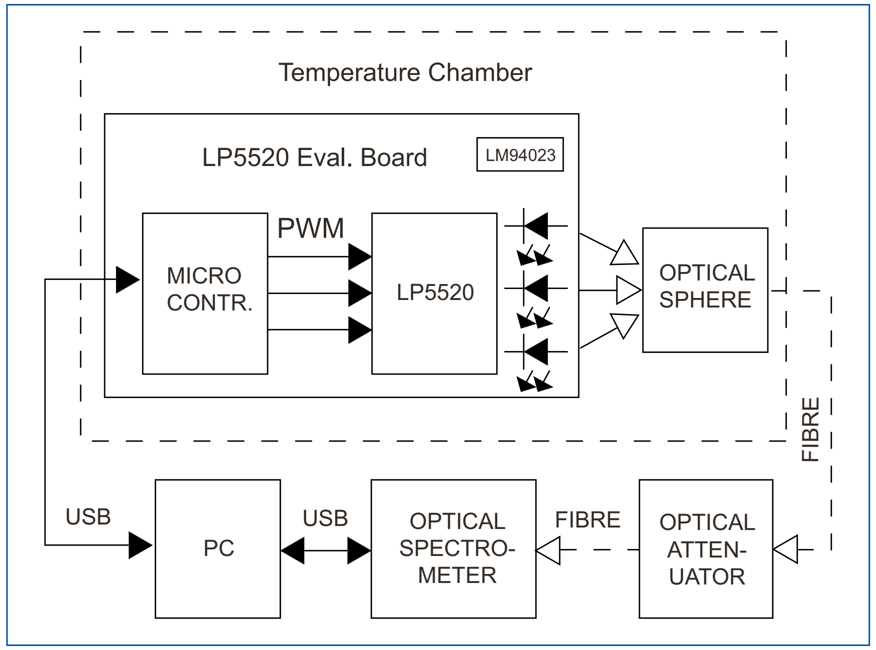

Figure 3: Block diagram of correction circuit.

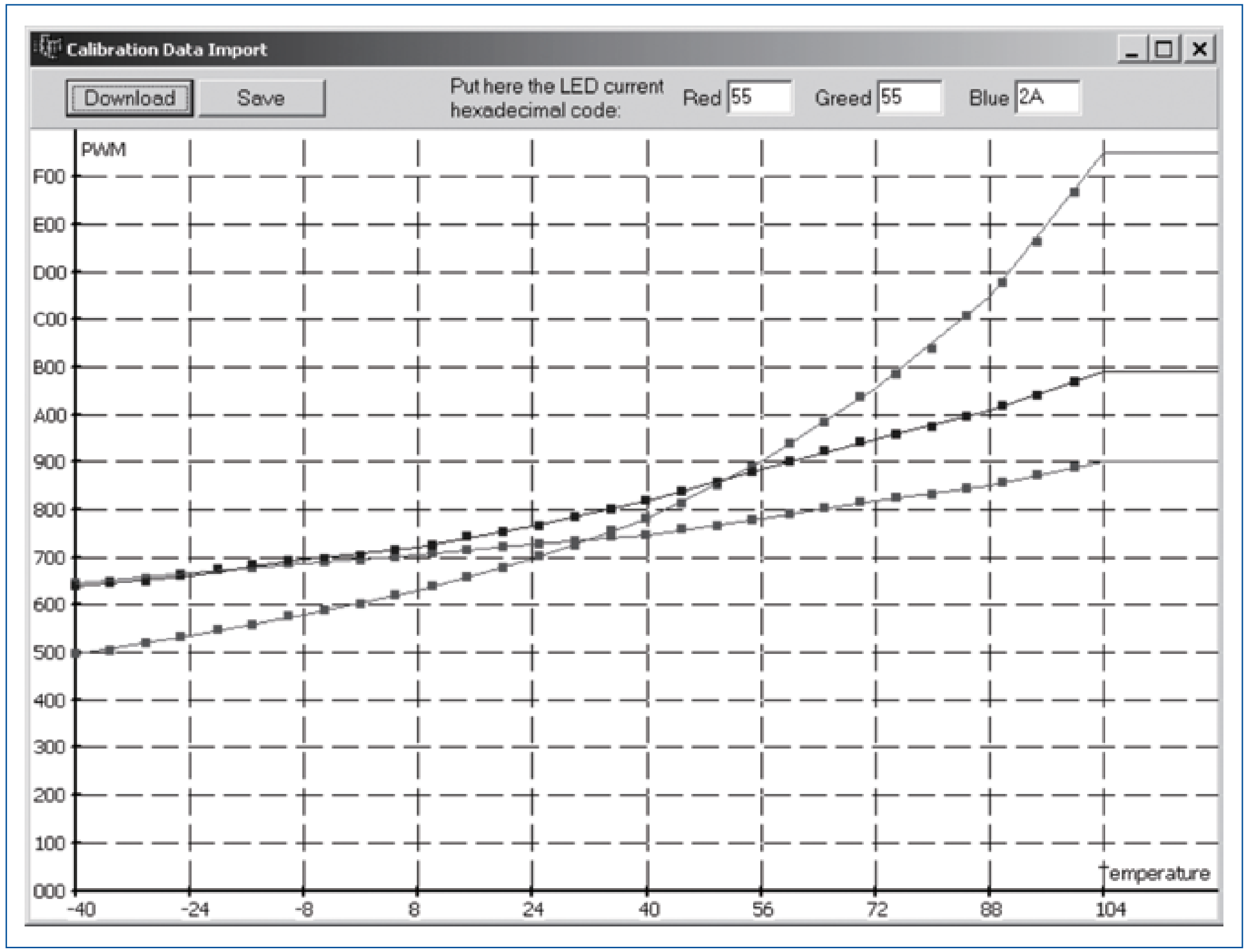

Figure 4: Correction and measurements of sample.

setting the PWM value. Theoretically, in the highest temperature range, the PWM mode operates at its peak duty cycle. In practice, however, the difference in the magnitude of the current must not exceed 50%.

2) Set the first temperature point (the highest temperature that can be measured - it should be slightly higher than 100ºC).

3) For the intensity of the blue light, a default value may be used (e.g. 1500 should be used for 4096 on the scale - this depends on the type of RGB LED used). In order to take full advantage of the PWM range, the PWM value of red light at high temperatures should be around OxF00 (3840). The software program will then ensure that the PWM values of all LEDs be re-set until the white light emitted meets specific color requirements. In order to ensure the highest degree of precision for all measurements, the amplitude of the highest frequencies measured by an optical attenuator on an almost full-range basis is then adjusted.

4) Change the temperature to the next measurement point (5ºC lower). A new PWM value is then used while white balance is maintained throughout by the software program. Once the temperature reaches the pre-set point, the PWM value of each LED is then stored. (The lowest temperature point used is slightly lower than -40ºC, with every 5ºC taken as one step change. The hot box used takes about an hour to cool down from its highest temperature to its lowest.)

5) Based on the measured values, a curve is then plotted (Figure 4).

Conclusion

The use of an internal correction memory enables the designer to use the LP5520 driver conveniently to control the RGB LED and ensure that it will produce a truly white light across a wide temperature range. This will then enable the LCD monitor to display the best possible images on the screen. In addition, the end-user may also adjust the LCD display according to individual preferences.

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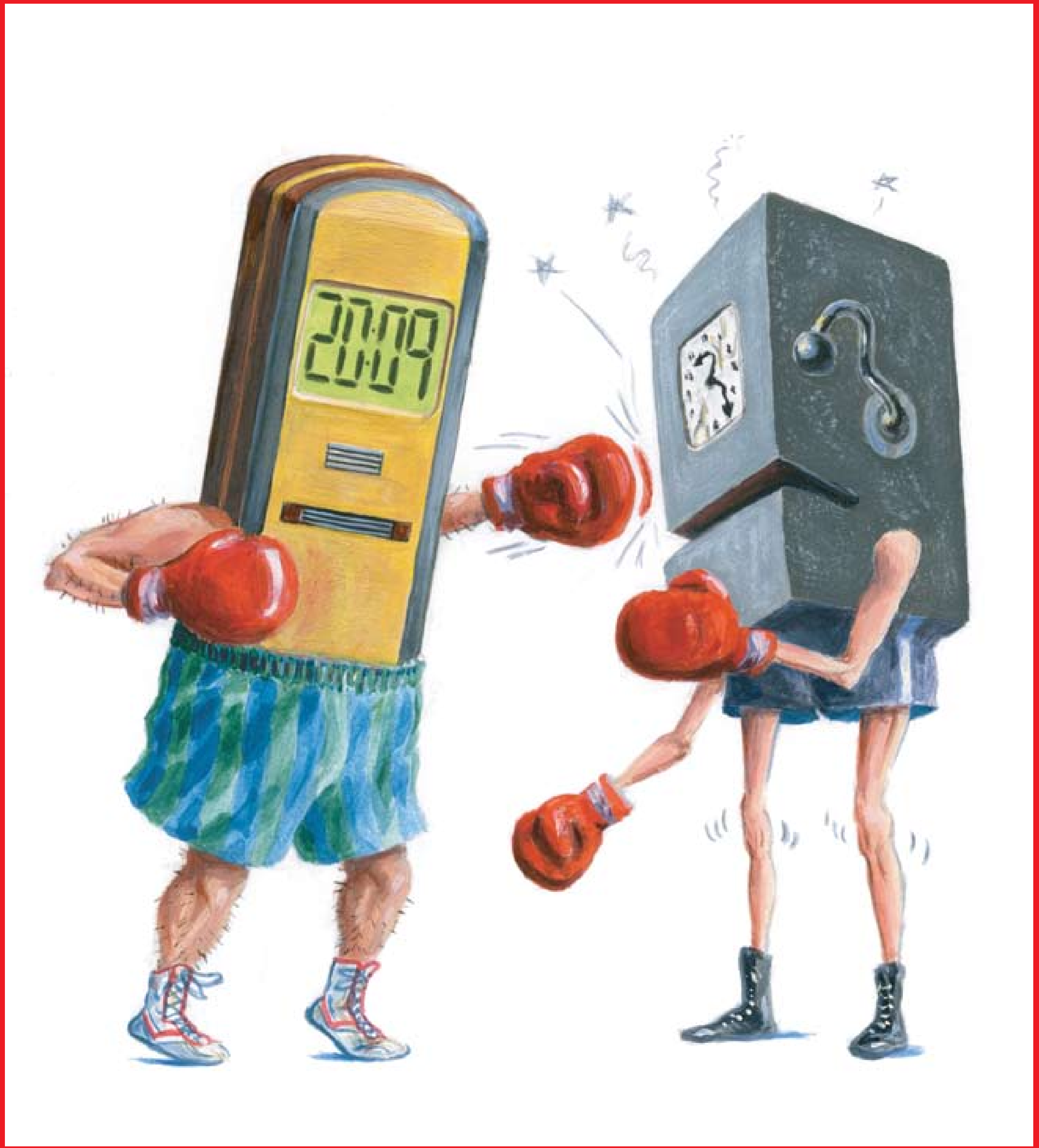

Digital Power Eases Designer's Burden

DC-DC conversion with Auto-control™

Regulation of supply rails, from a control perspective is traditionally the domain of analog integrated circuits. But current trends in power conversion are moving the industry to smaller and more efficient power architectures. The requirement to intelligently manage the multiple power rails under these constraints of space and efficiency is driving the industry towards research, development and adoption of digital power control and power management solutions.

By Anthony Kelly Ph.D. MBA, VP Digital Control, Powervation, Limerick, Ireland

The economics of IC design support the adoption of digital power control because the cost reduction of digital circuits is more rapid over time, leading to cost parity of digital and analog power control ICs, with digital solutions ultimately being cheaper. Factoring in the requirement for advanced power management, which is a digital function, the economics of IC design point to increased demand for digital power controllers and therefore they are expected to be a very significant proportion of the market (greater than 40%) by 2011.

Taken together, these trends indicate that there is significant potential for the development of power control technologies which harness uniquely digital techniques in order to deliver improvements in power system design. Indeed, such improvements have been looked forward to for some time. Now it is time to deliver.

We will examine DC-DC conversion from a control perspective, introducing key differences compared to analog techniques, looking at key control issues such as robustness and finally introducing truly adaptive Auto-controlTM technology which uses digital processing to deliver improved control.

Overview of Digital Power Control

Figure 1 illustrates a typical digital DC-DC converter, comprising of the power stage, output voltage V_{OUT} (y) sampling ADC, digital error amplifier / compensator, and digital Pulse-Width-Modulation (PWM).

There are several differences

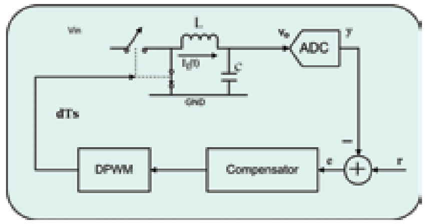

Figure 1: Typical Digital DC-DC Converter.

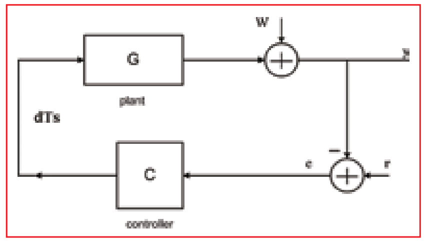

Figure 2: Representation of a feedback control system.

between analog and digital DC-DC converters, some of the most significant are:

a) The output voltage (y) as seen by the control loop is quantized in voltage. This means the output voltage is known to the resolution and accuracy of the ADC.

b) The output voltage is sampled in time and therefore is only known at the sampling instants.

c) The Digital Pulse-Width-Modulation (DPWM) is quantized in time and therefore discrete quantized pulse widths are available. The interaction between the DPWM's quantized levels and those of the ADC can result in limit cycling whereby the DPWM's pulse width never settles to a steady state. This results in a limit-cycle on VOUT, the amplitude of which is dependent on several factors and is a function of the DPWM's resolution.

d) The ADC requires some time to convert the VOUT reading into a digital value, adding to delay in the loop.

e) The compensator adds to the loop delay because it requires some time to compute the duty-cycle following each ADC reading.

The delays inherent in a digital PWM control loop place a bound on the achievable control bandwidth which in turn affects the control response and therefore the deviation in the transient response to a load current step. The maximum control bandwidth achievable when a control loop has a delay of Td is approximately:

$$f_{\max} \approx \frac{1}{2\pi T_d}$$

Intuitively this makes sense; the control loop cannot react to a disturbance until the ADC has measured it and the controller has calculated a response. In the meantime the output voltage will continue on its trajectory giving a minimum achievable voltage deviation to the load transient and equivalently, a maximum achievable control bandwidth.

This means that in a typical digital DC-DC converter where the ADC sample rate is the same as the switching frequency, and there is a one cycle delay from ADC sample to DPWM update the maximum achievable control bandwidth is:

$$f_{\max} \approx \frac{f_{sw}}{2\pi}$$

In reality the delay inherent in PWM modulation must also be taken into account, reducing the maximum achievable bandwidth even further.

Clearly the transport delay is an important figure of merit for a digital DC-DC converter. It is as low as 400ns for Powervation's technology.

The Role of Control

Consider the controller depicted in Figure 2 where the compensator and plant are represented by C and G respectively. The role of control is to ensure the output (y), tracks the reference (r), in the presence of a) unknown disturbances and b) uncertainty regarding the parameters (or structure) of the power stage. Feedback control facilitates this through high loop gain.

However, the gain must roll-off at high frequencies in any physically realisable system. This is illustrated in Figure 3, where the loop gain is shown as CG. As CG rolls off we can see there are conflicting requirements between loop stability and robustness. For example, to ensure that the loop is insensitive to a high degree of plant uncertainty requires high loop gain up to a high bandwidth. However, the loop gain must roll-off at high frequencies in order to ensure loop stability, with lower bandwidth systems being more stable. Therefore there is a fundamental trade-off between loop stability and robustness versus uncertainty regarding the power stage. In practice control loops are designed with lower bandwidths so they are stable despite plant uncertainty. Robustness is achieved by ensuring a high phase margin.

Robustness

Loop phase margins, gain margins and crossover frequencies are typically designed conservatively when robustness is considered in physical systems. This comes about because the control loop is particularly sensitive to inaccuracies in the dynamic modelling of the power stage as the loop gain rolls off and crosses 0dB.

We can view phase-margin as a measure of robustness against delay uncertainty at the 0dB crossover frequency, i.e. high phase margin systems can tolerate more uncertainty in loop delay without being unstable. The amount of additional delay a loop can tolerate (Tmax), for a given phase

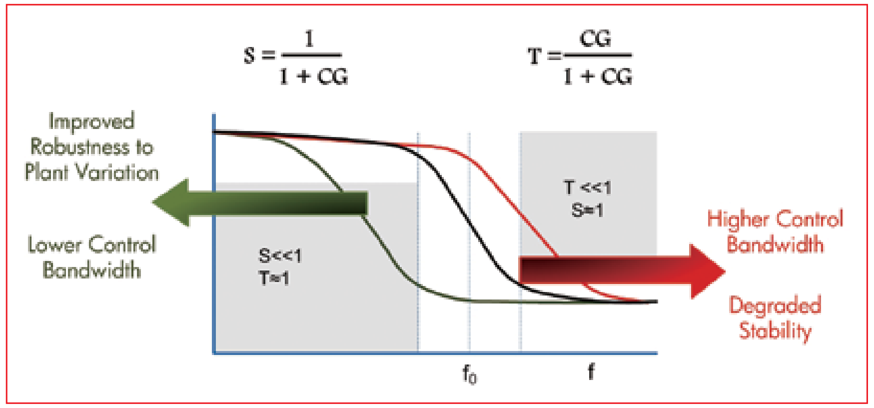

Figure 3: Conflicting requirements of Sensitivity and Robustness as the Loop Gain (CG) rolls off versus frequency.

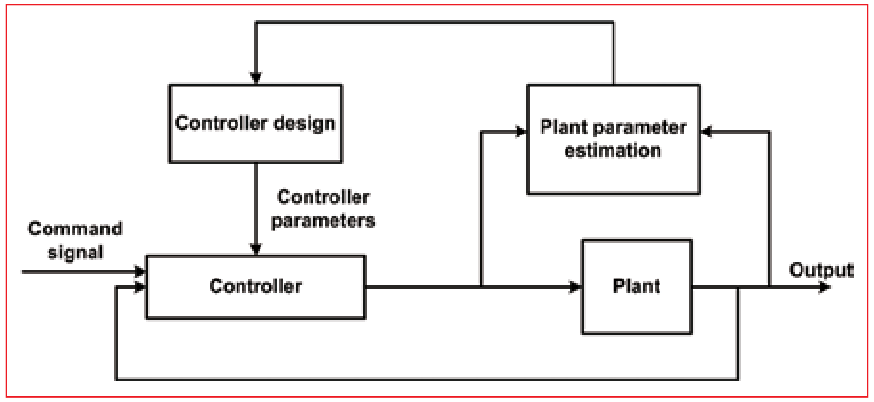

Figure 4: Typical adaptive self-tuning regulator.

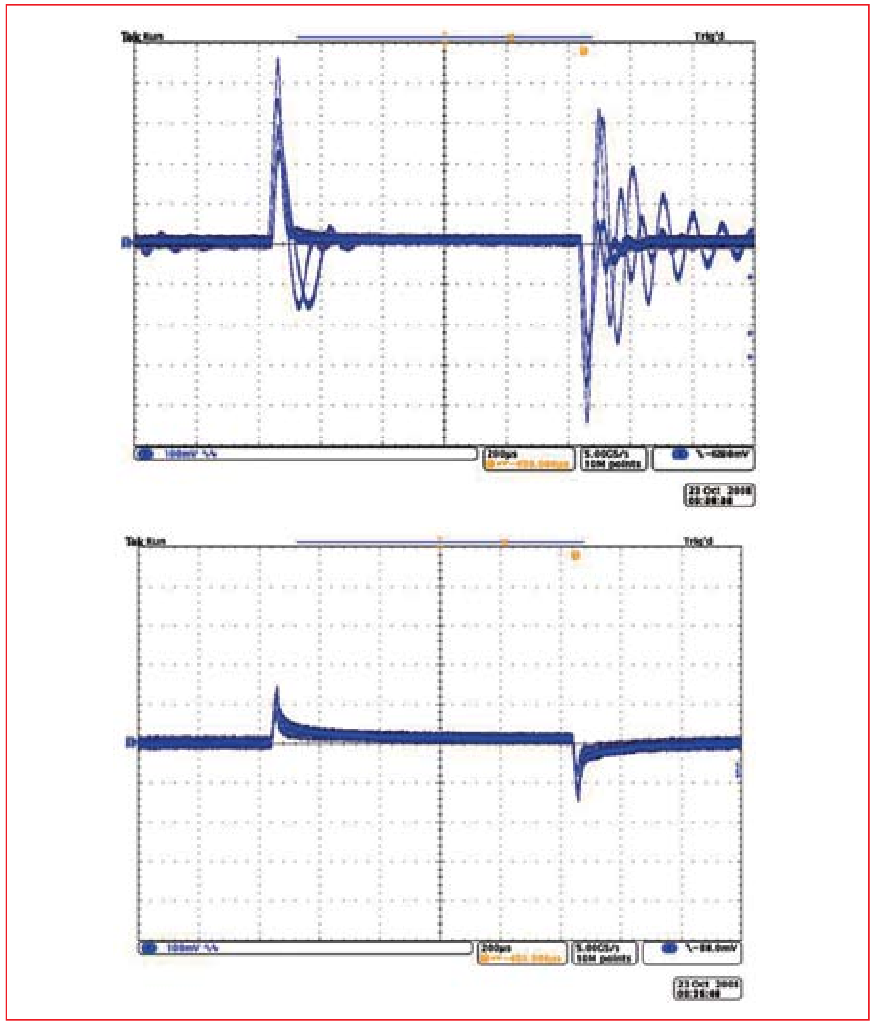

Figure 5: (a) Varying load step response as L and C vary in a DC-DC converter; (b) Improved robustness to variation when controlled with Powervation's Auto-controlTM technology.

margin (PM, in radians) and crossover frequency (ωc in rad/s) is given by:

$$T_{max} = \frac{PM}{\omega_c}$$

Therefore, loops with higher phase margin or lower crossover frequency are more robust against uncertainty in loop delay. Similarly we can view gain-margin as a measure of robustness against gain uncertainty at crossover, i.e. high gain margin systems can tolerate more uncertainty in gain at crossover without being unstable.

Adaptive Control

A typical adaptive control system is illustrated in Figure 4, whereby the parameters of the plant are estimated by the 'plant parameter estimation' block and the controller is designed on-the-fly by the 'controller design' block to meet some pre-determined requirements such as closed loop pole locations.

One of the main advantages of adaptive control is that plant uncertainty is reduced by the parametric estimation. As the uncertainty in the control system is reduced it becomes more robust, and the limitations on control performance to achieve robustness are relaxed. As such the loop can maintain high gain up to as high a bandwidth as stability will allow.

Traditionally gain and phase margins are chosen to yield a compromise between performance and stability. By using adaptive control high gain margins and high phase margins are not required in order to ensure loop stability. Therefore, higher performance control is possible.

Powervation has developed Auto-controlTM technology which brings true adaptive control to DC-DC conversion for the first time. The benefits of Auto-control such as improved robustness, maximum performance and ease of design are all made available through this technology.

Figure 5 illustrates the improved robustness compared to a fixed controller which is achieved automatically with Auto-controlTM.

Summary

As trends in power conversion move the industry towards power architectures which are smaller and more efficient, the requirement to intelligently manage the multiple power rails under these constraints of space and efficiency is driving the industry towards the adoption of digital power control and power management solutions. There is significant potential for the development of power control technologies which harness uniquely digital techniques in order to deliver improvements in power system design. Using traditional control techniques gain and phase margins are chosen to yield a compromise between performance and stability. By using Auto-controlTM, high gain margins and high phase margins are not required in order to ensure loop stability. Therefore, higher performance control can be achieved and unprecedented ease of use can be delivered as designers are freed from the burden of loop compensation.

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Ease of Implementation with Digital Techniques

Revolutionizes DC-DC converter design

The need for high power together with high availability for telecom and other demanding applications drives designers to adopt distributed power architectures that partition subsystems to spread the power load and accommodate redundant elements. Such systems typically comprise one or more ac-dc front-ends that isolate and convert utility power to an intermediate dc level. Each system board carries at least one intermediate bus converter (IBC) that isolates and down-converts this distribution voltage to a local level that suits down-conversion by point-of-load (PoL) regulators.

By Patrick Le Fèvre, Director Marketing & Communications, Ericsson Power Modules

The IBC is a crucial system element that is especially challenging to design. As well as tolerating worst-case voltage step-down ratios of 8:1 or more, the cascade nature of multiple high-current step-down stages makes conversion efficiency and power density crucially important factors. Minimizing conversion losses directly translates into lower energy costs within the converter and the cooling system, while the ability to handle high-power loads reduces the number of IBCs that are required. In addition, today's intelligent power-management strategies increasingly demand that the IBC has full system connectivity using the industry-standard PMBus protocols. Figure 1 shows an example board with two current-sharing IBCs and three PoLs running under the supervision of a power-system host via a PMBus interface.

The combination of electrical performance and embedded control requirements led Ericsson to consider a digital approach to power-converter design that culminated in its BMR453 quarter-brick module. By comparison with the company's PKM4304BI module that uses analogue control, substituting a digital core results in as much as 2% efficiency improvement and approximately 5% greater power-handling capacity. Moreover, the BMR453's digital core includes a

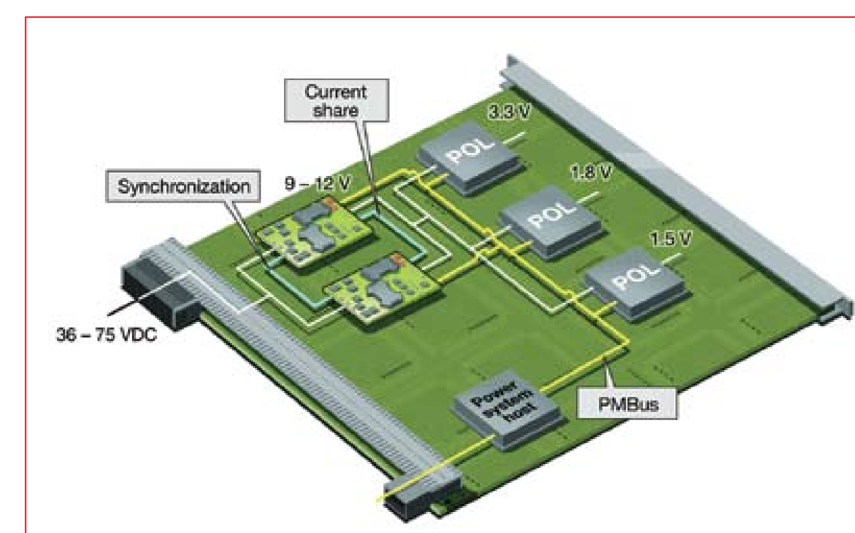

Figure1: Example board with two current-sharing IBCs and three PoLs.

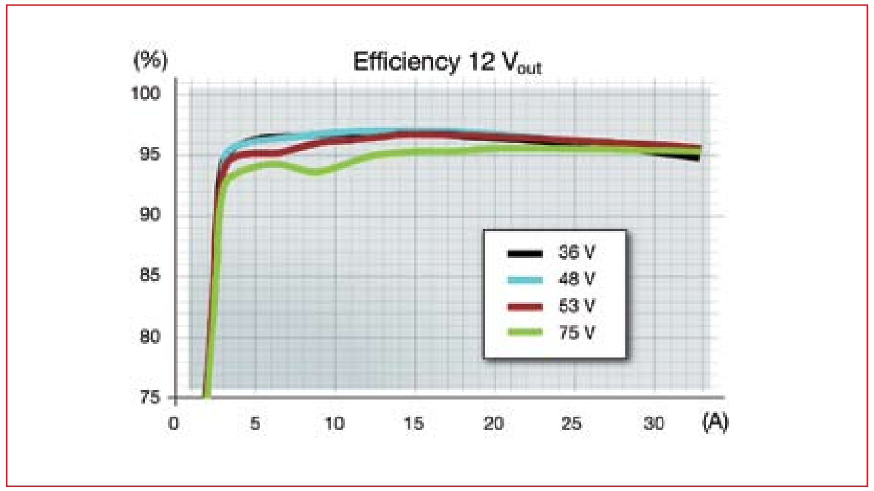

Figure 2: Comparing the BMR453 with its analog predecessor, the digital converter achieves 96% or better efficiency from about 3A upwards for a 48V input, and reduces losses at high input voltages by more than 2%.

PMBus interface that integrates an unprecedented level of control and monitoring functions.

Adaptive operation maximizes efficiency

A prime advantage that a digital core offers is the ability to adapt to input-line and output-load conditions to optimize converter efficiency across the widest possible range of operating conditions. For instance, a digital core can vary the dead-time between a buck converter's upper and lower MOSFETs switching; by comparison, passive components establish the timing constants within an analog control loop, which are then fixed. While it is essential to prevent the upper and lower MOSFETs simultaneously conducting, it's also desirable to minimize the dead-time period during which the lower MOSFET is off and a relatively inefficient Schottky freewheeling diode conducts. Some literature claims as much as 5% efficiency improvement due to this adaptive ability, but with highly-developed converters such as the PKM4304BI, Ericsson's experience is that 1% – 1.5% is more realistic.

The BMR453's full-bridge converter uses four n-channel MOSFETs to switch the primary winding of a centre-tapped transformer that determines the basic step-down factor and provides 1.5 kV of galvanic isolation to meet EN60950 requirements - see figure 3.

The control block continuously varies the duty cycle of the pulse-width-modulation (PWM) stream that controls the MOSFET drivers to maintain constant output voltage. The core of the control block is a digital synchronous buck converter IC that achieves 175 psec resolution at switching frequencies of up to 1MHz. A set of constants determines the response of a proportional-integral-derivative (PID) filter that compensates the control loop - see figure 4.

This process is the digital equivalent of setting poles and zeros using capacitors and resistors in an analogue converter. Crucially however, Ericsson's firmware can adjust the digital constants on-the-fly to compensate for varying line and load conditions—and unlike analog components, digital values do not drift with time and temperature. In addition to controlling the dynamics of inner-loop operation and performing house-keeping duties, the firmware also allows the end-user control of key parameters such as output voltage, which can range between 8.1 – 13.2V. One application is to optimize conversion efficiency for the IBC and the PoLs that follow.

At the transformer's secondary, six n-channel MOSFETs perform synchronous rectification. Their gate drivers operate in inverting mode to avoid pulling down the output rail during converter initialization if a pre-

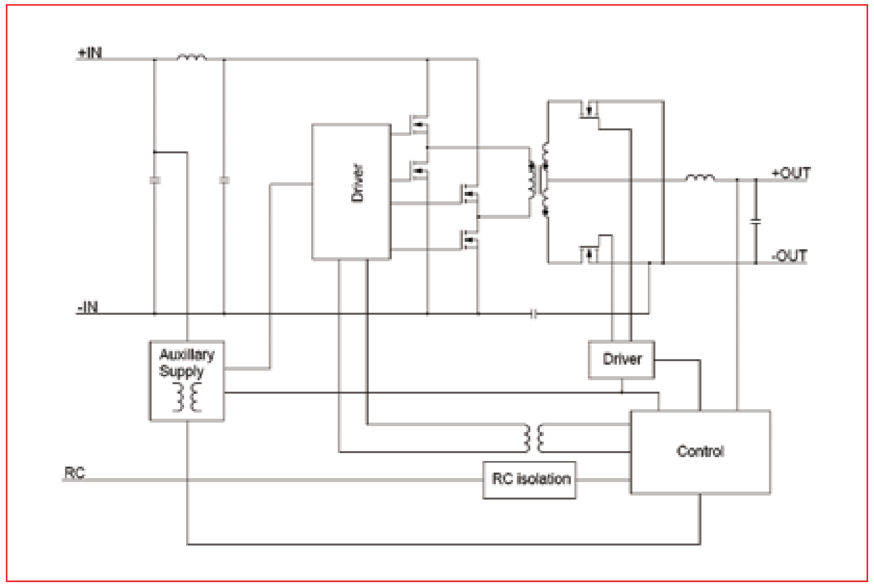

Figure 3: The underlying topology that achieves these results consists of a full-bridge converter, where two pairs of MOSFETs hard-switch the primary winding of a centre-tapped transformer.

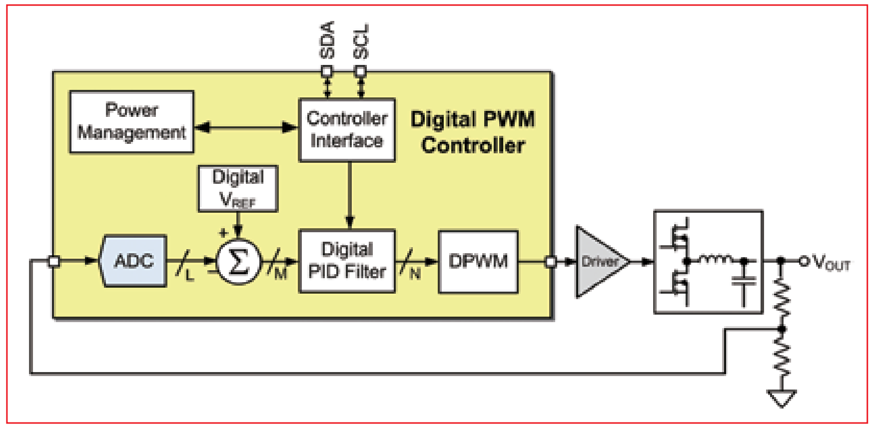

Figure 4: A set of constants determines the response of a proportional-integral-derivative (PID) filter that compensates the control loops.

bias voltage is present. The default switching frequency is 140kHz, which minimizes gate-charge losses and eases filter design - a simple external LC filter enables the converter to meet the class-B requirements of EN 55022, CISPR 22, and FCC part 15J. Clock synchronization logic allows users to lock the switching frequency to an external reference, or to ensure that multiple converters operate at exactly the same frequency. Users can also adjust the switching frequency via PMBus commands within a useful range of about ±10kHz. These features ease filtering in some situations.

Secondary-side control tightens regulation

One major architectural difference between the BMR453 and the analogue PKM4304BI is the relocation of the control circuitry to the secondary side. This strategy requires precise secondary-to-primary side gate-driver signal control across an isolation barrier, together with a primary-side auxiliary supply for the driver stage. The transformer that couples drive-control signals is a proprietary design that uses a trifilar winding to minimize leakage inductance. Low-capacitance diodes peak-rectify these control signals prior to amplification by the high-side gate-drivers. A flyback circuit that includes its own start-up logic, power switch, and under/over-voltage lock-out functions forms the auxiliary supply. These changes tighten the +4%, -9% voltage regulation that's typical of competing analogue converters to ± 2% with no degradation to noise or transient response.

Numerous additional design features help the BMR453 achieve its electrical performance while assuring a calculated mean-time-to-failure period of 1.1 million hours. For example, the transformer and output-filter inductors are proprietary planar designs that maximize magnetic flux to constrain their footprints to approximately 23.0x15.3x9.7mm. As figure 5 shows, these parts utilize through-board mounting to help facilitate the converter's quarter-brick format.

Also, the converter dispenses with failure-prone electrolytics in favour of chip capacitors, while the twelve-layer,

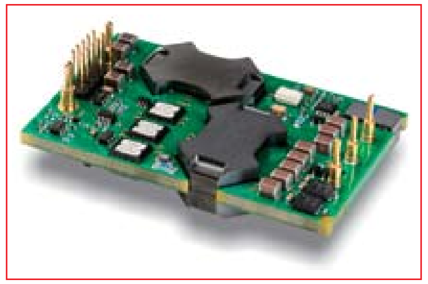

Figure 5: Innovative through-board mounting helps facilitate the converter's quarter-brick format.

3-mm thick PCB carries extensive copper areas with thermal vias and microvias aiding heat dispersal. A baseplate option is available to maximise thermal conductivity.

Ease-of-use is paramount

By slashing component count, digital control lowers cost-of-ownership while supporting traditional analogue functions such as remote sensing and protection mechanisms. In addition, the BMR453 has an active current sharing facility that ensures equal load-current distribution between modules operating in parallel, making it easy to implement load-sharing or redundancy schemes—no OR-ing diodes or MOSFETs are necessary, greatly improving efficiency in parallel operation. Furthermore, digital supervision and control makes it possible to enable and disable paralleled converters to maximize conversion efficiency for loads that one converter can supply

But from the user's viewpoint, the digital core's major advantage is easy integration with digital power-management schemes that require additional support circuitry when using an analog converter. Compatible with any standard two-wire I2C or SMBus hardware, the BMR453's PMBus interface allows users to set numerous operating characteristics, including soft-start ramp times and voltage margining thresholds. A system controller can interrogate the module to extract a wealth of data such as input and output voltages, output current, internal junction temperatures, switching frequency, and duty cycle. For evaluation and development, Ericsson's CMM software provides a graphical user interface that allows users to "see inside" the running converter. An evaluation kit is available with a board, operating manual, a CD that includes the GUI, and cabling.

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Power Factor Correction Techniques

MCU based digital feedback loop control

Power supplies in large systems that have input power of over 1KW typically use PFC for various reasons. Recent advances in PFC include interleaving of two out-of-phase circuits to gain many system level advantages. Enough has been discussed about the advantages of interleaved PFC; in this article we will focus on a comparison of the analog approach to the digital approach.

By Vipin Bothra, Application Manager and Robert Ortmanns, Application Engineer, STMicroelectronics.

The interleaving of PFC converters using analog controllers requires very sophisticated ICs that are dedicated for this purpose because of multiple loops within the system. A system based on analog controllers is forced to achieve a balance between complexity of the system and flexibility for adoption to various application needs. On the other hand, using an MCU to manage the feedback loop and management of

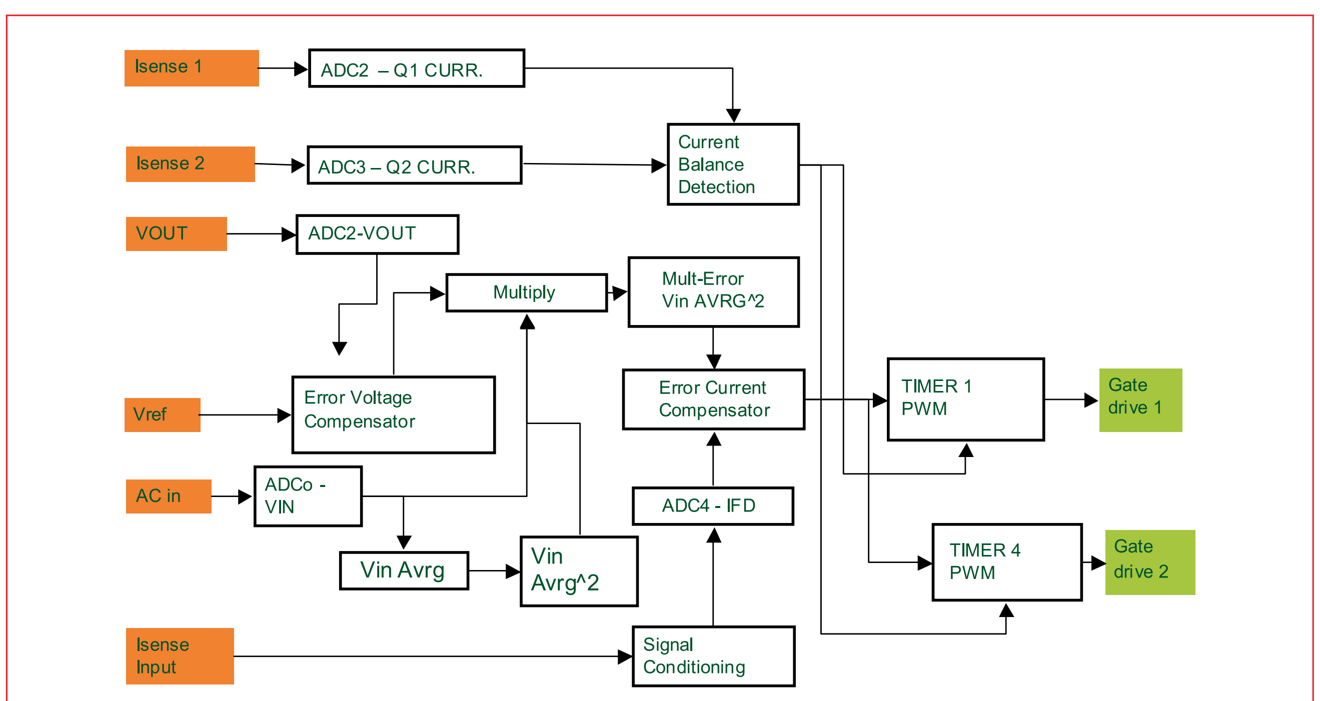

Figure 1: Functional block diagram.

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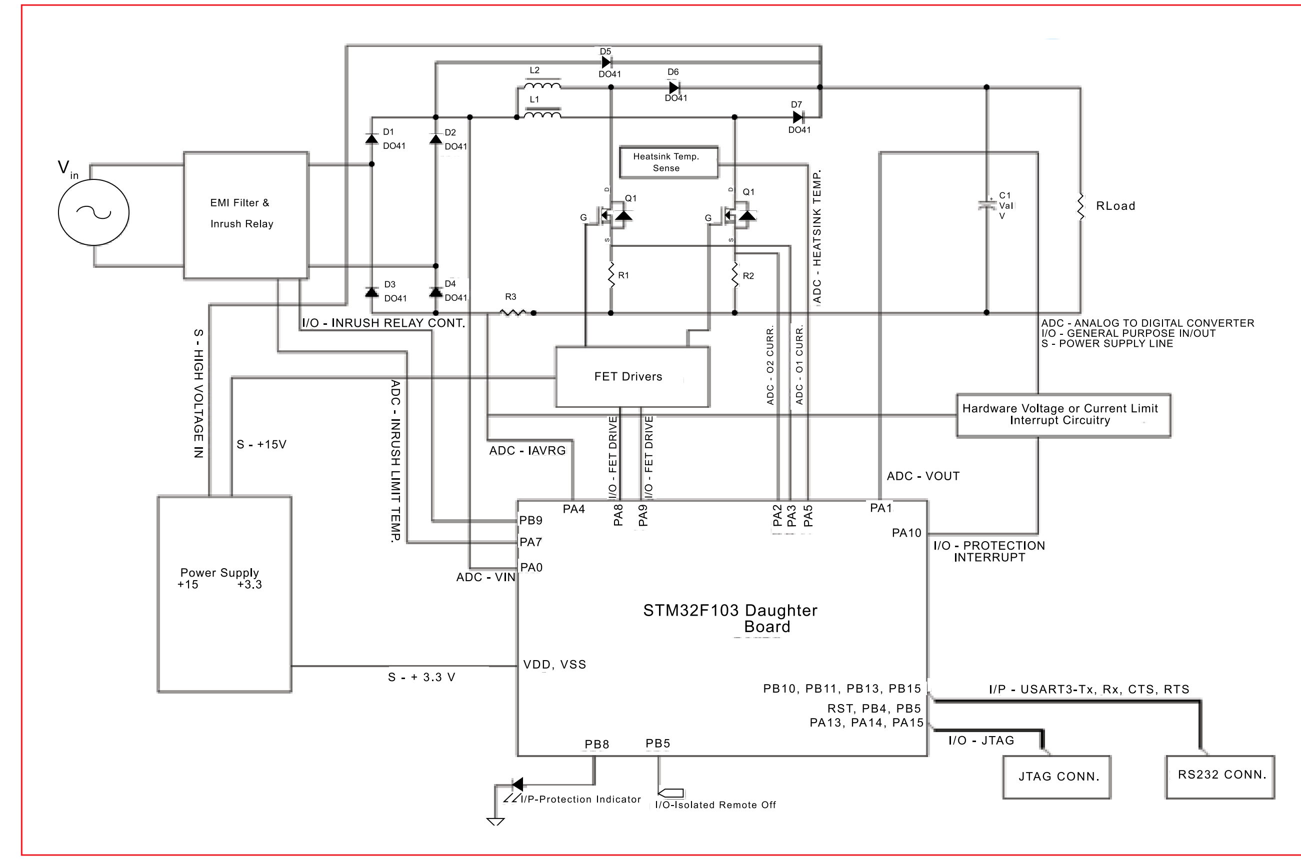

Figure 2: Component level block diagram.

peripheral functions provides utmost flexibility with only a slight increase in complexity.

Digital approach has two different meanings. One is the management of peripheral functions, which is commonly referred to as "digital management", and the other is feedback loop control, which is called "digital control." Digital control compared to analog control (of a feedback loop) does not really offer huge advantages; it is the combination of a digital control loop with digital management that creates a value that is more than a complete analog system.

MCU-based converters can measure and report the input power. The same input power measurement data can also be used internally to alter and optimize output voltage and switching frequency. Hence, with MCU-based converters, efficiency is optimized to the highest level and the efficiency curve can be flattened. Also, when demand for power is less than a certain threshold, one or more phases can be shut down to improve low load efficiency.

The cost of power components such as magnetics, MOSFETs and diodes, in higher power SMPS, is significantly higher compared to the cost of controllers. Hence, any saving in power components is easily paid off even if it requires higher cost in control components. Design for short circuit, power-up and power-down sequencing sometimes stresses power components beyond their normal operating level leading to the over-design of such components. With the help of the fuzzy logic of MCUs, it is very easy to implement timing and controls to minimize this over-design and reduce the overall cost of the system.

An MCU-based system also allows management of other functions in the SMPS that are beyond the realm of PFC, such as inrush current control and communication with the external world. A simple and cost-effective inrush current control can be implemented by using a resistor to limit the inrush current at start-up and then jumping the resistor out by means of a relay. A thermistor in contact with the resistor can be used to detect relay failures and prevent false startups of the circuit.

One or more thermistors in contact with major power components can be used to sense internal temperatures of the system which can then be reported to the external world. Moreover, the same information can be used to implement a precise fan speed control system by means of a simple lookup table. With digital control it is very easy to set boundary conditions to set operating limits for the converter and reduce waste of over designing in the system for taking care of abnormal operating conditions. An MCU-based system also reduces variations in the control module from one platform to another platform, compared with their analog counterparts, reducing engineering development time of future projects.

A functional block diagram of a typical interleaved PFC circuit with 2 phases based on ST's STM32F103 MCU is shown in figure 1.

Output of the system is a gate drive signal for the MOSFETs of the two phases of the interleaved converter. Inputs to the system, from the external world, are Voltage reference (V_{ref}), Output voltage (V_{out}), and AC input voltage (AC in). Internally generated inputs to the digital control loop are Input AC current (Isense input), Instantaneous current of phase 1 (Isense 1), and Instantaneous current of phase 2 (Isense 2).

The block diagram shows the three critical inputs used in the control blocks of the PFC circuit. These three inputs include voltage on ADC0, the boost output voltage on ADC2, and the current feedback signal on ADC4. The measured input voltage is used in two control functions: the first one is used as one of the inputs of the multiply calculation that along with the error term is used to shape the current waveform. The second one is used to determine the average input voltage used in figuring the maximum allowable current so that the maximum allowable power can be kept constant as the input voltage range changes. The output voltage is sensed by an ADC and compared to a numerical constant in the code. Based on that, an error term is calculated and multiplied with the instantaneous input voltage to shape the current waveform to match the input voltage wave form. By further dividing this by the square of the average input voltage, a current reference (Iref in the diagram) is established and is used to program the current compensator. The current compensator uses the last critical input, which is the current feedback level converted on ADC4. Implemented as a PID loop, the current compensator uses the Iref level as the set point and the ADC4 level as the process variable. The output of the loop programs the duty cycle of the MOSFET switches via peripheral timers one and four.

The inputs ADC2 and ADC3 measure the currents flowing in the boost MOSFETs of the two phases. With both converters being fed from the same voltage source, having equal value inductors and driven with the same value duty cycles, the average currents in the two phases share the output current almost equally. The measured values are compared relative to each other and if there is a large difference between the two currents, indicating trouble, the outputs are shut down and an error is reported via the communications link.

A test board based on ST's STM32F103 was designed to run at the 100W power level, 100 KHz switching frequency, with universal input range, and an output voltage of 400V. Because the timers of the STM32 can be triggered from one to the next with a precise time offset, it is possible to do interleaving, with as many phases as needed, limited by the number of timers on the device. Our testing showed good efficiency even with the overhead of start-up power regulators needed to boot up the MCU first. Based on the design value of power components, including boost capacitor, we see a significant cost saving at a typical power of 1000W.

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Designing for High Efficiency

Selecting the right topology for energy-saving power supplies

Initiatives to reduce energy wastage by electronic systems are forcing designers of single-phase AC input power supplies to use newer power supply technologies. For higher power levels, these initiatives call for efficiency levels of 87% and above. Traditional power supply topologies such as the standard flyback and the two-switch forward do not support these high efficiency levels and are gradually being replaced by soft-switching, resonant and quasi-resonant topologies.

By Jon Harper, Market Development Manager, Power Conversion & Industrial Systems, Fairchild Semiconductor Europe

Principle of Operation

Figure 1 shows the voltage and current waveforms seen on the switches used in three different topologies: the quasi-resonant flyback topology, the LLC resonant topology and the asymmetric half-bridge topology which uses soft-switching techniques.

All three topologies use different techniques to reduce the turn-on losses of the MOSFETs. The turn on losses are given by:

$$P_{TurnOnLoss} = \frac{1}{2} V_{DS} I_D \cdot t_{ON} \cdot f_{SW} + \frac{1}{2} C_{OSSeff} V_{DS}^2 \cdot f_{SW}$$

where ID is the drain current immediately after turn on, VDS is the voltage across the switch, COSSeff is the effective value of the output capacitance including stray capacitance effects, tON is the turn-on time and fSW is the switching frequency.

Figure 1 shows that the MOSFET in the quasi-resonant topology will have a zero drain current immediately after turn on, as the converter operates in discontinuous conduction mode. The switching losses are therefore determined by the voltage at the turn on time and the switching frequency. The quasi-resonant converter turns on the MOSFET at one of the minima in the drain voltage to reduce switching losses. This means that the frequency of switching is not constant: at lighter loads the first minimum on the drain voltage will come earlier. In older designs which always switched on the first minimum, the efficiency suffered at light loads as the switching frequency increased, offsetting the benefit of switching on at a lower voltage. In Fairchild Semiconductor's e-Series™ quasi-resonant power switches, the controller waits for a minimum time (therefore setting an upper limit on the frequency) and then turns on the MOSFET at the next minimum.

The other topologies use zero voltage switching. In this case, the voltage VDS in the above equation is reduced from the bus voltage, typically around 400V, to around 1V. This effectively removes the turn on switching losses. Zero voltage switching is achieved by forcing a current to flow through the MOSFET in a reverse direction through the body diode, then turning on the MOSFET. The voltage drop of the diode is typically around 1V.

Resonant converters achieve zero voltage switching by generating a sinusoidal current waveform which lags the phase of the voltage waveform. This is achieved by applying a square wave voltage to a resonant network. The fundamental frequency component of the voltage

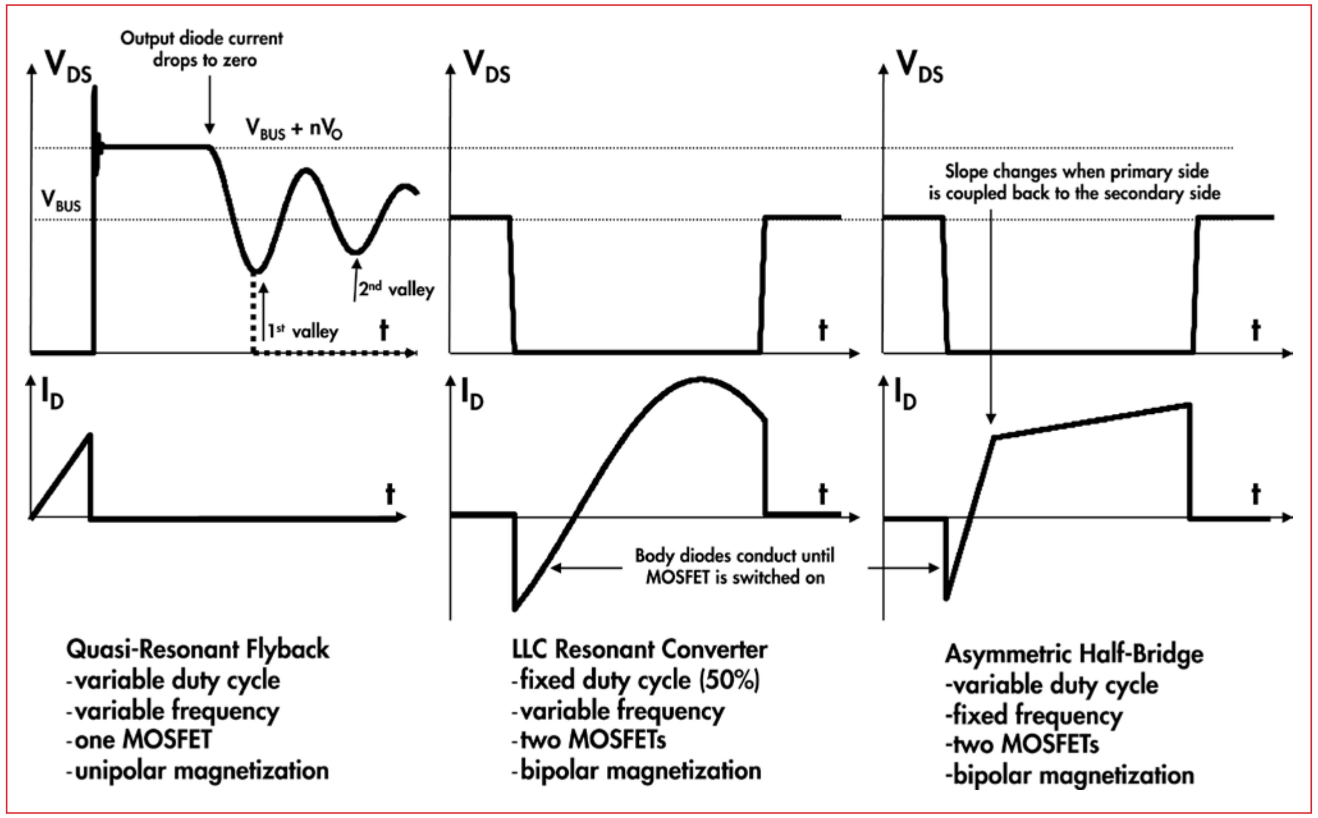

Figure 1: Comparison of quasi-resonant, LLC and asymmetric half-bridge topologies.

forces a sinusoidal current to flow (the higher order components can generally be ignored). Above resonance, the current lags the voltage, permitting zero voltage switching. The output of the resonant network is rectified to provide a DC output voltage. The most popular resonant network consists of a transformer with a specific magnetizing inductance, an additional inductor and a capacitor, hence the name LLC.

Asymmetric half-bridge converters achieve zero voltage switching by using a soft-switching technique. Here the voltage generated by the bridge is a rectangular waveform with a duty cycle of well under 50%. A coupling capacitor is required to remove the DC component before applying this voltage to a transformer, and additionally serves as an energy storage element. When both MOSFETs are switched off, the energy in the leakage inductance of the transformer forces the voltage on the half-bridge to the opposite polarity. This voltage swing is ultimately clamped by the relevant MOSFET body diode, which suddenly takes on the primary current.

Selection criteria

These energy optimization efforts result in excellent efficiency. A quasi-resonant converter design can achieve over 88% efficiency for a 75W/24V power supply. With synchronous rectification, requiring an additional analog controller and a PFC front end it is possible to increase this to over 90% efficiency at 90W/19V. Higher efficiencies can be achieved by the LLC resonant and asymmetric half-bridge converters at this power level, but they are more expensive to implement. Quasi-resonant converters are therefore generally used up to this power range. The e-Series range of integrated power switches is effective for applications ranging from small 1W auxiliary power supplies, through 30W set-top box power supplies right up to 50W industrial power supplies. Above this power level, the use of the FAN6300 quasi-resonant controller with external MOSFET is recommended. This brings in the extra flexibility of handling unusually high system input voltages, or optimizing cost versus efficiency by being able to select a wide range of external MOSFETs.

The quasi-resonant flyback uses one low side MOSFET, while the other topologies require two MOSFETs in a half-bridge structure. This makes the quasi-resonant flyback the most cost effective topology at lower power levels. At higher power levels, the transformer size increases which reduces both efficiency and power density. At this stage the two zero-voltage-switching topologies can be considered.

Four factors influence the design: the input voltage range, the output

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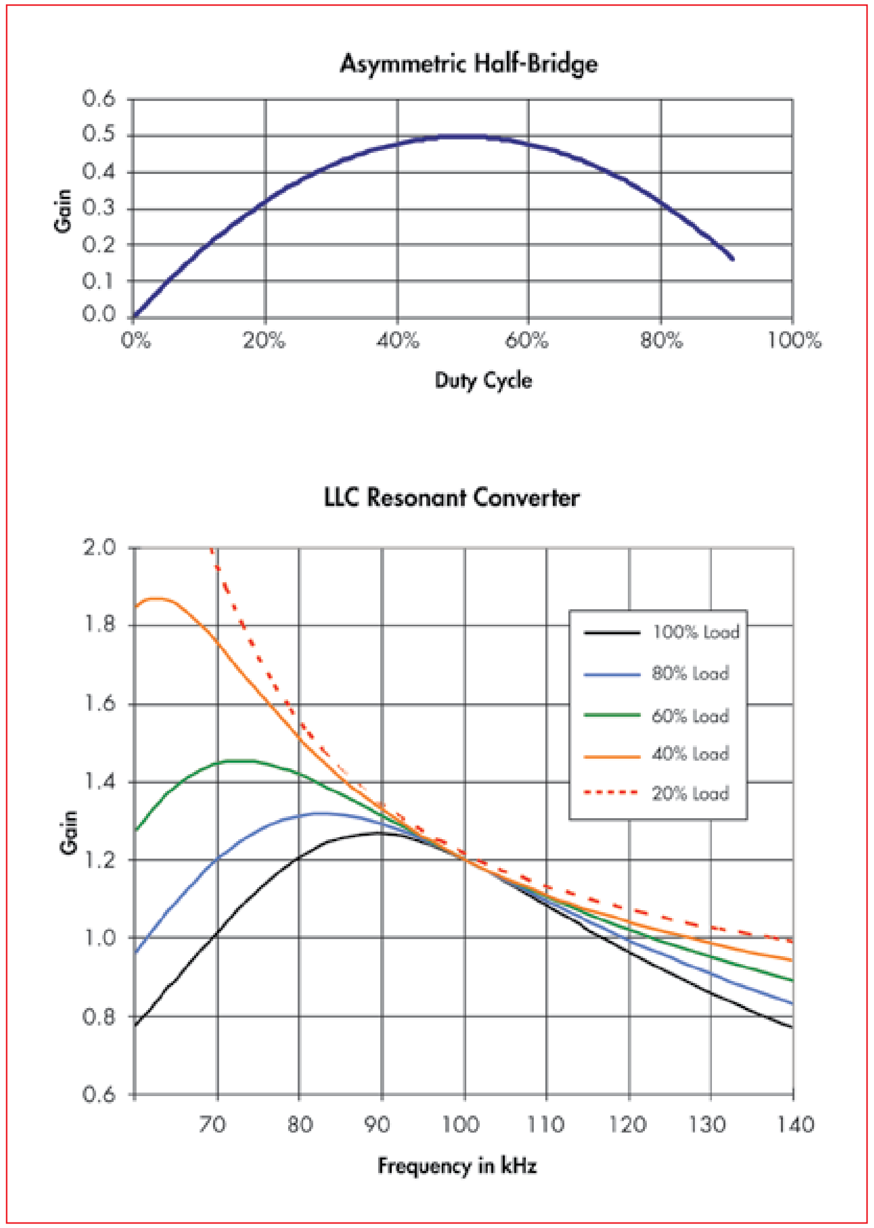

Figure 2: Gain curves of asymmetric half-bridge and LLC converters.

voltage, the ease of implementing synchronous rectification and the implementation of the leakage inductance.

Figure 2 compares the gain curves of the two topologies. For illustration, let us assume we need to support input voltages of 110V and 220V. For the asymmetric half-bridge, this is not a problem. We can set the operating conditions such that the gain is 0.2 for 220V and 0.4 for 110V. The efficiency would be worse at 220V as the magnetizing DC current increases as the duty cycle decreases. For the LLC resonant converter, the maximum gain is 1.2 noting how the full load curve is close to resonance. A gain of 0.6 would result in a very high frequency, resulting in poor system performance. In conclusion, an LLC converter is not suitable for wide range operation. With external adjustment of the leakage inductance, it is possible to operate it for the European input range, at the cost of higher magnetizing currents. It works best with a PFC stage in front. While an asymmetric half-bridge benefits from having a PFC stage on its input, it is possible to operate the circuit over a wide voltage input range.

For output voltages above 24V, an LLC resonant converter is recommended. The high output diode voltage stresses on the asymmetric half-bridge worsen efficiency because diodes with higher voltage ratings have higher forward voltages. Below 24V, the asymmetric half-bridge converter is recommended. The LLC converter has a far higher ripple current on the output capacitors, which increases with lower output voltages, resulting in a more expensive, bulky solution.

Synchronous rectification is possible for both topologies. It is very simple to implement for the asymmetric half-bridge (Fairchild Application Note AN-4153). For the LLC controller, a special analog circuit is needed to detect the current flow in the MOSFETs, the technique being simpler if the switching frequency is limited to the second resonant frequency (100kHz in Figure 2).

Finally, both designs rely on the leakage inductance of the transformer: in the LLC converter to control the gain curve (Figure 2) and for the asymmetric half-bridge to ensure soft-switching at light loads. For most applications we recommend using two separate inductors for this purpose. The leakage inductance is a poorly controlled parameter of a transformer. Additionally, the implementation of an unusual leakage inductance requires a non-standard coil former, increasing cost. Finally, for the asymmetric half-bridge, the resonant switching speed is at least ten times the switching frequency, resulting in higher losses if a standard transformer is used. In conclusion it is recommended to use a second inductor using normal ferrite for an LLC converter, and one using high frequency ferrite for an

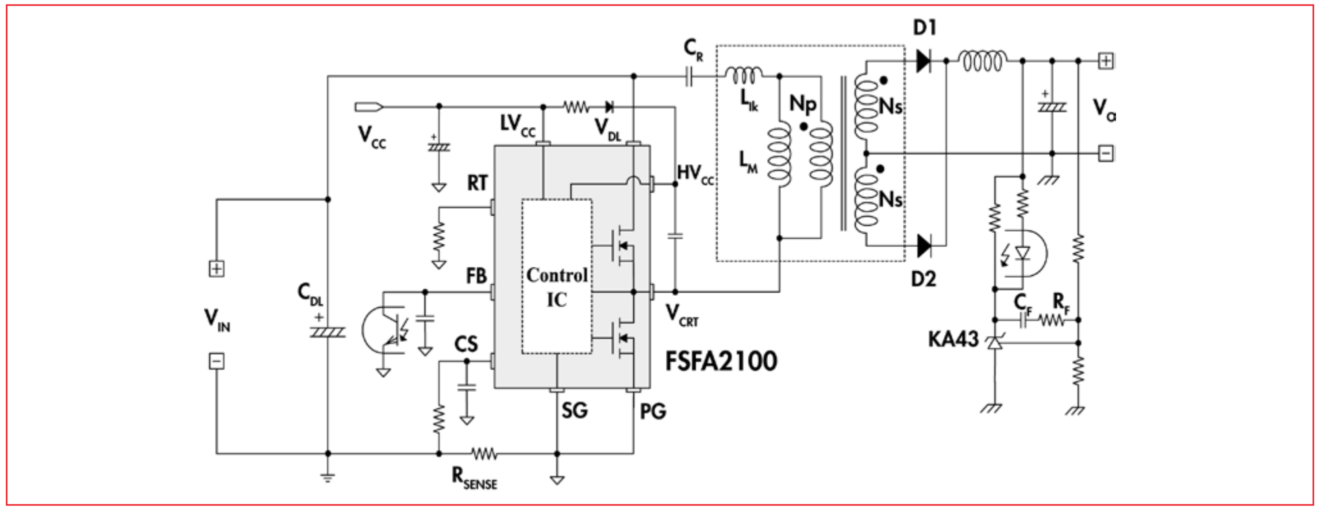

Figure 3: Asymmetric half-bridge converter based on the FSFA2100.

asymmetric half-bridge converter.

Figure 3 shows the circuit diagram for an asymmetric half-bridge converter. The circuit diagram is very similar to that of an LLC resonant converter, except that an LLC resonant converter does not require an output inductor and that the controller needs to be set up for frequency rather than PWM control.

The efficiency of a 192W/24V asymmetric half-bridge converter is around 93%. The 360W/12V current doubler version in AN-4153 also has a full load efficiency of over 93% between 20% and 100% of rated load.

The efficiency of LLC resonant converters are around 93% for 200W/48V power supplies, including the PFC front end. With synchronous rectification it is possible to raise the efficiency into the range 95%-96% for this power level.

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Securing Power –Perpetuating Jobs…

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

The power grid is becoming an extremely sensitive topic, both in North America and in Europe. In acknowledgement of this we will run a special report on this topic in the September-October issue of PSD North America. Forming the backbone of all industry and vital for consumers alike, this huge arterial network is also coming under attack from infiltrators and hackers. The implications of any serious downtime to the network, whether due to equipment failure or through malicious interference, are too terrible to comprehend. Here, the power industry is the vital element. Look out for the report.

Green power, in particular solar power, utilizing photovoltaic (PV) cells is really hitting the news these days with many investors eyeing-up the opportunities for a healthy return. Europe has been very fast in utilizing this technology, accelerated by government incentives to encourage homeowners to install these rooftop energy providers.

There are also incentives and rebates available to homeowners in USA for alternative energy systems installation. States and local municipalities have incentive programs to encourage solar power and other alternative energies in their areas. On a Federal level there are also incentives for solar power systems, renewables and energy efficient technologies. If the US administration follows the European path, a healthy growth could be envisaged for the PV industry.

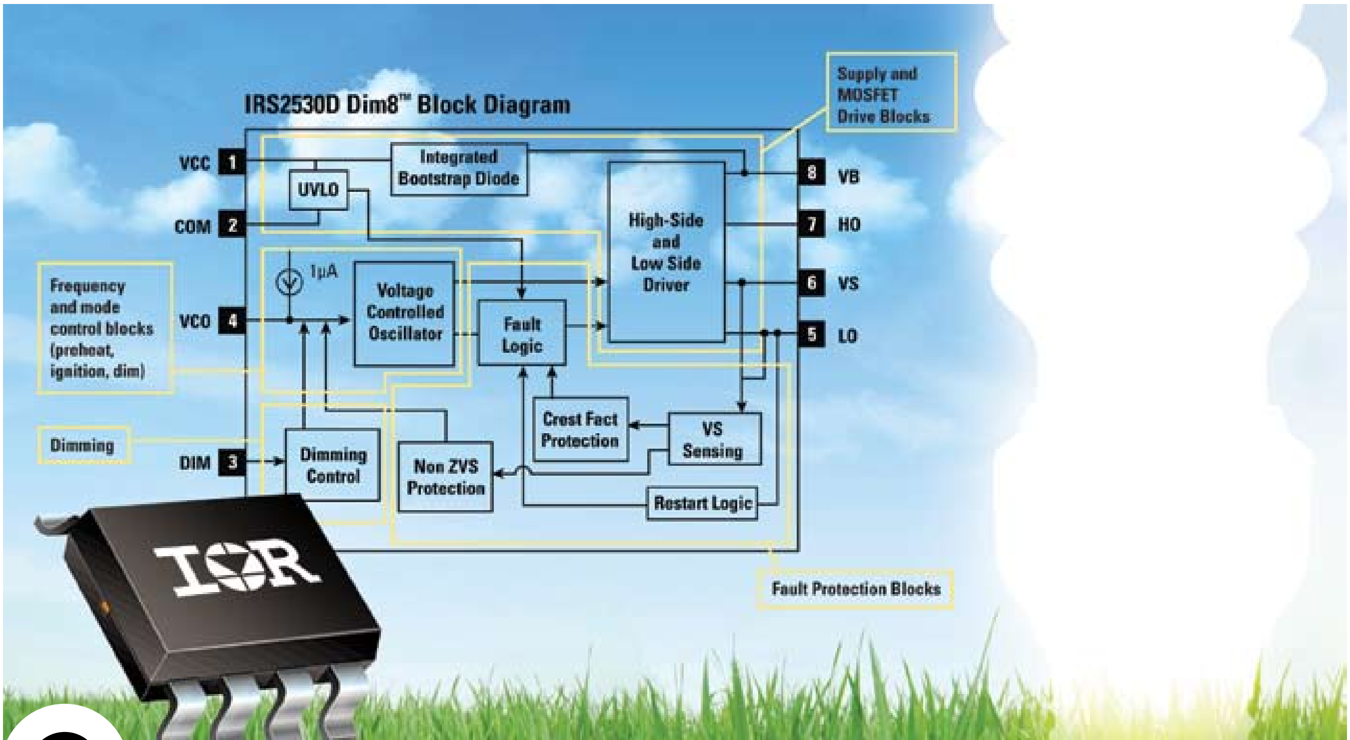
However, according to IMS Research's latest analysis, the global PV market is set to contract for the first time in 2009 in terms of new installations.

The analysis shows that although the PV market doubled in 2008 in MW terms, a contraction in shipments is anticipated in 2009. This will be caused by the sudden drop-off in demand from Spain, with its newly implemented 500MW cap. This is likely to result in a shortfall of some 1.5-2GW in 2009. The dramatic decline of the vast Spanish market will lead to an overall drop in worldwide shipments.

In spite of this, underlying demand for PV remains very healthy; long term, double-digit annual growth rates can be expected. The market is likely to see dramatic changes in the next few years, with the emergence of new technologies such as micro-inverters; and the development of new and attractive regional markets, especially in the US, which to date has made up a low proportion of the overall global market. Difficulties in obtaining financing will restrain US market growth this year. However, in the medium term it is anticipated to become one of the largest markets for PV.

Green jobs in energy are attractive to governments. Being heavily reliant on manpower, they have the potential to create new job opportunities in an economy that is suffering, although jobs have been lost in the solar and wind industries too due to the downturn. But with the new administration committed to a huge stimulus package and the growing swell in public and political awareness of clean and alternative energy sources together with the need for fossil alternatives, the mid term future at least looks positive.

www.powersystemsdesign.com/greenpage.htm



Slash Component Count; Simplify Design

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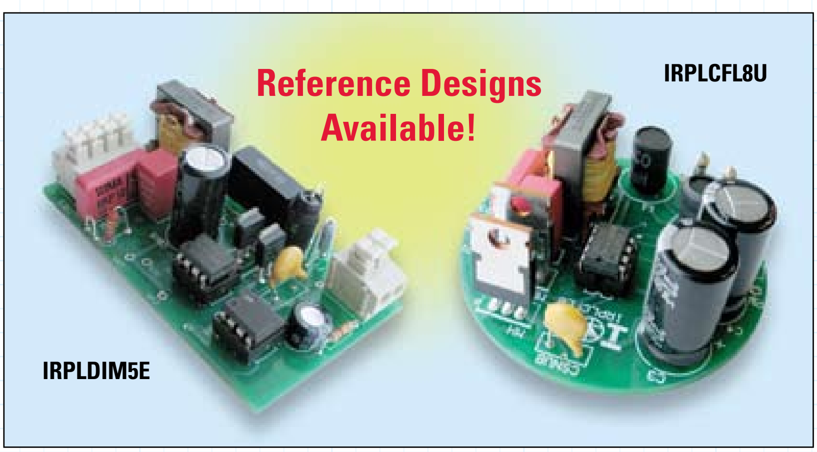

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