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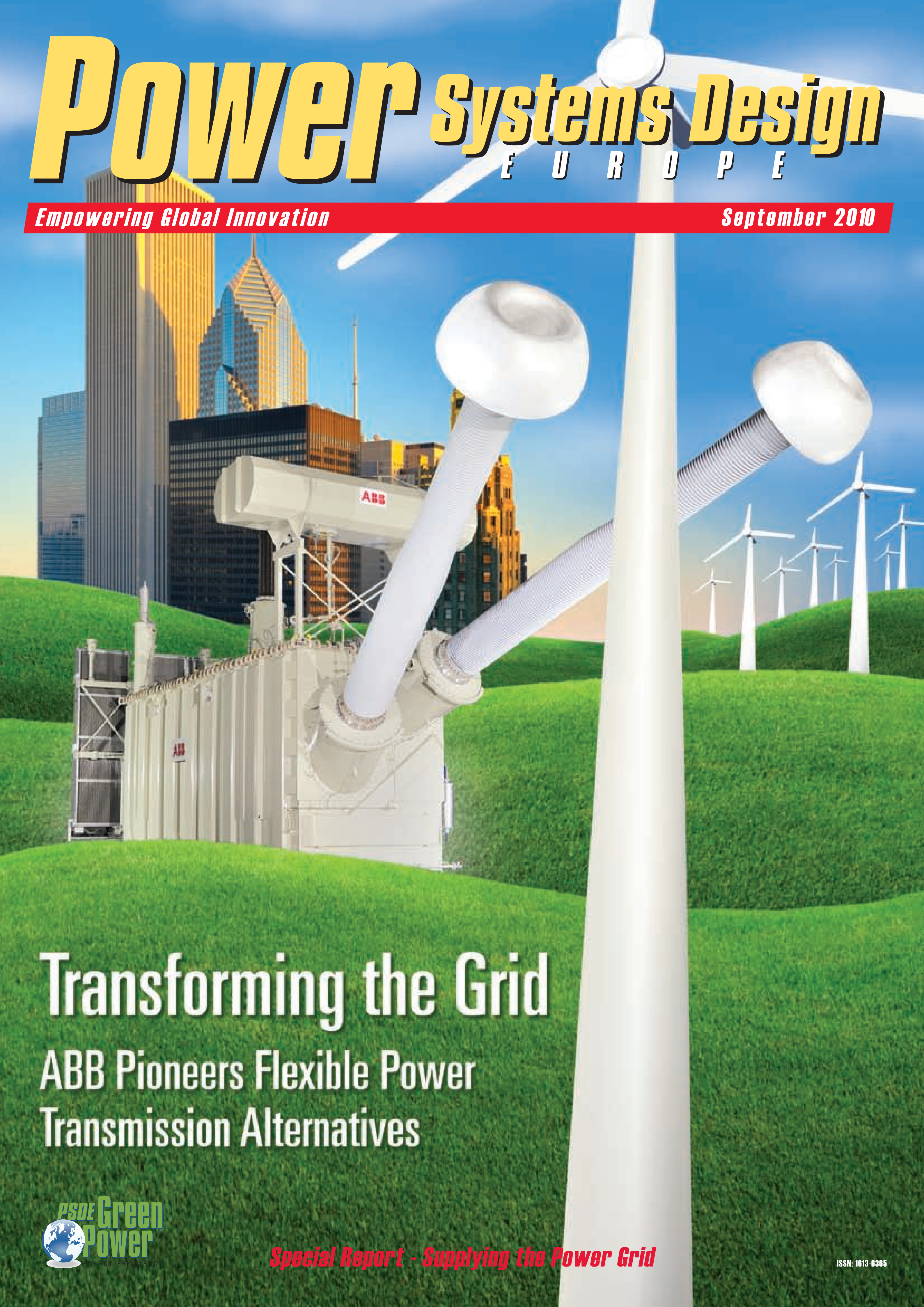
EUROPE

Empowering Global Innovation

September 2010



# Transforming the Grid

## ABB Pioneers Flexible Power Transmission Alternatives

PSDE Green Power

Special Report - Supplying the Power Grid

ISSN: 1613-6365

Power Systems Design EUROPE

PSDE Green Power
ENERGY EFFICIENCY

Power Systems Design EUROPE

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Volume 7, Issue 8

# Power Grid Fuels Growth

Welcome to this issue of Power Systems Design Europe, where we have prepared a special feature 'Supplying the Power Grid' covering one of the most important energy evolutions of our time.

The power grid, which most of us take for granted, keeps us connected, ultimately to the points of power generation. This vital and complex arterial network in many cases is now 'well past its best' and in need of urgent refurbishment or renewal. With governments and regional authorities in Europe pledging to upgrade and revitalize power grid systems in the name of energy efficiency, the environment and cost reduction - and because it is a way of attracting votes - there should be an adequate level of real funding for our power industry to engineer the refurbishment.

The aptly named Smart Grid is really the merger of two networks: the electrical transmission and distribution network, and the modern data communications network. While communications are not new to the electrical grid, the integration of renewable power generation, electric vehicles, and even consumers themselves into the grid requires the creation of an automated, distributed, and secure control system of tremendous scale, with reliable, flexible, and cost-effective networking as the fundamental enabling technology. The vertically-integrated Supervisory Control And Data Acquisition (SCADA) system silos of today are yielding to horizontally-layered communications architectures for substation automation, distribution automation, advanced metering, and home area networking applications. The smart grid will use a broad mix of public and private, wired and wireless, licensed and unlicensed, and standard and proprietary communications technologies. The Pike Research report covers these areas in detail.

The power management semiconductor industry fueled by gains in the commercial and industrial sectors, will finish 2010 on a high note that will be unmatched over the next few years, according to iSuppli Corp. Comprising integrated circuits and discretes, power management semiconductors will generate $31.4 billion in 2010, up nearly 40% from $22.4 billion in 2009. This year's expansion not only will reverse the losses of 2009—when revenue declined by 15.8%—it also will be unequaled during the next four years, where yearly growth is forecast no higher than 13%.

Over the next five years, a good part of growth in power management semiconductors will come from the vibrant alternative energy market, which will bring inverters to the attention of many suppliers. The need for inverters - devices that convert direct current to alternating current - will stem from applications in the automotive, solar and wind turbine markets. Revenue is expected to more than double by 2014, reaching $7.2 billion, compared to $2.9 billion in 2009.

Among the types of power management semiconductors, the fastest growth will take place among power MOSFETs, where revenue will increase at a Compound Annual Growth Rate of over 20% from 2009 to 2014.

I hope you enjoy this issue, please keep the very helpful and interesting feedback coming in and do check out our poignant fun-strip, Dilbert, at the back of the magazine.

All the best!

Cliff Keys

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# Nexans HV Submarine Power Link

Nexans, the worldwide leader in the cable industry, offers an extensive range of cables and cabling systems compromising low and medium voltage cables, high and extra-high voltage cables up to 400kV. The company is a global player in the infrastructure, industry, building and Local Area Network markets. Nexans addresses a series of market segments: from energy, transport and telecom networks to shipbuilding, oil and gas, nuclear power, automotives, electronics, aeronautics, material handling and automation.


Cable route

Nexans 170kV 3-core XLPE insulated sub-marine power cable

Nexans has now been awarded a € 64million turnkey contract by Greece's PPC (Public Power Corporation) – the country's largest electrical power utility – to design, manufacture and install the new high-voltage alternating current power link between Evia and the region of Attika on the mainland. The project will facilitate the development of wind power projects totaling around 400MW on Evia, the second largest of the Greek islands, by enabling the power they produce to be exported directly into PPC's national power transmission grid.

The 150kV link will interconnect the Nea Makri substation on the coast of Attika with the Polypotamos substation on Evia. Nexans will manufacture, supply and install three sub-sea cable circuits that will take a 21km route across the Gulf of Evia in waters reaching a maximum depth of 85 metres. Nexans is also supplying the underground power cables (27km) to provide the land connections at each end of the submarine cables together with associated accessories such as transition joints and outdoor terminations.

"The Nea Makri- Polypotamos contract further reinforces Nexans' position as a trusted partner for utility customers in the construction of the high-voltage sub-sea interconnection projects that are vital to the continued penetration of wind power as part of the global energy mix", says Yvon Raak, Nexans Senior Corporate Executive Vice President. "The key factors in winning this contract were our wealth of experience in many similar projects, combined with our capability to provide a complete in-house service from design and manufacture of the sub-sea and underground cables to installation and commissioning."

**Submarine cables**

The 150 kV submarine cables will be manufactured in Nexans' specialized submarine cable facility in Halden, Norway. They will feature XLPE insulation and comprise three power cores with a copper cross-section of 630mm2. Three cable circuits will be installed across the Gulf of Evia to provide two circuits in normal use with one spare to ensure continuity of operation. Each circuit will have a nominal capacity of 200MVA.

Installation is planned to be carried out by Nexans' own cable ship, the C/S Nexans Skagerrak. The cables will be buried approximately 1 metre below the seabed. The project is scheduled for completion within 36 months.

**Underground cables**

The 150kV underground cables will be a single core design for installation in three circuits, each circuit comprising three individual cables, over a 2.75km route on the Attika side and a 330 metre route on the Evia side. They will be manufactured by Nexans in France.

www.nexans.com

# Smart Grid: Comms is Key

*By Thomas Hillmann, Marketing Manager - Smart Grids & Smart Metering technologies EMEA, Texas Instruments*

Today's power grid has evolved for more than a century to generate, transport and deliver electric energy from centralized power plants to millions of end points which results in an unidirectional flow of power. With the dawn of large scale deployments of plug-in hybrid and electrical vehicles, an ever increasing percentage of renewable energy and the generation of electrical energy in small decentralized units in order to minimize transportation losses the power grid as it is today will soon become insufficient.

The smart grid is needed in order to accommodate these new trends. There are many visions on what the smart grid should be capable of, but all have one thing in common: the bidirectional flow of power and information. This would enable a vision of a real-time energy market place. If power generation data and also power consumption data could be communicated in real-time then the overall supply and demand would result in energy spot price that could fed back to consumers. This real-time price information would then potentially influence their behavior and avoid peaks by increasing the energy price. Charging an electric car during mid-day for example, may be more expensive than re-charging it late night in the future.

These visions are supported by a clear political will. The 3rd energy package issued by the EU (directive 2009/72/EC) is a major driver towards smart grids and smart metering. It states that member states shall ensure the implementation of intelligent metering systems that shall assist the active participation of consumers in the electricity supply market and that at least 80% of consumers shall be equipped with intelligent metering systems by 2020.

Some countries have already laid out detailed timelines for the implementation of smart meters including the UK (Gas + Electricity), Spain, France, Italy (Gas) among others. The key aspect of a smart meter is communication. The devil is in the detail as it is not yet clear what communication protocols should be used - it has to be a 'standard' according to the European mandate 441. This mandate has the general objective to create European standards that will enable interoperability of utility meters.

Different European and National bodies, industry groups and individual companies need to agree on these standards before deployment – a process that takes time. At the same time there are tough timelines for the implementation of smart meters. The answers to these dilemmas are 'smart-ready' meters, e.g., meters that could adjust to different standards depending on what the regulators and the market demands.

Texas Instruments provides a range of 'smart-ready' hardware solutions that are able to support most if not all of the currently discussed standards. Firmware updates ensure that these solutions are kept fully up to date.

Despite all this 'smart-readiness', decisions will have to be made eventually. Some major developments that are expected in the near future which may or may not influence some of the National, European or even worldwide developments in the smart grid arena are described here:

***PLC in Spain/Portugal:*** Many people will be eager to hear more from the large scale deployment of PRIME meters in Spain and Portugal. The PRIME PLC standard seems to be the most advanced open and royalty free AMI PLC protocol in terms of maturity of technical specification but also in terms of organizational structure of the PRIME alliance.

***PLC in France:*** Great interest will also be generated by G3 which has some promising technical aspects. A smaller scale G3 test pilot of 2000 meters will be watched very closely by the industry. One can also remain curious on how the relationship between the sibling OFDM narrowband technologies PRIME and G3 will develop in the future.

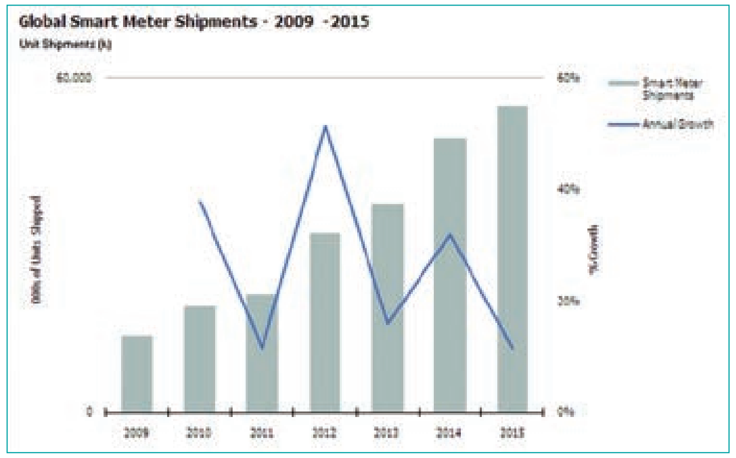
***Radio in Italy:*** The Italian Gas Committee (CIG) will decide on the wireless communication standard for Italian Gas meters – possible candidates include Wireless M-Bus and Zigbee 2.4 GHz amongst others.

**www.ti.com**

# Supplying the Smart Grid – What is Next?

*By Michael Markides, Senior Analyst and Research Manager, IMS Research*

The term "smart grid" is widely used throughout the electronics industry. Over the last couple of years, its frequency of usage appears to have ramped up, even to the extent whereby commercials are touting grid evolution as the next big thing. In reality, these two words somehow seem inadequate in communicating the shear scale and complexity of the issue. At IMS Research we are concerning ourselves with how the smart grid trend will create additional revenue opportunities beyond what conventional grid investment provides companies involved in this infrastructure, from utilities all the way to IT consultants. Without having a broad view of the entire landscape of products and services affecting the smart grid, it's hard to measure the rate of its evolution. One method that provides a decent proxy for measuring this evolution is to look at the smart meter market, which is a key technology in the overall implementation.




Halfway through 2010 the smart meter market is experiencing record growth globally, with IMS Research predicting some 20 million unit shipments in 2010. With over 50 million more smart meters under contract in North America, and mandates in Europe for complete nationwide rollouts, it is apparent that utilities see value in updating their respective electricity grid infrastructure with modern communications electronics and IT investment.

IMS Research uses a very strict set of guidelines when reviewing the entire spectrum of advanced electricity metering, limiting our definition to any meter with the ability to remotely communicate. The booming sector of smart meters is defined as any advanced electricity meter that is installed in an infrastructure network (AMI), has two-way communication capability, and has embedded firmware in the meter itself to facilitate smart grid functions at the home, or building on which it is installed. An example of smart grid applications would be "time of use" (TOU) pricing, in which the pricing model for electricity is communicated to the customer in real-time and is altered dependent on overall electricity consumption in the neighborhood, or at the municipal level.

North America and Europe are the regions where smart meter installations are currently happening, and projected to dramatically grow over the next five years; thus it makes sense that we should expect to see the largest smart grid investments here. IMS Research has also identified pilot programs in Latin America, the Middle East and Asia; however, it is currently unclear whether smart grid functionality beyond automated meter reading will be implemented in these regions.

This begs the question of how else will smart grid investment take place. Home area networks (HAN) are being discussed in North America and Europe, but are these an important driver for installing smart meters worldwide? Will developing regions, with much more operational side savings to be realized, install basic two-way AMI meters only without any consideration for HAN adoption? IMS Research is working to outline a clear understanding of how the smart grid evolution is altering the electronics market and new studies, such as exploring the market for distribution (substation) automation, will be the next step to answering some of these questions.

www.imsresearch.com





# Power Supply Development Diary

## Part VI

*This article continues the series in which Dr. Ridley documents the processes involved in taking a power supply from the initial design to the full-power prototype. In part VI, attention is turned to implementing proper current limiting to ensure a rugged power supply under all conditions.*

*By Dr. Ray Ridley, Ridley Engineering*

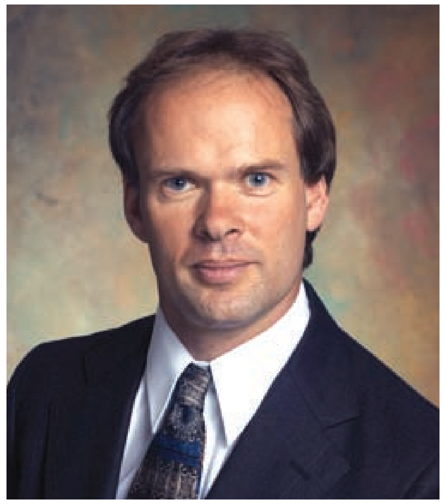
**Primary Current Sensing**

In Parts IV and V of this series of articles [1], voltage spikes were properly controlled on both the primary and secondary of the power supply to prevent failure of the power semiconductors. With this done, the power supply can be taken up to full input voltage, and full load on the output.

It is tempting to do a substantial amount of data collection at this point to make sure the power supply is regulating properly, and to test parameters such as efficiency, regulation, and thermal rise. However, it is advisable to move on to a phase of testing that most designers do not look forward to – current-limit testing, and short-circuit testing to make sure the power supply is rugged.

Many engineers leave the short-circuit testing until the end of the power supply development. Experience tells them that this is often a destructive and time-consuming process, and they are reluctant to damage their first prototype so early in the testing process. However, it should be done immediately. Changes to the current-limiting and current-sensing circuits may lead to power component changes in order to survive short-circuit testing.

The UC3825 control chip provides for two levels of current protection. The first level is implemented in the main PWM comparator, and the error voltage from the voltage feedback sets the



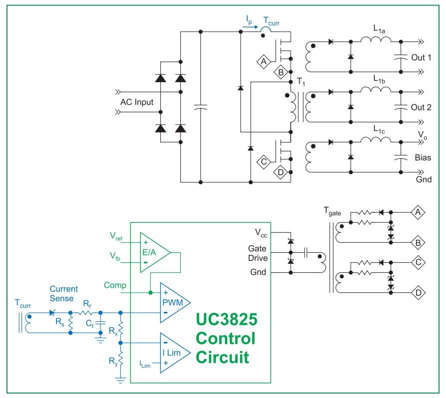



*Figure 1: Two-switch forward converter with current sensing network. Current sensing components are shown in blue in this figure. It is recommended that a converter have two levels of current sensing – one for normal peak current limiting, as part of the main PWM control loop, and a second level for short-circuit protection.*

peak current level on each cycle. This error voltage is clamped to around 4.5 V, providing a fixed limit to the current regardless of the state of the output voltage. However, this current sensing mechanism also has leading edge blanking, and for the first few hundred nanoseconds, the signal is ignored.

The filtered current sense signal is also divided by resistors Rx and Ry in Figure 1, and this is fed into the second current limit input, which has an immediate response when the signal exceeds the threshold of ILim. No leading-edge blanking is applied on this input, allowing for fast protection during short circuits.

**Power Supply Startup Current Waveforms**

The first instance of current limiting normally occurs during the startup of the power supply. Initially, the output capacitor of the power supply is discharged. For a few milliseconds, the capacitor looks like a short circuit. The severity of this test depends on the settings of the soft-start circuit. If the soft-start is very slow, current limit may not be encountered during start-up. With a faster soft-start, current limiting will be encountered during the turn-on process.

Figure 2 shows a waveform of the primary switch current during turn-on of the power supply. This is a waveform with a characteristic that you will hopefully not see in your power supply. There is a distinct curve at the top of the yellow waveform, showing that the power magnetics are saturating. A well-designed converter should never exhibit this characteristic under any test conditions.

There are two magnetics in the forward converter that can saturate – the power transformer, and the output inductor. Figure 3 shows a diagram of the components of the current sense waveform on the primary of the forward converter. The current transformer senses the reflected output inductor current, plus the magnetizing current of the power transformer. When looking at the waveform of Figure 2, you cannot initially tell which of the two magnetics is saturating.

The output inductor and the power transformer are saturated through two different mechanisms. The output inductor saturation depends upon the current flowing through the main inductor to the load. Transformer magnetizing saturation depends upon the input voltage and duty cycle, not upon the load current.

When the current sense resistor, Rs, is increased to 68 ohms from 47 ohms, the peak current is reduced, as shown in Figure 4 (notice the change of the vertical scale). The saturation characteristic is completely eliminated. This shows that the output inductor is the component that was saturating, not the power transformer.

With the startup waveforms corrected with the increase current sense resistor, short circuit testing can now be done.

### Short Circuit Current Waveforms

One of the harshest tests to a power supply is to place a short circuit on the output, and to abruptly apply high input line voltage. The power supply controller ramps up the current through the soft-start period, then cuts back to a very small duty cycle to protect the power switches. A well-designed converter should survive this test, and it must be done early

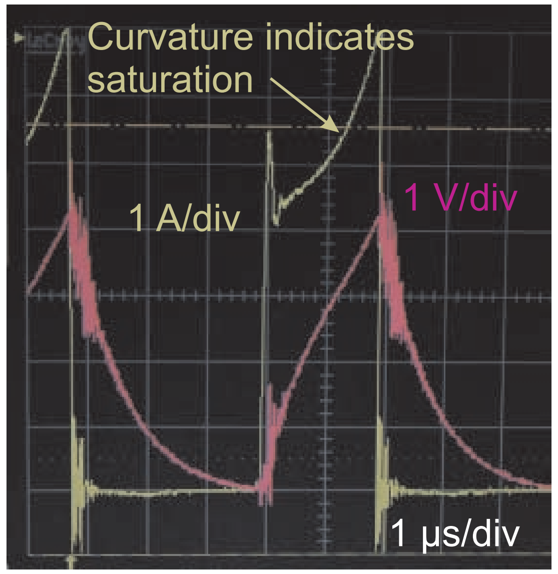



*Figure 2: Current-sense waveform with abrupt application of input voltage, and output capacitors discharged. Soft-start provides protection in addition to the current limiting. However, magnetics saturation is clearly visible in the current waveform. The red waveform shows the filtered current signal after the components Rf and $C_f$.*

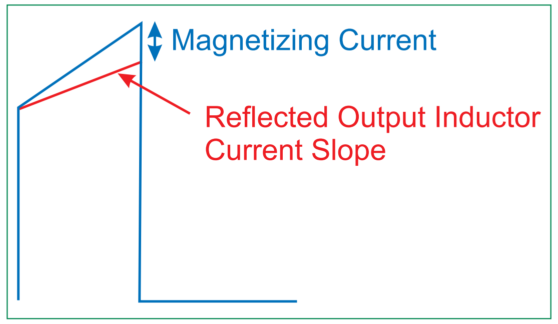



*Figure 3: Components of primary current, showing contribution of magnetizing current of transformer.*

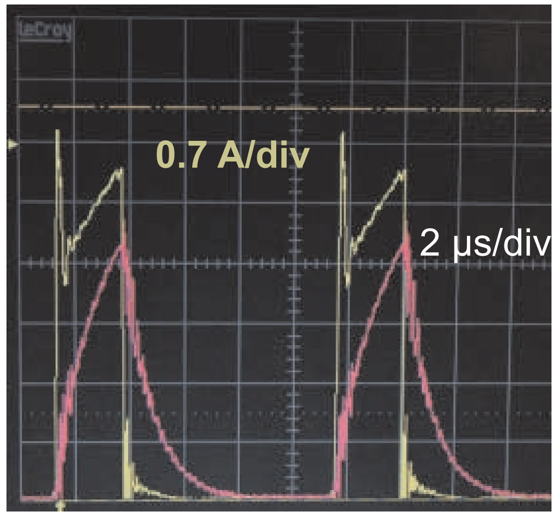



*Figure 4: Increased current sense resistor (reduced current limit level) eliminates saturation. This shows that the output inductor is saturating, not the power transformer.*

in the design process.

To avoid too much destruction, it is a good idea to monitor the primary current, and perform this test starting at low line, and gradually increasing the line voltage. It may be necessary to adjust the filter components and the divider resistors in the current sense network during this process to achieve the proper degree of protection.

Figure 5 shows the current sense waveform under short-circuit conditions. The current pulse is cut back to just 100 ns before the gate drive is turned off. This is well within the leading-edge blanking time of most PWM controllers, which is why a second current-limit level is recommended. Once this higher current level is reached, a soft-start sequence is initiated by the controller after a substantial time delay of several milliseconds. This protects the converter components.

While it is painful to do this test early on, you will find that once you have set the current sensing properly, you feel much more confident about the ruggedness of your design, and you can move on to the next stage of testing.

### Summary

The final stage of protection of the power circuit is not in place. Rugged current limiting will protect the semiconductors under all test conditions without any failures.

So far, the power stage testing has followed this order:

1. Check gate drive circuit waveforms.
2. Test primary circuit with resistive load.
3. Insert magnetics into circuit and verify low-voltage waveforms.
4. Design proper voltage clamps on primary switches.
5. Design proper voltage clamps and snubbers for secondary diodes.
6. Design proper current sensing circuits, test for startup and short-circuit.

The circuit is now ready for use at full power and the full range of test conditions.

During the six steps listed above, and described so far in this series of articles, there have been multiple modifications to component values, board connection changes, and other additions and corrections. At this point in the development cycle, it may be wise to redo the PCB layout to accommodate all of these changes. Or, if time is an issue, testing can continue with the present PC board. For an experienced power designer, there are normally a minimum of three PC board iterations. Choosing the right time to turn the board is important. It is desirable to delay the PCB change to work as many changes into the second iteration as possible, but at some point, the number of jumpers and changes will force the issue.

For this example of a two-switch forward, further testing was done before revising the PC board layout.

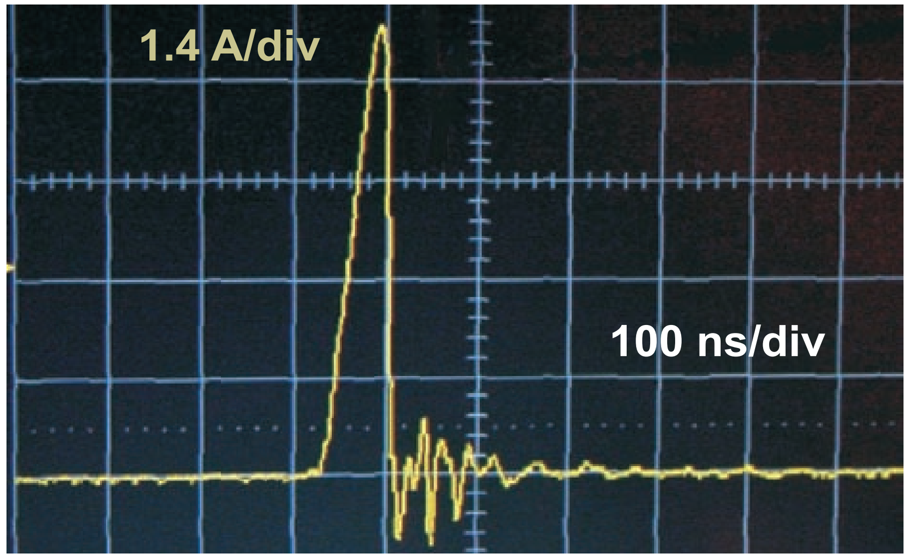



*Figure 5: Current sense waveform with high-line voltage input and short-circuit on output. Notice that the current pulse is reduce to just 100 ns. When this current signal exceeds a second current limit threshold, soft-start is reinitiated, and the converter enters a burst mode of operation at low frequency, protecting the semiconductors from overstress.*

*References*

1. *"Power Supply Development Diary Parts I-V", Ray Ridley, Power Systems Design Magazine, 2010.*
2. *Book on current-mode control design, http://www.ridleyengineering.com/cmode.htm*

**www.ridleyengineering.com**

TechTalk

# IDT Innovates

## *Industry's most flexible intelligent system power management IC*

*I had the pleasure of talking with Casey Springer, Senior Product Marketing Engineer who is based at the company's HQ in San Jose, California. IDT celebrates its 30 year anniversary in the provision of mixed signal semiconductor solutions and has design, manufacturing and sales facilities throughout the world. Casey talked about IDT's newest, highly integrated total power management IC with built-in CPU making it deal for portable consumer applications.*

*Reported by Cliff Keys, Editor-in-Chief, PSDE*

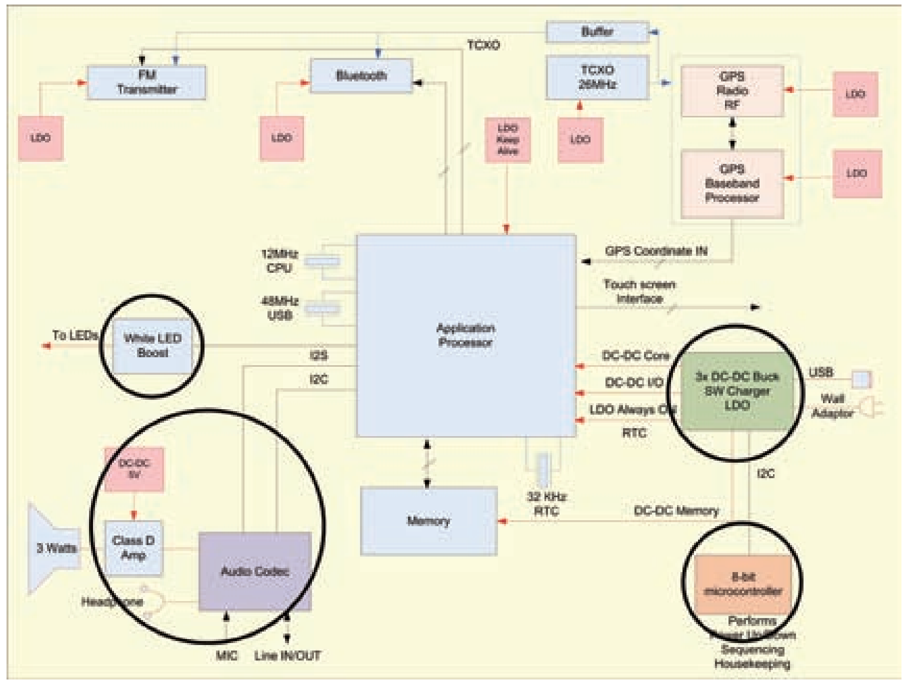
Integrated Device Technology, Inc. is a leading provider of essential mixed signal semiconductor solutions that enrich the digital media experience. What I found initially encouraging was that the company reinvests over $140M year in R&D, a reassuring investment that has resulted in over 900 patents to be founded.

IDT announced a highly integrated microcontroller-based Intelligent System Power Management Solution targeted for portable consumer products, such as Smartphones, portable navigation devices, mobile Internet devices and

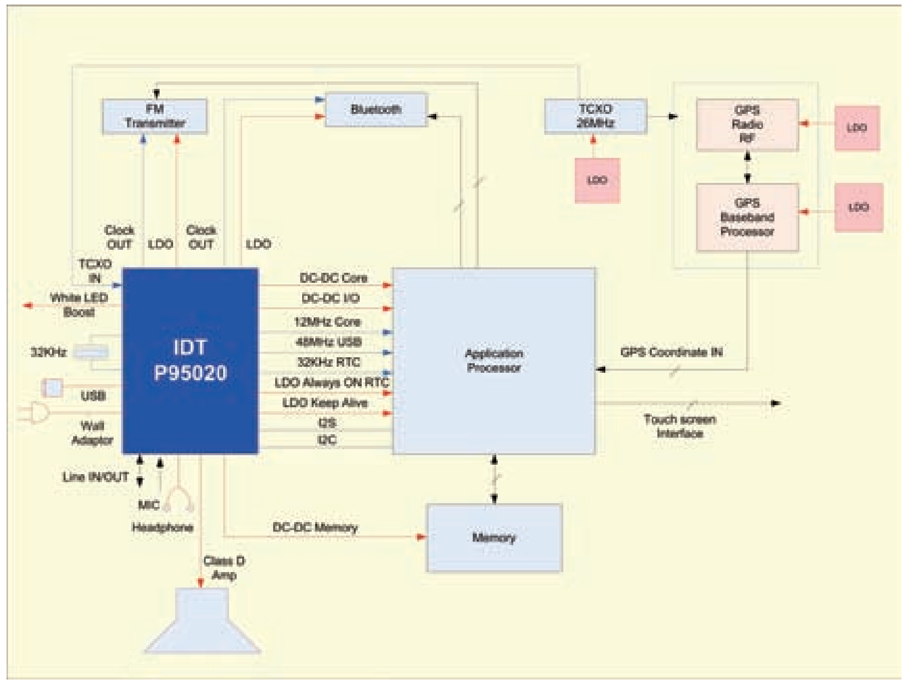

eBooks. The company has channeled its engineering talent to integrate the vitally-important power management function building on its considerable silicon heritage to add value to its core technologies.

The trend in portable devices is for continuous growth in for example, Smartphone, portable navigation, portable gaming, MID and eBook, with many more about to launch into this potentially lucrative market. Common expectations and requirements are:

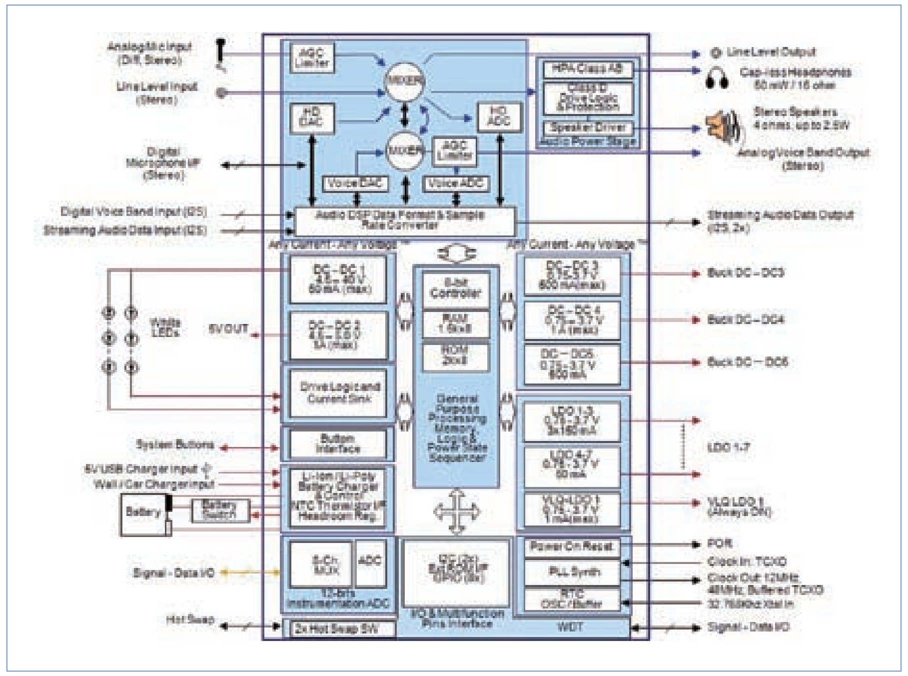
- More connectivity and functionality (Bluetooth, GPS, WiFi, Mobile TV …)
- Emphasis on audio quality with new classes of mobile phones, such as Multimedia and Music phones and MP3, stereo capability in numerous systems
- Emphasis on user interface with touch screen now a common and well accepted feature
- Rapid product lifecycles: Currently 9-18 months prime market life with just 3-6 months development cycle




*Portable Navigation Device (PND) with discrete components*




*IDT's P95020 dramatically simplifies a typical PND application, reducing time-to-market, lowering power consumption and increasing reliability*




*P95020 block diagram*

But in this crowded market it is important for IDT not only to meet these requirements and consumer expectations but to exceed them and to differentiate by adding more features such as:

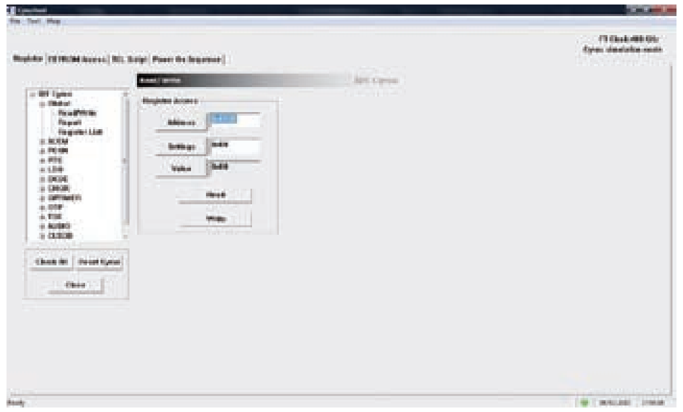
- Better audio fidelity, loudness, high-efficiency audio amp
- More integration
- Longer battery life
- Smaller form factor
- Modular platform approach

IDT has researched the market and observed that current audio and power regulation (PMIC) solutions lack the flexibility, programmability and intelligence to address all of these challenges. The result of the company's creative engineering has resulted in its latest product launch into this tough market with the introduction of the P95020 Embedded Mixed-Signal Controller.

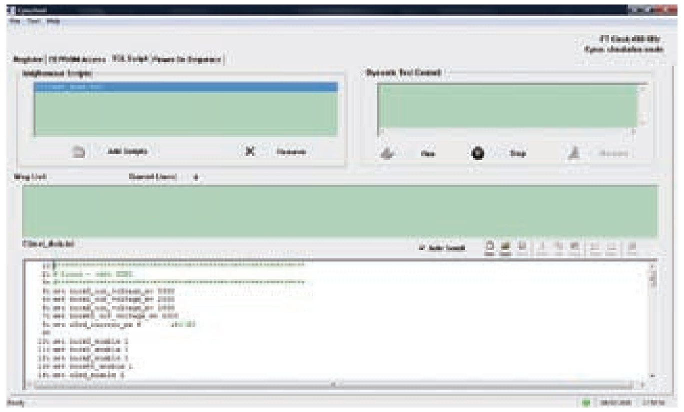
The unique architecture of the IDT P95020 features a best-in-class high-fidelity audio subsystem, clock generation, resistive touch controller, backlight LED driver, Li+/Polymer battery charger, multi-channel DC-to-DC converters and a high resolution analog-to-digital converter (ADC).

By embedding a microcontroller, the IDT P95020 offers full programmability and flexibility into designs using leading multimedia application processors. All of the functional blocks can be accessed via I2C and programmable regulators, satisfying the dynamic voltage adjustment required by application processors.

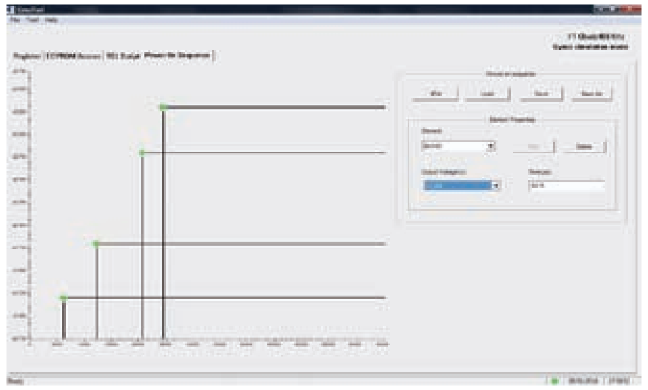
Casey explained further, "The IDT P95020's innovative architecture, with an embedded CPU, can manage all on-chip resources and also offload general housekeeping and I/O processing tasks from the application processor. This unique feature, along with programmable system power regulation blocks and an on-chip power management scheme, results in higher system performance and longer battery life. Building around the IDT digital heritage combined with leadership in high-performance silicon timing, PC audio codec excellence and integration of newly developed high-performance mixed-signal mega blocks, the IDT P95020 is the first in a series of next-generation Intelligent System Power



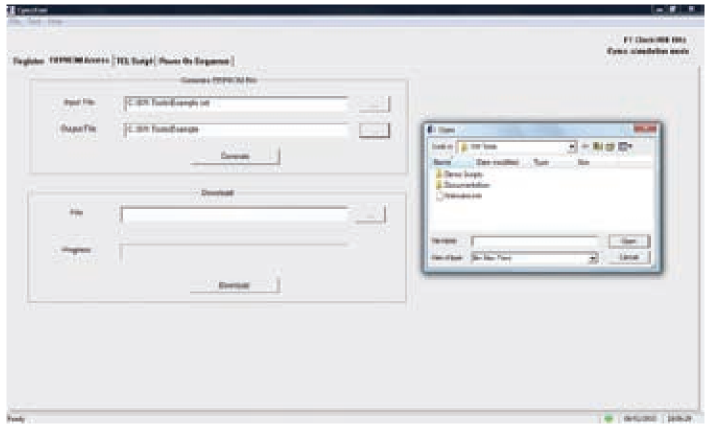
*The GUI allows the user to quickly and easily monitor and change P95020 register settings*



*The user can also generate and run TCL scripts using the GUI to put the P95020 through a pre-defined sequence of actions/settings*



*The GUI features a user-friendly drag-and-drop interface for defining power rail sequencing. These sequences can then be saved as script files*



*Once scripting files have been completed, the GUI can convert them to *.bin files and to load them to the EEPROM on the mezzanine card*

Management solutions being developed by IDT as part of its mixed-signal SoC growth strategy."

The IDT P95020 is the latest generation of cost-effective, customizable Power Management Integrated Circuits (PMIC) that provide optimum performance, functionality, programmability and flexibility to the system designer of portable consumer applications. Its subsystems consist of multiple switch-mode DC-to-DC converters and low-dropout (LDO) regulators, battery charge management, white LED drivers, low-power stereo audio and voice codecs with a mixer function, Class-D amplifier and headphone driver, a PLL for on-chip and off-chip clock generation, and a touch-screen controller. The embedded CPU utilizes on-board system management resources, such as instrumentation SAR 12-bit ADC and a real-time clock to provide optimum flexibility while reducing overall system power dissipation. The IDT P95020 PMIC is the first of its kind to integrate all the system power regulation and management functions along with human interface subsystems, such as audio and touch user interfaces.

**Making design-in simple:**

To help customers design their next-generation devices using the IDT P95020, IDT provides evaluation kits, pre-defined sample scripts and the IDT GUI-based scripting tool.

**GUI Firmware Environment:**

The IDT P95020 is currently sampling to qualified customers and is available in a 10mm x 10mm, 132-pin QFN package and a 7mm x 7mm WCSP package. The IDT P95020 is priced at $3.72 for 10,000 units.

Additional information about IDT is accessible at www.IDT.com

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# Flexible Power Transmission

## *Transmission solutions for fast-track, integrated renewable power*

*Advances in global long-haul, high-powered transmission technologies and capacity create an imperative for renewable generation in the U.S. and beyond.*

*By Martin Gross, Global Head of Grid Systems Business, ABB*

It certainly is an interesting time in history to be involved with electricity. The power industry is on the verge of the biggest breakthroughs in generation and grid transformation since the days of Thomas Edison and George Westinghouse. As we all know, George got it right and AC transmission has been dominating the power infrastructure until lately. However, during the last decade, DC transmission technology has made great strides and has become a vital part of modern, intelligent and flexible transmission systems. The name of the game is no longer AC against DC – it's the intelligent combination of both.

Today, three major issues are on the minds of citizens, government officials and policy makers in many nations around the globe:

- the status of the global economy
- energy reliability and independence
- environmental sustainability

Electricity providers are directly impacted by these issues as they seek to responsibly apply alternative generation sources, energy efficiency technology and engineering solutions that will not only deal with these issues, but help them move forward into a new decade fueled by an ever-growing portfolio of renewable generation.

This article will briefly explore how recent breakthroughs around the world in power transmission systems have led to an imperative in the United States to develop a more intelligent, flexible, long-haul transmission network that has the ability to carry renewable energy from remote locations to major population centers.

**Renewable Portfolio Standards are driving the build out of renewable generation**

Today in the United States, 33 out of 50 states have some kind of renewable standard. These Renewable Portfolio Standards (RPS), and their corresponding deadlines for compliance, have had significant impact on recent generation spending.

*ABB's new 800 kV UHVDC (Ultra High Voltage DC) transformer can deliver vast amounts of electricity over very long distances. This transformer is being used on the world's longest power transmission link across more than 2,000 kilometers in China.*

Proposed goals for a national renewable portfolio standard vary from 12 to 25 percent, and should such a national standard be released by the government, it is estimated that incremental capacity additions of over 300 GW will need to occur. However, transmission capacity for this new and mostly remote generation currently does not exist.

And with an average construction schedule of 60-72 months for a 500MW at 345kV transmission line, it could take well beyond 2025 until it would be in place.

Among other things, NERC's October 2009 publication, "2009 Long Term Reliability Assessment 2009 – 2018," notes that although existing reserve margins are adequate across the U.S. for the next few years, the first priority must be to expand the grid and increase the capacity of transmission to handle the expected growth of renewable generation.

The report concludes by saying: "More than 11,000 miles (or 35 percent) of transmission above 200kV proposed and projected in this report must be developed on time to ensure reliability over the next five years." NERC strongly believes that construction siting is the most urgent issue for the electric power industry, now and well into the future.

*Renewable resources and transmission in the western United States. Western USA holds vast wind and solar resources, but many are not served by existing HV* transmission lines.*

** Shown: 500kV and above*

### Bulk transmission capacity: Pre-requisite for large-scale renewable generation

If utilities are to harvest the vast renewable power potential in remote locations of America, or anywhere in the world, they need to be able to move it in a highly efficient manner from its production point to cities and load centers where people live and work.

Bulk transmission capacity is a prerequisite for large scale renewable generation. While the intermittent nature of many renewable power sources creates new challenges for grid reliability, there are indeed proven, readily-available and cost-effective transmission technologies to mitigate their impact. Reliable, cost-effective transmission technology exists to support massive amounts of new renewable generation, and they are available right now. These technologies include:

### High Voltage Direct Current (HVDC) and HVDC Light

High voltage direct current (HVDC) transmission moves bulk power from remote generation areas to load centers, by using DC rather than AC transmission. Though this technology was pioneered more than 50 years ago, it is enjoying increasing popularity now.

Similarly, ABB introduced "HVDC Light" just over 10 years ago. HVDC Light is a landmark HVDC technology that enables a host of new applications such as wind parks far out at sea and underground power transmission over long distances. This technology is now running on four continents, and is ideal for transporting renewable energy without many of the common siting and overhead line political and regulatory issues of recent years. For remote offshore power it is the key enabler as the usage of AC cable technology becomes unfeasible beyond a certain distance.

Direct current transmission technology has lower losses and a smaller footprint than alternating current systems (AC). HVDC Light is based on voltage-source converters (VSC's) and uses IGBT's (Insulated Gate Bipolar Transistors) to convert electrical current from AC to DC. HVDC Light is now available at a power level of 1,200 megawatts (MW).

### Flexible AC Transmission Systems (FACTS)

Intelligent transmission systems like Flexible AC Transmission Systems (FACTS) increase the capacity of existing transmission networks, improve reliability and enable effective integration of renewable generation. The replacement of local generation with remote generation requires additional reactive power support. The intermittent nature of wind and solar may require dynamic VAR support for system stability.

One FACTS power system growing in popularity is known as a Static Var Compensator (SVC). SVC systems 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. SVC's also improve the local environment, since much less local generation is required due to the increased capacity on existing networks.

In the last three years, ABB has built the world's largest cluster of SVC's for a major utility in Texas and the largest single SVC power solution in western Maryland. These FACTS devices will facilitate and enable future integration of wind and solar power as more and more renewable energy sources go online in the near future.

There are several key transmission projects in the U.S. today that are focused on transmitting renewable generation. For example:

- FPL's NextEra Energy has completed much of its merchant transmission associated with its Horse Hollow Wind Energy Center project in Texas.
- Southern California Edison continues to add transmission to support wind generation in the Tehachapi region.
- San Diego Gas & Electric – SDG&E's Sunrise PowerLink will play a major role in bringing renewable generation from the Imperial Valley into southern California, even though one of its primary reasons for existence is system reliability and load growth. According to the Renewable Energy Transmission Initiative, the Imperial Valley region has potential for 6,870MW solar, 3,495MW wind and 2,000MW geothermal power generation.
- LS Power's Southwest Intertie will move renewable power from Wyoming and Montana to substations near Las Vegas, using combinations of AC and possibly high voltage DC transmission.
- Another LS Power project, called Overland Transmission, will apply either high voltage AC or DC circuits across 560 miles to move renewables-fueled generation between eastern Wyoming and southern Idaho.

*High-voltage direct current (HVDC) systems, like this Sharyland HVDC station connecting power grids between Texas and Mexico, enable bulk transmission across long distances.*

Although there are multiple major transmission projects underway or nearing construction in the U.S., they are by far not enough to support RPS requirements. The two key impediments for the expansion of the renewable power transmission capacity are:

- The fragmented and time consuming regulatory approval process and
- The absence of an integrated renewable generation and transmission strategy

To get an idea of what the future could look like in U.S. transmission, let's take a quick look at a couple of examples of recent transmission successes in Europe and China.

### Europe: Visionary governments, regulators pave way for offshore wind power

In the North Sea, 81 miles off the coast of Germany, the world's largest offshore wind farm is connected to the grid using advanced HVDC technology. With HVDC cables lying both underwater and underground, the environmental impact of the project is minimized and the regulatory and siting procedures have been swift. The project connects the wind generators and transmits the power to a new substation on the coast of Germany that is then connected to the existing transmission grid.

The BORWIN 1 offshore wind farm demonstrates how HVDC can effectively accumulate power generated in remote locations and transmit it to load centers. Through the use of HVDC and wind generation, Transpower, the project owner, expects to avoid CO2 emissions of 1.5 million tons per year by replacing fossil fuel generation.

Additionally, several European countries are currently discussing ways to build up a renewable generation DC Grid in the North Sea linking multiple offshore wind farms with hydro power generation from Norway to create a firm renewable power source.

### Coming Soon: An 800MW Offshore Wind Farm

Just this summer, an even larger project off the coast of Europe was launched. ABB is working with the transmission grid operator, Transpower, to supply an 800 megawatt (MW) power link. This project will involve HVDC Light technology to transmit power from the 400MW Borkum West II wind farm and other wind farms to be developed nearby. The wind farms will be connected to an offshore HVDC converter station which will transmit electricity to the onshore HVDC station at Dörpen, on the northwest coast of Germany via 165km of underwater and underground DC cables. The Dörpen/West converter station will in turn feed AC power to the mainland grid. At 320-kilovolts, this will be the highest voltage level of extruded cable ever used for HVDC.

State-of-the-art transmission technologies like these are integrating renewable energy sources efficiently, ensuring grid reliability and stability, and lowering environmental impact. HVDC Light transmission systems offer numerous environmental benefits, such as neutral electromagnetic fields, oil-free cables and compact converter stations. It is an ideal solution for connecting remote offshore wind farms to mainland networks, as well as connecting remote renewable energy sources to load centers far away with underground cable transmission. These technologies overcome distance limitations and grid constraints and ensure minimal electrical losses.

This offshore wind project is scheduled to be operational by or before 2013, and is expected to avoid three million tons of carbon dioxide emissions per year by replacing fossil-fuel based generation. Germany currently meets about eight percent of its electricity requirements with wind power, and expects to double that by 2020.

Several other HVDC offshore wind projects are underway in Europe. Sweden is, for example, implementing this same HVDC Light technology off

*Flexible AC transmission systems (FACTS) enable and support remote variable generation with great reliability.*

*An ABB engineer tests HVDC Light valves to be used for the connection of a remote offshore wind farm north of Germany in the North Sea.*

the island of Gotland, the same island where the world's first HVDC line was installed in 1954. Again this advanced technology is used to carry wind power from the coastal areas onshore to load centers on the mainland.

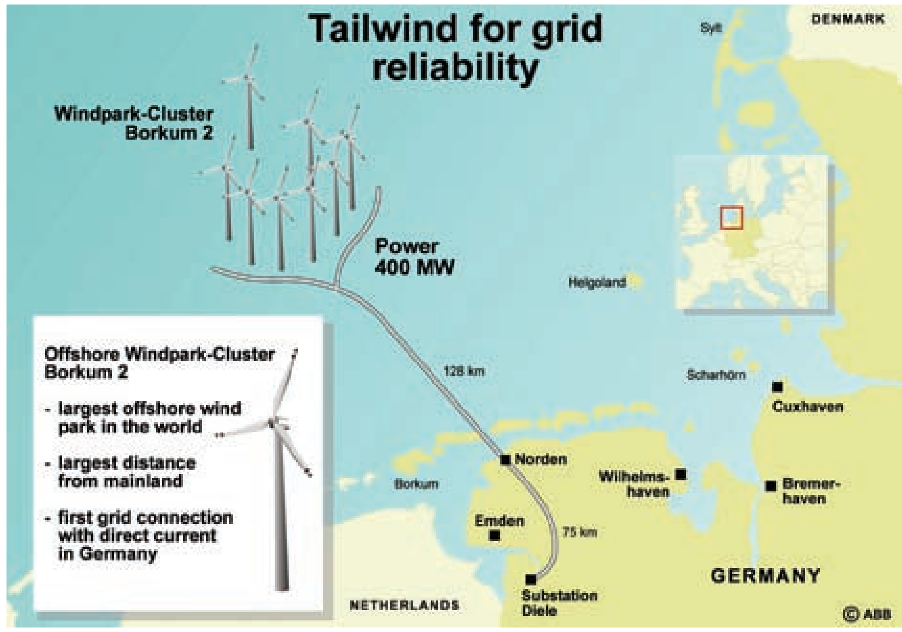
**China: World's longest and most powerful transmission link up and running**

China continues to set the example and lead the way in developing advanced transmission technologies that tap the power of renewable energies without many of the state or national obstacles faced in the U.S. or Europe. For example, ABB recently worked with the State Grid Corporation of China (SGCC) to create the world's first Ultrahigh-voltage direct current (UHVDC) transmission link for commercial operation. This represents both the world's longest and the world's most powerful transmission link.

The ±800kV Xiangjiaba-to-Shanghai UHVDC link has the capacity to transmit up to 7,200 megawatts (MW) of power from the Xiangjiaba hydropower plant in southwest China to Shanghai, the country's leading industrial and commercial center, about 2,000 kilometers away in eastern China. The new link is able to meet the electricity needs of about 24 million people, and sets a new benchmark in terms of voltage levels and transmission capacity, superseding the 600kV (kilovolt) Itaipu transmission line in Brazil, which was also developed by ABB.

The high-capacity power link comprises a single overhead line and occupies less space than the existing system. Moreover, transmission losses on the new line are under seven percent, again, considerably less than the existing 500kV system. The electricity saved is equivalent to the power needs of around one million people in China.

UHVDC transmission is a new and expanded development of HVDC. This technology with an advanced control system represents the biggest capacity and efficiency leap in power transmission systems in more than two decades. It is particularly suitable for vast countries like China and India, where consumption centers are often located far from power sources, including renewables.




*In Europe: Visionary governments and regulators pave the way: E.ON Borkum 2 Wind Farm applies HVDC to move generated wind power off the coast of Germany.*

**United States: Regulatory, political obstacles can be overcome**

While in other parts of the world, governments, regulators, utilities and industries are working towards common goals, many transmission projects in the United States have not yet overcome regulatory hurdles.

The good news is that there is proof that things can be done differently. In Texas, unique cooperation between utilities, multiple regulatory agencies, generation companies, and reliability councils are executing a Public Utility Commission order effectively, timely and fairly. Hallmark to this activity is the PUC-driven coordination between transmission and generation stakeholders. When completed by the end of 2013, this Texas CREZ initiative should realize incremental addition of more than 5,000 miles of high voltage AC transmission, reliably moving 18GW of renewable generation from west Texas into Dallas, San Antonio, and Austin.

Multiple scenarios were developed and studied by ERCOT in consultation with other regional transmission organizations, independent organizations, independent system operators, and utilities. The Texas Department of Wildlife provided impact analysis. Based on ERCOT recommendations, the Commission chose one out of four CREZ scenarios and ordered its development in the State.

Simultaneous guidelines and protocols were provided to generation stakeholders to assure that neither generation nor transmission investment will be "stranded," and that generation stakeholders produce sufficient assurance such that wind generation is built.

To comply, wind generators have been busy. Nearly 11GW of wind are installed, there are 450 megawatts of new wind under construction, and nearly 13GW of wind are in development.

The bottom line in Texas: these projects got off the ground in a matter of years, not decades.

What is needed to resolve key obstacles delaying renewable energy and related transmission build out across the U.S. and other nations grappling with this issue are: Swift regulatory and siting procedures; fair cost allocation; and political courage to execute.

If there's a progressive PUC in place, as there is in Texas, and if there is cooperation between the various regulatory agencies that have agreed on common goals and executed the reviews and permits needed to keep schedules on track, then there is the real possibility for successful breakthroughs.

**Conclusion**

Idaho Governor C.L. Otter recently said, "The recent economic recession has slowed the growth in demand for electricity, but we cannot squander this opportunity to address future needs. It is clear that coordination among states, the federal government, all segments of the industry and non-governmental organizations is essential for the region to meet its clean energy needs."

The Texas CREZ is an excellent example of how things can get done in the U.S. A visionary PUC with political support, a coordinated regulatory process, and the courage by everyone involved combines for a favorable environment for sustainable renewable power growth. This model can, and hopefully soon will be, applied across the United States as it is elsewhere.

Only when a fast track, integrated renewable power and transmission strategy is set in motion, will the United States meet its RPS targets and be in position to take full advantage of these rapidly-growing transmission technologies, systems and capacity already being built and implemented throughout Europe, China, and several other countries around the world.

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Power Modules

# Power Optimization

## *CIPOS™mini – The benchmark of intelligent power modules for home appliances*

*All applications, which support the comfort in our daily life, are supposed to be invisible – or at least small, light weight, and silent. These applications are home appliances, such as vacuum cleaners, washing machines, fridges, freezers and ventilation systems.*

*By Wolfgang Frank, Heiko Rettinger, Infineon Technologies AG, Germany;*
*Junbae Lee, Daewoong Chung, LS Power Semitech, Republic of Korea*

Noise emissions in these applications are especially crucial, because many of these systems run 24 hours a day and noise is critical, particularly during sleeping time. Variable speed drives are an important step to reduce acoustic noise. Additionally, the drives´ electronics is likely to be integrated within the motor into a small space. Increasing the power density requires mandatorily an excellent thermal concept of the system or lower power dissipation. Many applications, for example electrical drives, already use modules having a high functionality including logic, analog, and power features. Such modules are the core of the system. Hence, the modules themselves need an excellent thermal performance and integrated components which dissipate less energy.

This leads to the well known optimization forces:

- Optimization of thermal performance of the package.
- Optimization of the electrical performance of the integrated power devices

The optimization of the power semiconductors are the key to higher integration ratios, which means higher power density and higher efficiency. The less losses being dissipated inside a space unit, the smaller the space can be.

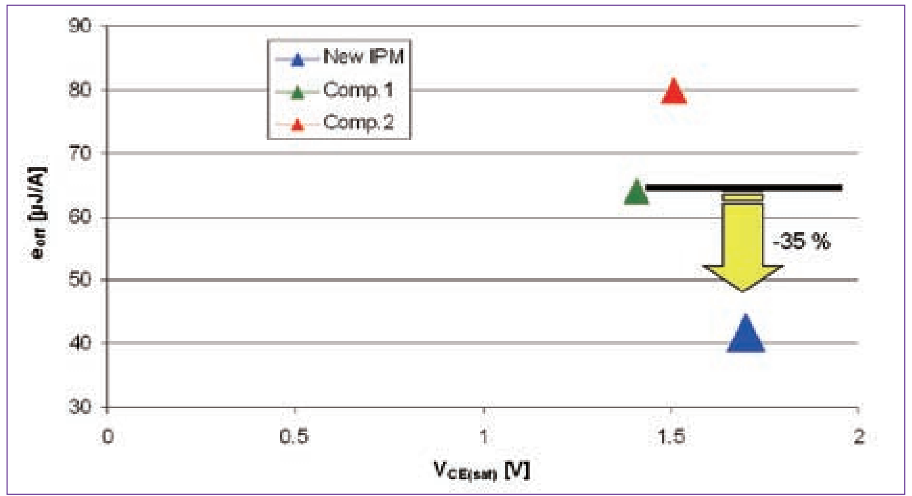



*Figure 1: Comparison of turn-off energies of market relevant IPM*

### IGBT Technology

Infineon Technologies is the technology leader in diode, IGBT, and MOSFET technology. It developed thin wafer technologies, trench gate technologies, and recently reverse conducting technologies. These technologies cover the market trends of high efficiency and reliability and open the door towards ongoing miniaturization.

The superior performance of Infineon's reverse conducting IGBT is demonstrated in the technology trade-off plane. This plane shows the turn-off energy $e_{off}$ normalized to the rated current versus the saturation voltage $V_{CE(sat)}$ according to Figure 1. It can be seen, that the turn-off energy eoff of Infineon's IGBTs is significantly lower than the turn-off energy of state of the art IPMs (-35 %). This is a big step to lower switching losses for all applications, especially for those, which operate at high switching frequencies, such as fans.

### Package concept

The new reverse conducting IGBT technology is employed in a new generation of intelligent power modules (IPM). In respect to the excellent electrical performance of the IGBT, it is possible to provide the markets smallest form factor in the area of IPM up to 2.5kW. The package concept avoids expensive materials such as ceramics, insulated metal substrates (IMS) or direct copper bonded substrates (DCB). The key technology is to generate an extremely thin mould compound layer above the lead frame, so that the thermal resistance for the heat flow is very low.

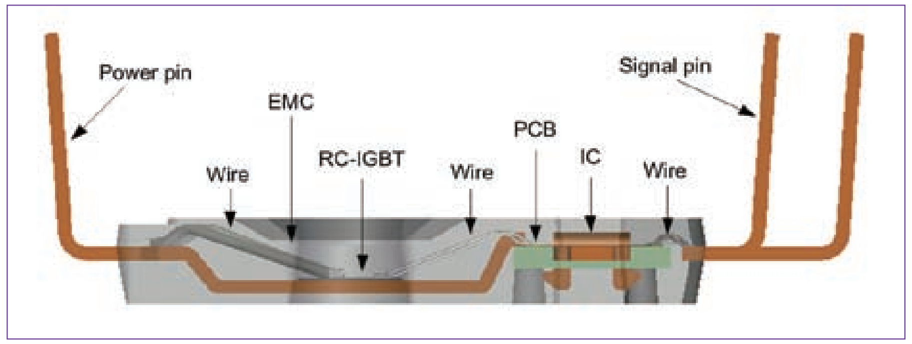



*Figure 2: Package cross section*

Figure 2 shows a cross section of the new package concept. A lead frame construction carries the power semiconductors. Only a thin mould compound layer insulates the heat sink from the lead frame. The gate drive IC is mounted on a PCB.

### Gate driver technology and protection

The gate driver is based on silicon on insulator technology. This means, that the gate driver IC is exceptionally robust against transient negative voltages. Such voltages may occur, when parasitic inductances generate voltages, which reversely bias high side pins in respect to ground. The inherent technological insulation inhibits substrate currents. The specified negative voltage transient SOA is fully rectangular with -50V for a duration of 500ns according to Figure 3. The driver IC shows therefore stable operation in these cases.

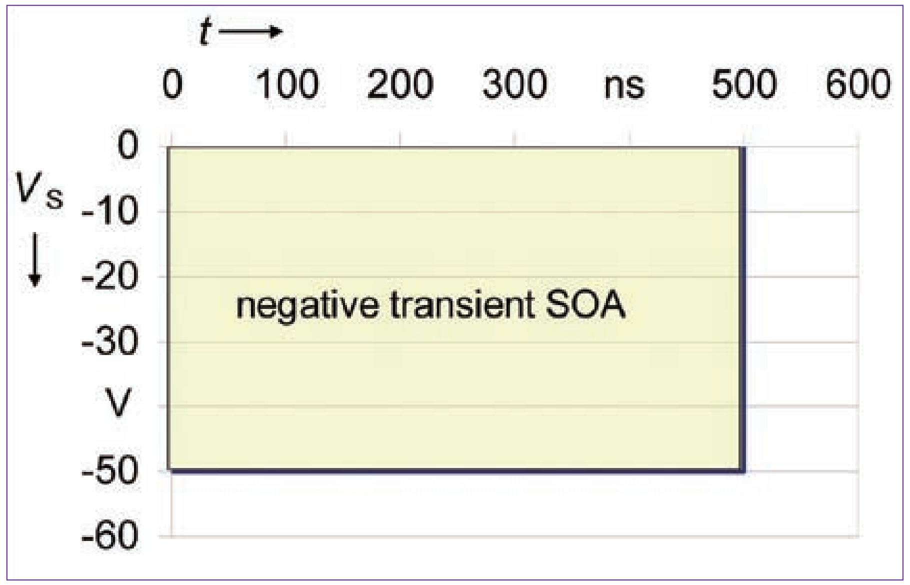



*Figure 3: Negative transient voltage capability of IC (negative transient SOA)*

Other monolithic technologies react with latching the current status of the high side for several 100µs or even milliseconds, so that repetitive short circuit is the consequence. The gate drive IC supports system reliability with the following features:

- Integrated boot strap diodes
- Over current comparator
- Under voltage lockout
- Fault signal feedback
- Hardware interlocking function
- Hardware fixed dead time
- Optional temperature sense

The used gate driver IC is a 6 channel driver, which means it controls all 6 IGBT by means of a single IC. This has the advantage, that the internal propagation delays of each channel are trimmed and managed by design. A mismatch of the delay time leads continuously to a zero component of the three phase voltage system inside the motor. The zero component generates a counter torque, which breaks the motor, and leads to enlarged losses of the converter and therefore to a reduced efficiency of the drive system. The typical matching of the IC delay is 70ns for turn on and 90ns for turn off respectively.

Furthermore, a single gate driver can shut down all 6 IGBT extremely fast in case of over current or under voltage on the control side.

These features lead to a fast development of drive systems with important integrated hardware protection functions.

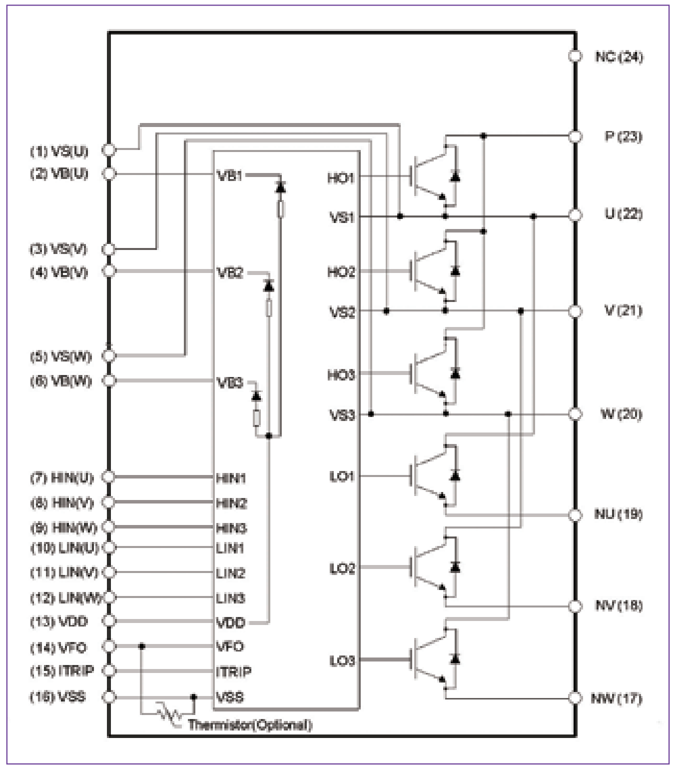
### Full product family in same form factor

The new product family is available in 4 current classes from 6A over 10A, 15A up to 20A. Two more current classes of 4A and 30A will optimise the extremely high cost performance ratio of home appliance applications. The portfolio will therefore give a powerful answer to all requirements.

The dimensions of the package allow even two different module topologies:

- Topology with three phase inverter
- Topology for three phase inverter and input rectifier bridge

The topology of b) in Figure 4 is extremely attractive for applications below 300W. It offers integrated



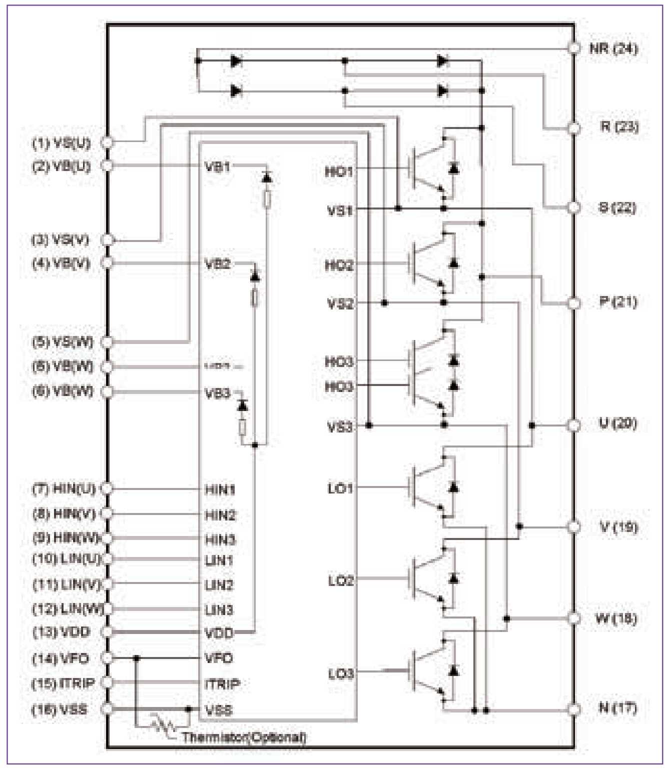




*Figure 4: Basic topologies of CIPOS™mini*
*a) standard topology (3 phase inverter) in 4A, 6A, 10A, 15A, 20A, and 30A*

*b) Standard topology incl. bridge rectifier in 6A*

rectifier diodes, which reduces the required space on system level. The target applications are speed controlled compressors in refrigerators, small pumps, and freezers. The total power dissipation inside the package

*Table 1: Portfolio of CIPOS™mini*

| Module | Temperature sense | Bridge Rectifier | |
|---|---|---|---|
| IGCM04F60HA | – | – | |
| IGCM06F60HA | – | – | |
| IGCM10F60HA | – | – | |
| IGCM15F60HA | – | – | |
| IGCM20F60HA | – | – | |
| IKCM30F60HA | – | – | |
| IGCM06B60HA | – | ✓ | |
| IGCM04F60GA | ✓ | – | |
| IGCM06F60GA | ✓ | – | |
| IGCM10F60GA | ✓ | – | |
| IGCM15F60GA | ✓ | – | |
| IGCM20F60GA | ✓ | – | |
| IKCM30F60GA | ✓ | – | |
| IGCM06B60GA | ✓ | ✓ | |

is then increased by means of the additional losses of the rectifier. However, it is easy to understand, that also the mounting effort is reduced compared to systems with a separate bridge rectifier, because a separate one needs an additional screwing process. This keeps the assembly process of devices in mass production lean and low-cost. Table 1 shows the full portfolio of the CIPOS™ mini family.

**Conclusion**

The CIPOS™mini family provides a complete portfolio of products for cost sensitive variable speed drive systems for home appliances, heating and ventilation and pumping applications. The setup of the three phase inverter with rectifier is considered to be the cost efficient solution for drives up to 300W, while the modules with inverter only cover a power range from 150W up to 2.5kW. The use of reverse conducting IGBT brings excellent conduction and switching properties for highest efficiency.

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# Automotive Energy Efficiency

## *Power Management for electric and hybrid electric vehicles*

*With the ever increasing number of Internal Combustion Engine (ICE) vehicles on the roads, the demand for fossil-fuels is rising steeply leading to increased CO2 emissions that are harmful to the environment. Also, as the world reels under a supply crunch of fossil fuels, their prices are touching all-time highs making them an unattractive option for vehicles.*

*By Ravi Kadabi, Practice Head Powertrain and Vehicle Electronics Applications, Automotive Group, Wipro Technologies*

As a result of this scenario, Governments world over are introducing legislations to curtail emissions, provide incentives for more fuel efficient vehicles and reduce dependency on fossil fuels. Also, as the automotive industry faces competition and cost pressure, technological innovations in this area are becoming inevitable. The Electric Vehicle (EV)/Hybrid Electric Vehicles (HEV) are industry innovations addressing this issue.

The required infrastructure which include Vehicle-To-Grid (V2G) and Grid-To-Vehicle (G2V), Home Energy Management, Smart Metering, Timed Energy Transfer, Charging and Bill Payment Services as well as Telematics Services, are drivers for the advancement of technologies including power management. As the existing power demand from domestic/ industrial sectors is increasing and with EV/HEV vehicles' requirement of additional electrical energy, grid-power management has to work in a more stringent environment. It is estimated that the world energy consumption will grow by 49 percent from 2007 to 2035.

In this paper, we will discuss the current status and future trends for various energy sources that are going to be used in the automotive industry. The related challenges in automotive power electronics will also be discussed.

**Power Management in Automotive**

Automotive segment is one of the largest consumers for power management devices, as it forms the key component for EV/HEV. The key semiconductor power devices include smart IGBT/BJT, Power MOSFET, Power ICs as well as SiC that is expected to reach a $5 billion market in 2020.

Automotive vehicles are classified into Micro-Hybrid (~6kW, also called as Start-Stop), Mild-Hybrid (~10kW), Full-Hybrid (~20kW), Plug-in-Hybrid (~30kW) and Electric Vehicles (~75kW). The HEVs are classified into Serial-Hybrid (Range Extender), where the drive-shaft gets driven by electric motor and Parallel Hybrid where the drive-shaft shares the load between ICE & electric motor.

Among hybrid vehicles, Micro-Hybrid will have the highest growth due to its low cost and easy integration. Mild and Full-Hybrid vehicles will continue their strong penetration in the automotive market. Plug-in-Hybrid vehicles and Electric vehicles use the same technology for high voltage range and plug-to-grid for recharge.

A typical configuration is illustrated in the block diagram:

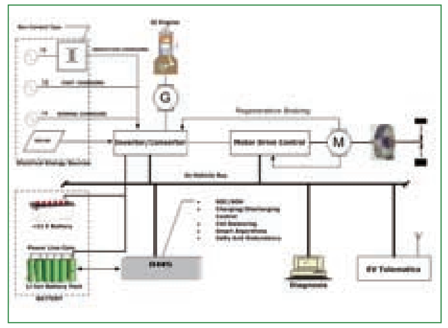

*Figure 1: Power Management in EV/HEV*

**Power Management in EV/HEV**

The key subsystems of EV/HEV vehicles are illustrated in the above block diagram. The Inverter/ Converter is the main power house of a vehicle and manages the power according to the load-demand and stores sufficient energy from different power sources. Permanent magnet motors are widely used in the vehicles because of their high torque density, potentially wide constant power range, and relatively small required inverter rat-

| Functional Requirements | Non-Functional Requirements |
|---|---|
| Energy management and inverter/converter design | System reliability |
| Microcontroller/DSP based designs | Timing requirements |
| High voltage safety and redundancy | Form factor, weight and cost |
| Regenerative braking | Mounting position/Heat sink, vibrations/shock |
| Torque enhancement | EMC/EMI including self-generated |

ing. Also the kinetic energy generated in the motor during braking is used as regenerative electrical energy. A relatively small ICE is used in serial-hybrid vehicles as a Range Extender while the energy of the battery gets depleted.

**Battery Management System (BMS)**

As the BMS is an integral part of a vehicle, Wipro has developed a generic BMS framework which can be customized according to the requirements of Battery Manufacturers, Tier1/Tier2 & OEMs. The key features of this BMS include plug-and-play of battery-pack, energy management via smart algorithms, scalable battery capacity which depends on vehicle type, energy storage via regenerative braking, power line communication, safety and redundancy as well as battery analyzer including telltale of the battery health parameters. It also includes communication interfaces to other electronic control units like instrument cluster for displaying battery data, PC for reconfiguring BMS software for a given battery-pack and telematics for remote monitoring with LCD.



**Trends**

Automotive power electronics industry started to focus on the integration of inverter/converter and BMS with electric motor functionalities that has the 'power' to reduce the cost of hybrid vehicles. Currently, Li-Ion batteries and ultra-capacitors are power storage devices with the greatest development potential. A combination of ultra-capacitors and battery optimizes the vehicle's power resources.

**Design Challenges**

As power electronics for the automotive industry is a relatively new development, there are multiple challenges that need to be addressed, some of which are illustrated here:

- The functional and non-functional requirements of vehicles (key cases as mentioned in the table) bring in new challenges and opportunities for design engineers in power man agement areas.
- The challenges faced for these requirements including EMC/EMI can be addressed through technical innovations. The EV/HEV technolo gies provide an opportunity to ad dress the above design challenges.

**Conclusion**

To succeed in the 21st Century, the automotive industry has started to focus

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# System-Level PA Solutions

## *Improve power amplifier efficiency in wireless communications*

*Power amplifier (PA) efficiency is a key factor in wireless system design. Due to the inherent nonlinearity of the PA, a large signal would be distorted and its spectrum would be broadened to disturb its adjacent signals. To keep the input signal in a linear region, we have to reduce the input signal level, which causes low PA efficiency.*

*By Lekun Lin, Staff Wireless Systems Architect, IDT*

To achieve high PA efficiency, many PA linearization solutions are proposed. Among them, the solutions attracting the most attention include feed-forward linearization, Cartesian feedback, digital pre-distortion and power supply control schemes.

In this article, we introduce and compare these methods. By examining the complexity and performance trades-offs, we recommend guidelines for practical system implementation.

**Feed-forward linearization**

Instead of simple power back-off, a conventional PA linearization method is feed-forward linearization. A typical feed-forward linearization system is shown in Figure 1, where the PA gain is G, the attenuation of the attenuator is 1/G, and PA2 is an auxiliary PA with a gain of G. Here, s denotes the input signal, s1 denotes the PA output, s2 denotes the attenuator output, and s3 denotes the output of the entire linearization system.

The idea of feed-forward linearization is simple: attenuate the PA output, s1, to the same level of the input signal, s,

s2 = s1/G;

and then obtain the distortion by comparing s2 with the input signal, s,

e = s-s2 = s-s1/G.

With the auxiliary PA, the distortion can be amplified and subtracted from the original PA output.

s3 = s1+e*G = s1+(s-s1/G)*G = G*s;

Although feed-forward linearization is stable and has potential high performance, it suffers from high cost and poor power efficiency of the entire scheme since an auxiliary PA is needed.

**Cartesian Feedback**

Feedback methods are also used to achieve PA linearization. Multiple types of feedback methods exist, including envelope feedback, polar feedback and Cartesian feedback. Among them, Cartesian feedback is most widely studied.

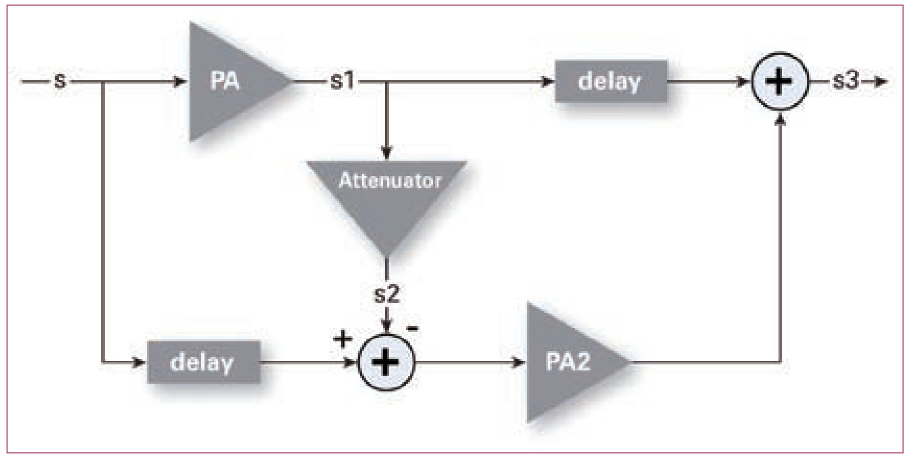


*Figure 1: Feed-forward linearization*

Power Amplifiers

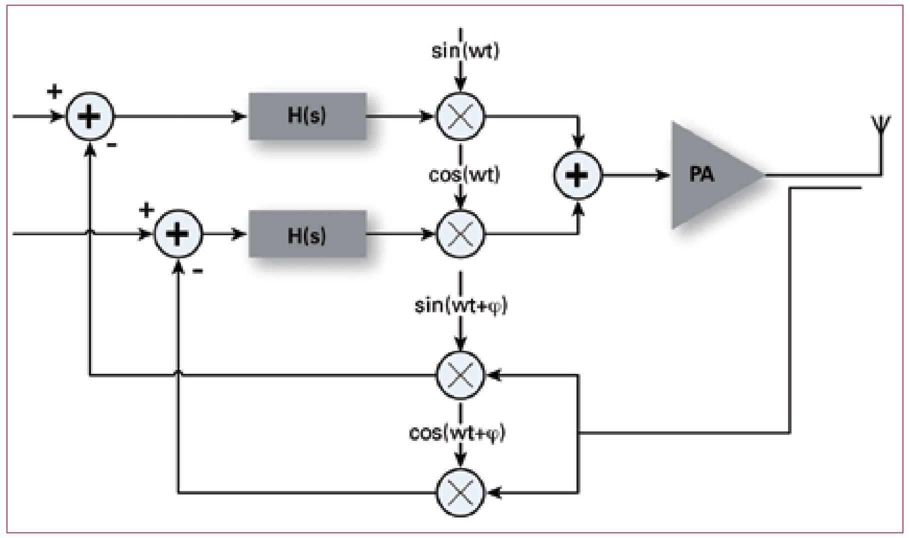


*Figure 2: Cartesian feedback*

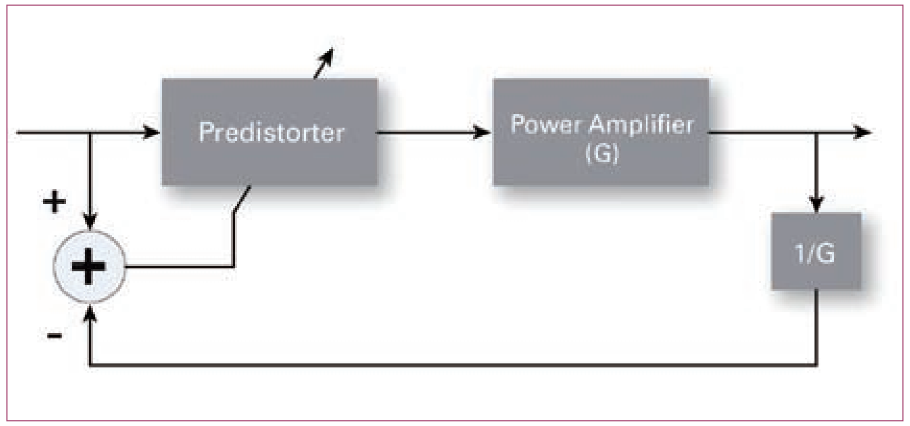


*Figure 3: Digital pre-distortion - Direct learning structure*

In Cartesian feedback linearization, shown in Figure 2, the distorted PA output is fed back through an I-Q demodulator to build two negative feedback loops. The major issue of Cartesian feedback is to keep feedback phase alignment, i.e. keep being zero. The feedback phase misalignment would compromise the system stability.

Cartesian feedback has multiple advantages. The PA model is not necessary to be characterized in Cartesian feedback, and it is simple and robust to PA drift and aging.

**Digital pre-distortion**

Among all PA linearization methods, digital pre-distortion (DPD) is one of the most efficient methods. It uses a nonlinear digital predistorter in baseband to compensate the distortion introduced by the nonlinear PA. With a digital predistorter, a PA is able to work at the nonlinear region without performance loss, and therefore improve the efficiency.

Conventional digital predistorters focus on memoryless PAs, where the PA outputs only depend on current PA inputs. This kind of DPD could be implemented with a look-up table utilizing the PA feedback signal.

In recent years, wide-band systems are deployed to pursue high throughput, such as WiMAX and LTE. The memoryless PA model is no longer suitable in wideband systems. The DPD design has to consider the memory effect of PA. Studies showed that the memoryless DPD suffers significant performance degradation when compensating a PA with memory effects.

The key part in DPD design is to calculate the coefficients used in predistorters. Among the current literature, two types of approach are studied, i.e., direct learning structures and indirect learning structures.

The direct learning structure is depicted in Figure 3, where the coefficients of the digital predistorter are adaptively adjusted to minimize the error between the digital predistorter input and the PA output. In direct learning structure, the PA model should be identified before adjusting the predistorter coefficients. Instead of adaptive coefficient adjusting, the predistorter coefficients could be calculated by inversing the PA model. However, obtaining the inverse of a nonlinear system with memory is generally a difficult task.

Another type of approach is to use the indirect learning architecture. As shown in Figure 4, a predistorter training block is used in the feedback path to compensate the PA output. The predistorter training block is adaptively adjusted to minimize the error between the PA input and the predistorter-training output. Once the adaptation completes, it is copied before the PA as a digital predistorter. The advantage of the indirect learning structure is that it eliminates the need for PA model identification.

In a real application, the RF analog impairment must be considered in DPD design. Some analog impairment, such as I/Q imbalance, would degrade DPD performance. Since digital predistorter would introduce nonlinear distortion, which has wider bandwidth than the signal, the analog circuit should be able to deal with the wide bandwidth.

**Power supply control**

By controlling the power supply of PA to reduce thermal dissipation, power supply control schemes are potentially offering the highest power



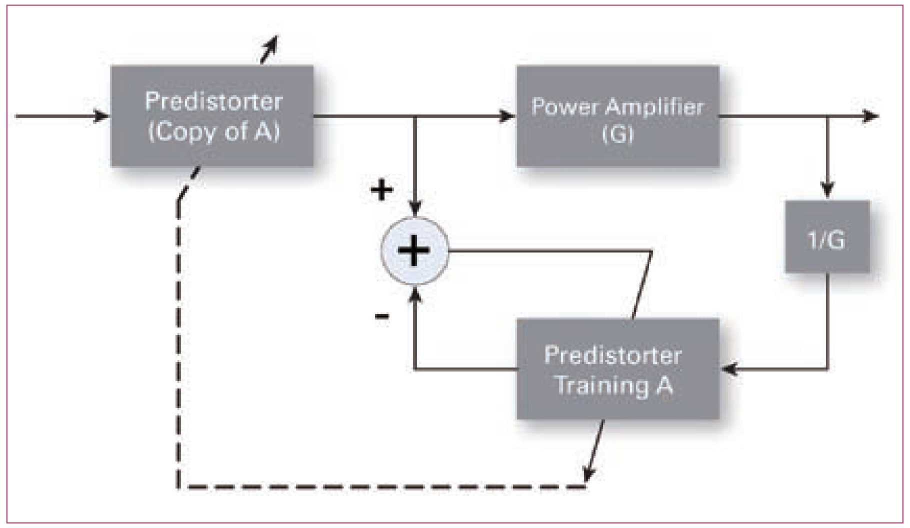


*Figure 4: Digital pre-distortion - Indirect learning structure*

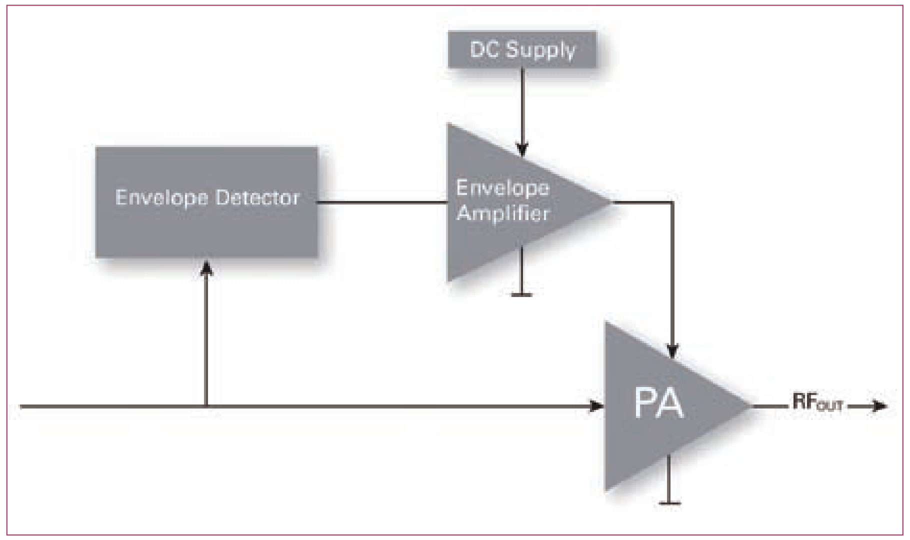


*Figure 5: Envelope tracking*

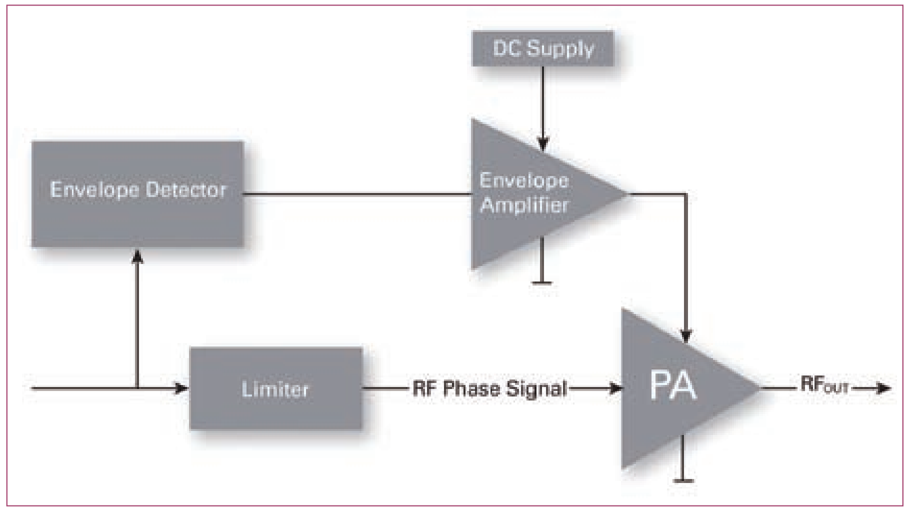


*Figure 6: Envelop elimination and restoration*

efficiency. Two major power supply control schemes currently exist: Envelop Tracking (ET), as shown in Figure 5, and Envelop Elimination and Restoration (EER), as shown in Figure 6.

An ET system uses a linear PA whose power supply voltage follows the signal envelope to reduce thermal dissipation. In an EER system, the amplitude is eliminated from the RF signal. By controlling a switching PA, the amplitude is restored and high efficiency could be achieved.

The two main challenges of ET and EER are high voltage, high efficient wide band envelope amplifier design and timing alignment between the envelope and the RF input signal. Both ET and EER suffer from performance degradation due to timing misalignment. EER especially has a very high requirement on timing alignment, which keeps it from being widely accepted by the industry, regardless of its high potential efficiency.

**Summary**

In this article, we analyzed multiple PA linearization solutions in terms of complexity, challenges and performance. While conventional linearization solutions, such as feed-forward linearization and Cartesian feedback, are still used in many applications, digital predistortion is becoming more widely accepted in wireless systems, especially in 3G and 4G base stations. ET and especially EER still have difficulties in implementation, but they are attracting more attention because of their high efficiency.

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# Designing with Power Modules

## *Simplify designs, reduce component count & space requirements*

*Engineers and designers on product deadlines need all the time they can get to focus on what matters most - the core architecture of a system design. Designing with an FPGA, DSP, or microprocessor is the most time consuming and critical part of the design. System level designers can benefit by focusing on system design and they also need resolution to issues such as time to market and achieving small form factors. Using the latest generation DC-DC non-isolated point-of-load power modules provide them major advantages.*

*By Joshua Broline and Nattorn Pongratananukul, Intersil Corporation*

Power modules have a high level of integration and density, advanced package technology to take advantage of the high levels of power density, and very reliable overall performance - even for the toughest power management requirements. Using power modules means minimal external components are required, so designers can realize a complex power management design quickly, and focus on the core design. Power modules are useful even if power supply requirements change during the middle or at the end of the design cycle.

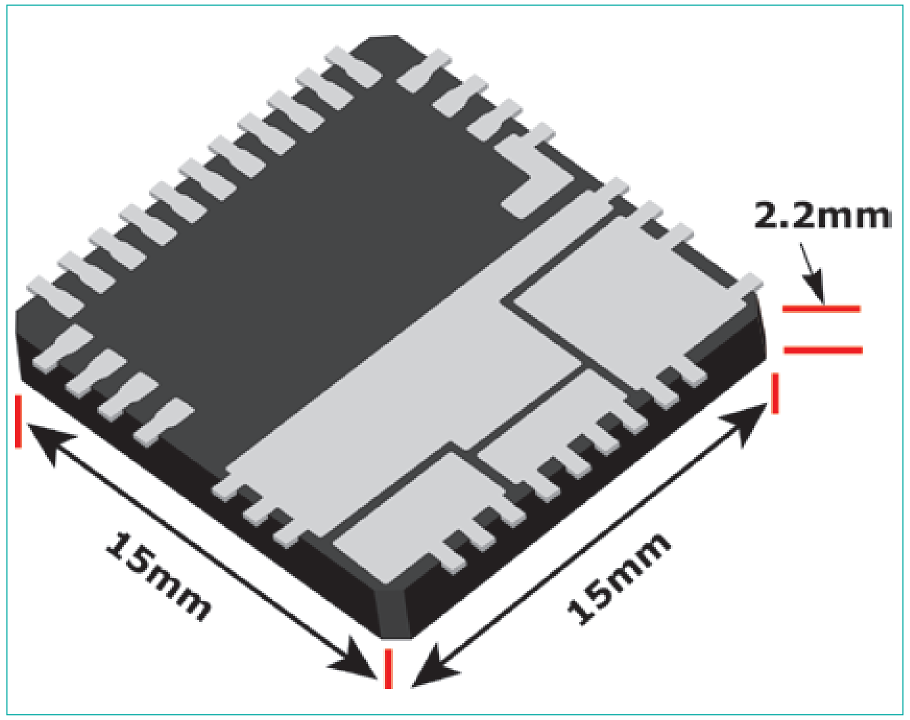


*Figure 1: Package dimensions of the new ISL8200 power module*

Before detailing specific power module benefits, let's look at the design issues. There are several that a designer must consider when working with a discrete (non-module) solution. And all can slow the process and delay a product's time-to-market. For example, selecting the proper PWM controller, FET drivers, power FETs, inductor, in order to meet the specific power supply requirements represent the first stages in what is usually a long discrete power supply design cycle. After these main power components are selected, designers have to develop a compensation circuit per output voltage specifications of the various loads that will be used in a given system. This can be tedious and





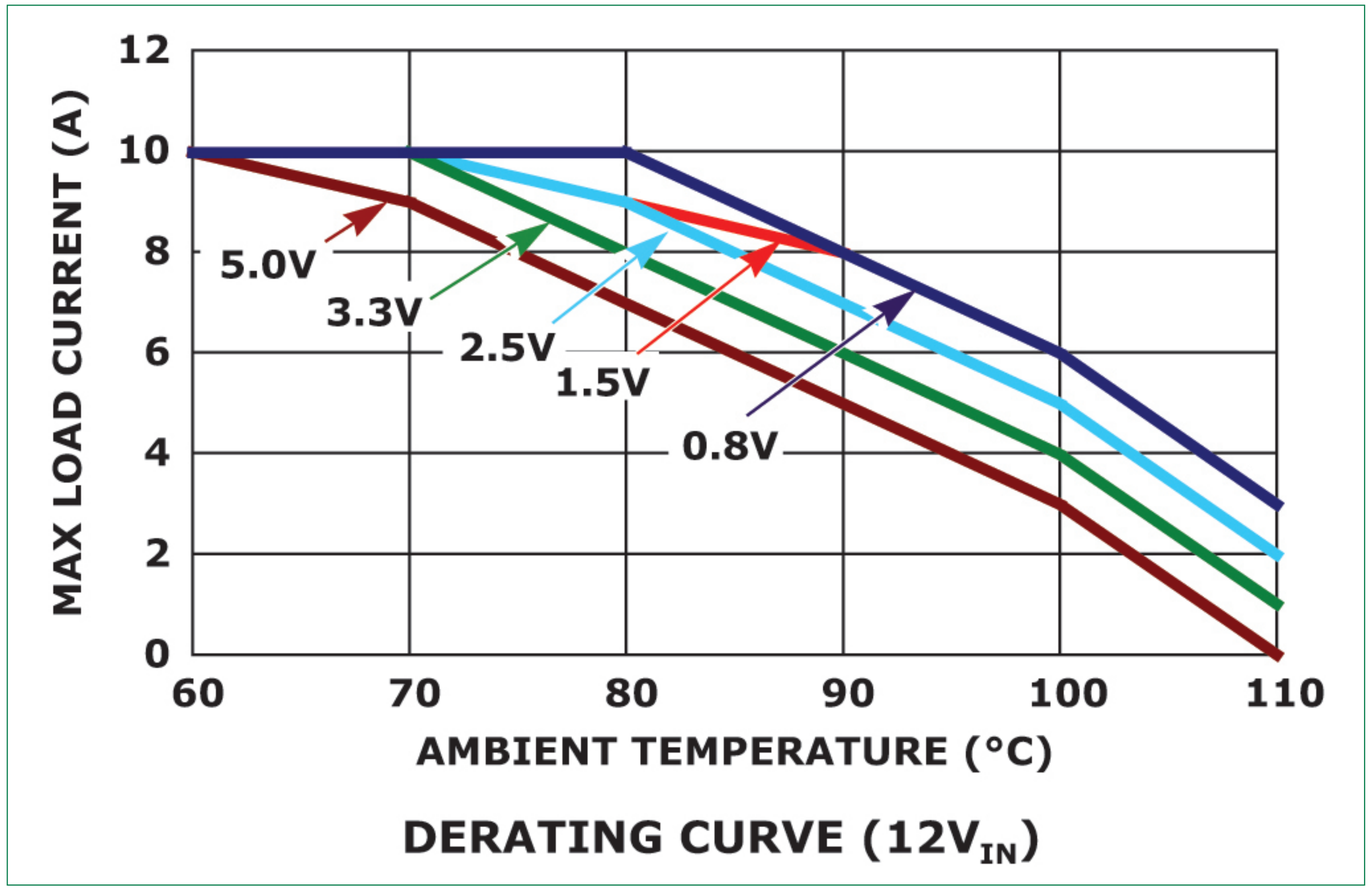


*Figure 2: Derating curve (12Vin)*

take up a lot time -- and often requires rework. In addition to the compensation circuit design, the power stage, driver, power FETs, and inductor, need to be generated to meet power efficiency targets. This may take several iterations of component selection over varying application requirements.

After designing the discrete power supply, the layout work -- with considerations for noise and thermal requirements - adds to the complexity of the design cycle. All in all, it's a cumbersome process.

But power modules such as the Intersil DC-DC POL ISL8200M power module change the process, by integrating the PWM controller, driver, power FETs, inductor, IC support discrete components, and an optimized compensation circuit. And they are all contained on a 15x5mm QFN package. The supply is scaled according to output power requirements with its current sharing architecture, and the module comes in a thermally enhanced package and low profile of 2.2mm so it can be mounted on the back side of the PCB.

When top side PCB space is an issue, the ISL8200M low profile QFN package of 2.2mm package is a benefit. The low profile package will meet most PCB back side clearance requirements, especially since the QFN package does not require a heat sink or air flow to cover the full output power range over most of the industrial temperature range. With a very low theta J/C of 2C/W on the bottom of the QFN package, most of the heat is dissipated through the bottom of the package and safely through vias and down to a PCB ground plane. This is because the internal high power dissipation components such as the power MOSFETs and the inductor are directly soldered down to these large conductive pads, allowing efficient heat transfer from the module down to the PCB for optimal thermal efficiency, ultimately allowing a 360W max point-of-load power solution to be mounted on the back side of the PCB. This is empowering when a complex power supply design is required and top side PCB space is limited, because it reduces the form factor and enables greater system functionality. In addition to the thermal capabilities, the QFN package has exposed leads around the edge of the package, which allows for access to all pins for debug and solder joint verification.

Load current requirements may change during a system design cycle, but the power supply does not have to change. The ISL8200M can support load current from less than 10A, all the way up to 60A across temperature. Each individual power module can support 10A of output current independently, but by using the module's patented current sharing architecture, the modules can be paralleled for up to 60A of output current. So once the ISL8200M is designed in, the power supply can quickly be modified to meet a wide range of changing application

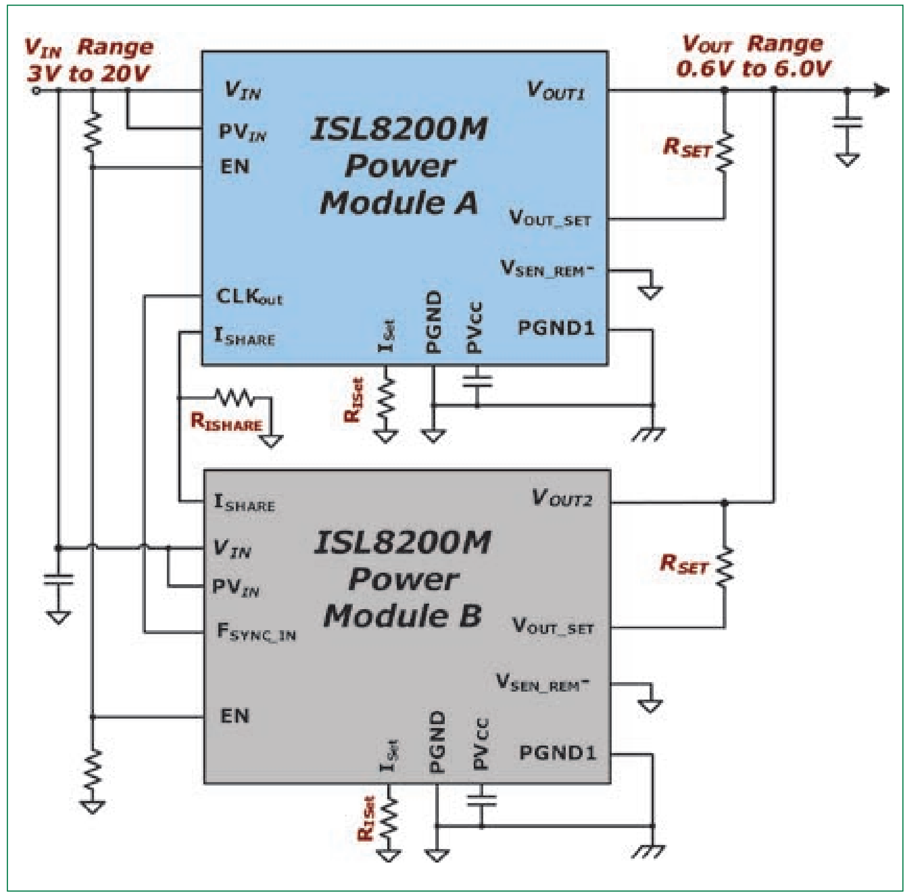


*Figure 3: Simplified schematic of a dual module system*

requirements. Furthermore, if layout constraints become an issue when a high power solution is required for a given application, paralleling multiple ISL8200M modules will provide the flexibility to help overcome this challenge due to the patented current share architecture of module. The main connections required to connect modules in parallel reduces layout sensitivity concerns as the output voltage regulation is not impacted by the layout of the module connections required. Output voltage remote sensing and active current share balancing between the modules reduces the sensitivity to PCB trace layout, so flexibility can be exercised for most complex power supply design and layout challenges.

When power requirements are greater than 10A, only 5 main connections are required to parallel up to 6 modules. The input and output voltage rails need to be connected and bulk capacitance is required to reduce transients affecting the power supply. A total of 220uF of capacitance it recommended on the input and a total of 330uF is recommended on the output voltage. If very tight noise specifications are required, bypass capacitance can be added in order to filter out external high frequency noise. Next, the enable pins need to be connected in order for the supply to be disabled or enabled per system requirements. The connected enable pins can be used as a critical fault protection feature, the products fault handshaking function. If there is a fault on one of the modules and the module is disabled, all connected modules will also be disabled in order to prevent overstress conditions on the load or power modules. Then the CLCKOUT and FSYNC_IN pins should be connected. The module with the CLCKOUT pin connected is consider the master power module and will set the reference switching frequency.

In a two module operation, the module with the FSYNC_IN connection will have a switching frequency 180° out of phase. For more than two modules in parallel, the phase control is adjusted by adding a resistive divider per the datasheet recommendation to the PH_CNTRL or phase control pin. With multiphase operation where the respective switching frequencies are programmed out of phase, lower external noise or ripple can be realized. This reduces the amount of external capacitance or capacitors that are required to hit the critical output voltage regulation requirements for a given point of load. Finally, a connection between the ISHARE pins is required. This pin is used to balance the load current per module. A resistor, RISHARE, is place on this connection in order to set the overall output current. An additional resistor on the module's ISET pin is used to create an internal voltage that is used to compare to the ISHARE bus in order to help balance the output current per module. Compared to equivalent solution types on the market today, the ISL8200M parallel operation has a lot less complexity due to minimal connections between the modules and minimal consideration for layout sensitive during the design cycle.

Once a power module like the ISL8200M is designed in, the ability to quickly parallel 6 modules for up to 60A will accelerate future designs or quickly adapt to design requirement changes during the design cycle.

Power modules deployed in non-isolated DC-DC POL power supply can save time, help reduce R&D cost, speed time to market, and allow designers to spend more effort on core system design. The power module's high level of integration, thermally enhanced low profile QFN package and patented current sharing architecture help expedite the design cycle. The power module also has an online simulation tool (iSim) and evaluation boards available. Visit www.intersil.com/powermodules for further information.

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# Digital Power Supply Control

## *Delivering on the promises*

*Control of switch mode power supplies (SMPSs) has traditionally been carried out with purely analog circuitry. The advent of low-cost, high-performance digital signal controllers (DSCs) provides a practical route to realizing the benefits of digital power supplies.*

*By Bill Hutchings, Product Marketing Manager, High Performance Microcontroller Division, Microchip Technology Inc. Phoenix, Arizona*

DSCs can provide an elegant and cost effective way forward to realizing the many benefits of digital power opening up new possibilities for innovation in the power supply world. Some of the benefits include:

- Bill-of-materials (BOM) costs for digital vs. analog power supplies
- Control flexibility and the ability to control advanced topologies
- Implementation of added-value functions without adding to the cost

### Digital PSU cost savings

The diagram illustrated in Figure 1 shows a high-level block diagram for a generic two-stage analog AC-DC power supply.

Key functions include:

- Power train: semiconductor switches, inductors, capacitors and power transformers.
- Power switch drive: gate drivers and supporting circuitry.
- Feedback: sensors, amplifiers and resistor networks.
- Control: dedicated controllers for

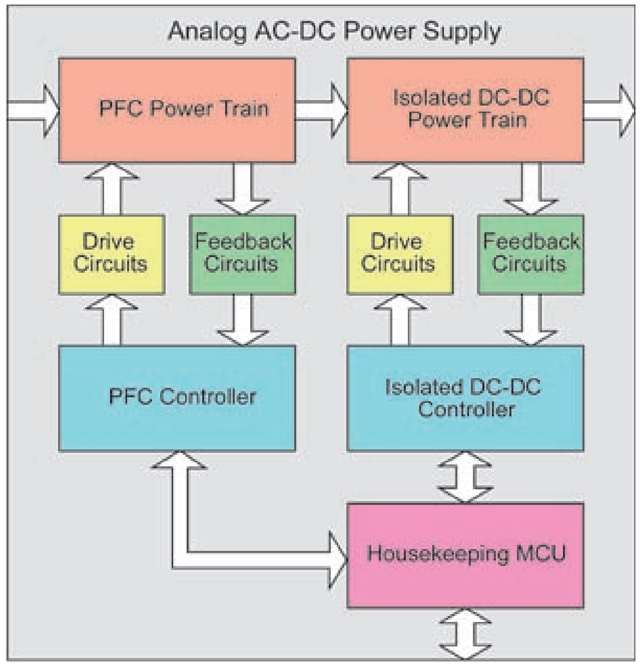


*Figure 1: This diagram shows, in a high-level view, the major functional blocks in a conventional analog-controlled switching power supply*

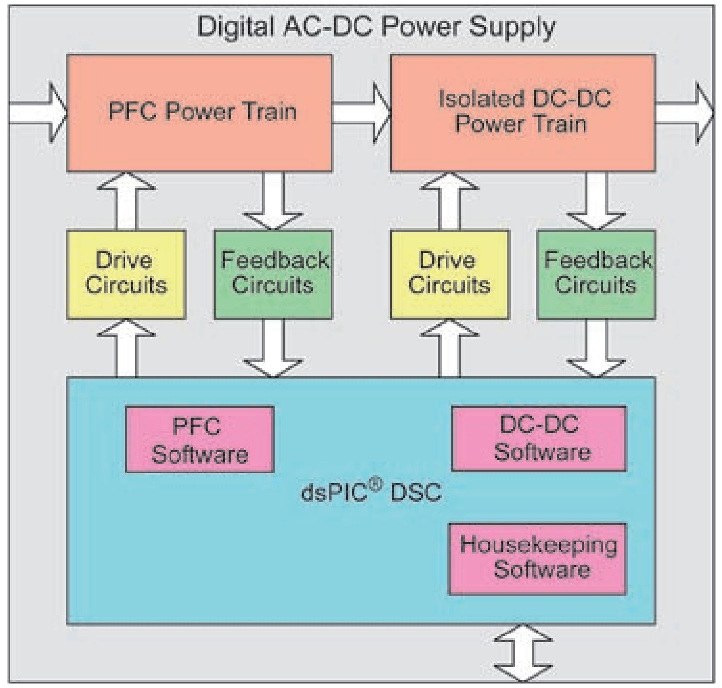


*Figure 2: In the digital-control implementation of the same PSU as Figure 1, software replaces hardware for a number of key functions*

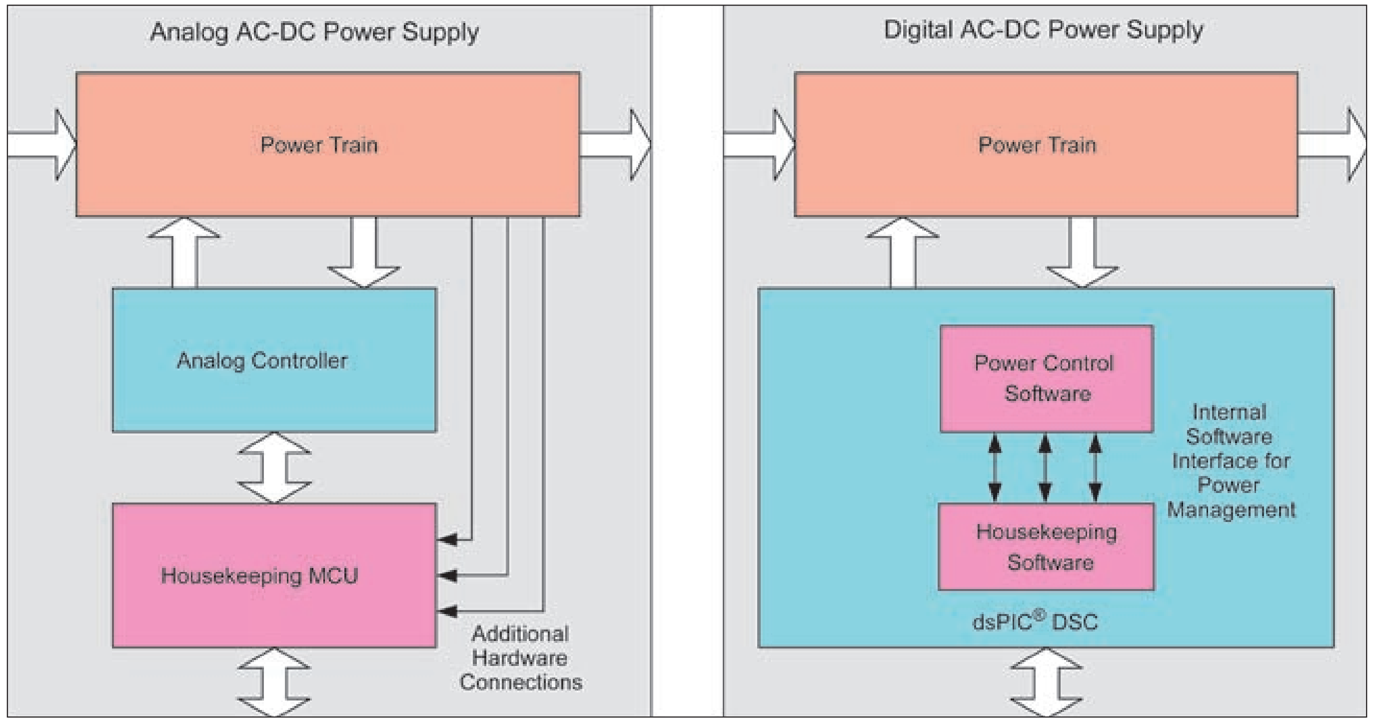


*Figure 3: Control of the main power-flow path, and power-supply housekeeping functions – separate circuitry in the analog design – are executed together in a single controller in the digital version*

each power stage.

• Housekeeping: a dedicated microcontroller and supporting circuitry for sequencing, monitoring and communications.

For the purpose of comparison, a two-stage power supply is considered. The front end converter is a boost power factor correction (PFC) circuit, while the second stage is a DC-DC phase-shifted full bridge converter.

Some of these elements, for example the power train, drive and feedback circuits are essentially identical in an analog or a digital power supply. Figure 2 illustrates the corresponding digital power supply for the same example. For the digital version of this power supply, the functions of both the dedicated analog controller, and housekeeping MCU can be combined in a single dsPIC® DSC.

Figure 1 and Figure 2 show only the major differences from a high level perspective; however, all supporting circuitry must also be included in the comparison. Each stage of the analog supply typically requires circuitry to provide auxiliary power, plus leading-edge blanking, oscillator, sequencing control, soft-start, and compensation functions, all connected to a central controller. A digital implementation will still need hardware for auxiliary-power circuitry, but each of the other functions listed above become software running on the central controller. Not only are fewer components required, but physical connections (PCB tracks) are also greatly reduced. Analysis of the bill of materials should consider the cost of this supporting circuitry, layout complexity, and the size of the PCB. Some of the functions identified above may (in the analog implementation) require no more than a few passive components, while others have a higher cost (a separate MCU for housekeeping functions, for example).

Some may argue that a digital solution requires the use of dedicated MOSFET gate drivers, while an analog solution may provide the gate drivers on-chip. While this is true for low-power designs, most high-power analog designs will still need to use external gate drivers.

A detailed comparison of BOM costs will invariably show a significantly lower total for a digital supply over a comparably-featured analog design. A simple summation of component costs is only part of the story: there are many consequent savings that follow from digital power supplies offering simpler layout, smaller PCBs, reduced PCB fabrication and assembly costs, and improved quality and reliability.

**Efficiency optimizations**

In recent years, continuous improvement in power transistor performance and use of novel topologies, have contributed to significant improvements in power supply efficiency. However, quoted maximum efficiency figures most often apply only at certain specified operating conditions (peak efficiency may be specified at half-load, or at high line voltages). Digital power supplies offer added versatility to optimize the efficiency at multiple operating points.

For the PFC boost converter, switching losses can be reduced at lighter loads by operating the converter at a lower switching frequency. Due to the lighter load, the magnetic components will still perform adequately at the lower switching frequencies. If an interleaved PFC converter is implemented, one phase can be turned off at light loads.





Similarly, for a phase-shifted full-bridge converter, extra switching losses can be eliminated at light loads by turning off switching of the synchronous MOSFETs, and using the devices' body diodes instead.

Another example occurs in a buck converter application. Synchronous buck converters are typically preferred for high current outputs. However, using a synchronous MOSFET leads to circulating currents at light loads, which in turn causes higher losses. Therefore, the synchronous/free-wheeling MOSFET in a buck converter can be disabled when the converter operates in discontinuous-current mode.

These techniques supplement the efficiency gains obtained through use of advanced topologies, such as resonant and quasi-resonant converters. Digital control fully supports these advanced topologies, including phase-shifted full-bridge, and LLC-resonant converters, to achieve very high efficiency and power density. As a result, digital control provides many options to optimize the efficiency of power supplies over the entire range of operation.

**Power management**

A typical analog power supply will accomplish its power management requirements using a housekeeping MCU (Figure 3). This housekeeping MCU transmits the local system parameters to a master controller or data logger: it uses additional sensing circuits to collect the required data, and then re-transmits it. In some cases, a remote system may also send out instructions to control operation of local power converters. This configuration requires the addition of hardware interfaces between the housekeeping

```
void PFCSoftStartRoutine()
{
    Delay_ms(STARTUP_DELAY)
    pfcVoltagePID.controlReference = pfcInitialOutputVoltage;
    while (pfcVoltagePID.controlReference <= PFCVOLTAGE_REFERENCE)
        {
            Delay_ms(SOFTSTART_INCREMENT_DELAY);
            pfcVoltagePID.controlReference += PFC_SOFTSTART_INCREMENT;
        }
        pfcVoltagePID.controlReference = PFCVOLTAGE_REFERENCE;
}
```

*Listing 1: This code fragment shows how a soft-start function is typically implemented at source-code level*

MCU and the power conversion circuits, adding cost and complexity.

A digital power supply eliminates the need for this additional circuitry as all of the system parameters are already measured by the DSC. These parameters can be stored in the DSC's memory and transmitted to the remote system using on-chip communication peripherals such as SPI, I2C™, UART or CAN. Any modifications to the system operation can also be made by a simple software routine without additional hardware.

The digital power supply also reduces overall cost of the system by eliminating redundant circuitry. In the same example of a two-stage AC-DC power supply, the first stage measures the output voltage for its control loop operations. As this voltage provides the input to the second stage, the same data is also used by the second stage either for feed-forward control or input under/over-voltage protection.

A single DSC eliminates redundant measurements, and internally provides all the options for different control or protection features. The DSC also helps the system react to fault conditions much faster and more effectively than with discrete analog controllers. For example, in a two-stage analog AC-DC power supply, if a fault occurs on the downstream converter, the front-end PFC boost converter will not be aware of the fault until this condition has been communicated to the PFC controller. A digital controller can detect fault conditions in the entire system and can therefore react almost instantaneously to a fault regardless of where it occurs.

**Soft-Start and sequencing**

When a power supply first starts up, the various storage elements, such as capacitors and inductors, contain no energy. To avoid large current and voltage transients, and consequent stress on system components, soft-start is implemented in all stages of the supply. Many (but not all) analog controllers provide a built-in soft-start feature. Analog controllers provide limited flexibility in choosing the soft-start duration and startup delays with additional circuitry.

In multi-stage power supplies, there is also a need for sequencing the outputs in a predefined manner, as some outputs are dependent on others. This can be accomplished using a separate sequencing chip, or by using the housekeeping MCU with additional circuitry.

A digital power supply eliminates the need for additional hardware because all sequencing and soft-start routines, which can employ a variety of strategies, can be implemented as part of the power supply control software. A soft-start routine can be implemented for each stage of the power supply, in each case combined with a configurable duration and delay. A typical soft-start routine is shown in the C code fragment in Listing 1.

In the code, the soft-start routine is called immediately after the initialization of the dsPIC DSC. A startup delay is first called, and then the output voltage reference is set to the measured output voltage. The reference is then incremented by a fixed amount until the final desired reference is reached. At this point, the soft-start routine ends and normal system operation begins. The digital controller allows for very flexible use of this soft-start routine. The same routine can be called with different parameters at different times. For example, if the system is attempting to restart after a fault has occurred, the startup delay and soft-start duration can be modified to a different value.

**Leading-edge blanking (LEB)**

Current feedback signals from most power converters must be filtered to eliminate noisy measurements and false tripping of current-limit and fault circuits. Faster switches tend to generate higher levels of noise, and that noise is also present in feedback signals. In some situations, the noise spikes due to MOSFET switching instants may even exceed the maximum current-limit setting.

It is difficult to filter out (using analog techniques) this level of noise from the current feedback signal without adversely affecting the wave shape. It is desirable to preserve the wave shape for accurate control loop operations and current-limit protection. Therefore, a technique called LEB is often employed so that the controller ignores the noise spikes on the feedback signal close to the PWM switching edges.

For an analog controller, this involves designing a hardware blanking circuit that inhibits response to (or "blanks") the feedback signal for a fixed duration – typically, sensing is enabled by a transistor switch controlled from the power MOSFET's gate drive, via an R-C delay. The delay ensures that measuring circuitry does not "see" the first instants of each conduction cycle. In the dsPIC33F "GS" series of devices, LEB is a standard feature, and the delay is set by a software parameter. The LEB feature can be enabled or disabled at any time and the user can choose which PWM edges to blank out.

**Adaptive and non-linear control**

With digital power supply controllers comes the ability to change the operation of the power supply at runtime. This capability opens up numerous opportunities for innovation and a chance to gain a competitive advantage over other available products.

One of the possibilities for adaptive control is to use multiple sets of control loop coefficients. As the performance of the system changes at different line/load conditions, the coefficients can be modified on-the-fly to achieve the best performance possible at each operating point.

As another example, consider that a system is rated for operation up to 50ºC; however, for some reason, the ambient temperature exceeds this limit. In this case, the software can be written to reduce the current limit settings. This implementation can help to safely extend the operation of the system beyond its normal limits, albeit with some added restrictions.

The introduction of the dsPIC33F "GS" series Digital Signal Controllers has made it possible to achieve all the potential of digital power supply control, opening up new possibilities for innovation in the power supply world.

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# Clamp Sizing Protection

## *For MOSFET reliability in flyback power supplies*

*AC-DC power supplies up to approximately 100W commonly utilize the flyback topology. Its low cost and ability to provide multiple tracking outputs with a single controller have made it a favorite among designers and a de facto standard for low component count AC-DC converters. One disadvantage of a flyback converter is the high stress placed on the primary switching element.*

*By Paul Lacey, Applications Engineer, Power Integrations, Inc., San Jose, California*

Flyback topologies operate by storing energy in the transformer during the on-time of the power switch and transferring this energy to the output during the off-time. A flyback transformer is comprised of two or more coupled windings on a core containing a series air gap across which (magnetizing) energy is stored until it can be transferred to the secondary. In practice, the coupling between the windings is never perfectly matched, and not all of the energy is transmitted across this gap. A small amount of energy is stored within and between the windings in what is referred to as the leakage inductance of the transformer. When the switch opens, the energy in the leakage inductance is not transferred to the secondary, but instead generates a high voltage spike across the transformer primary winding and the switch. It also results in high frequency ringing between the effective capacitance of both the open switch and primary winding, and the leakage inductance of the transformer (Figure 1).

If the peak voltage of this spike exceeds the breakdown voltage of the switching element, which is normally a power MOSFET, it can result in a destructive failure. Moreover, the high amplitude ringing on the drain node causes a significant amount of EMI. For power supplies above approximately 2W, a clamp circuit is used to limit the voltage spikes across the MOSFET by safely dissipating leakage inductance energy.

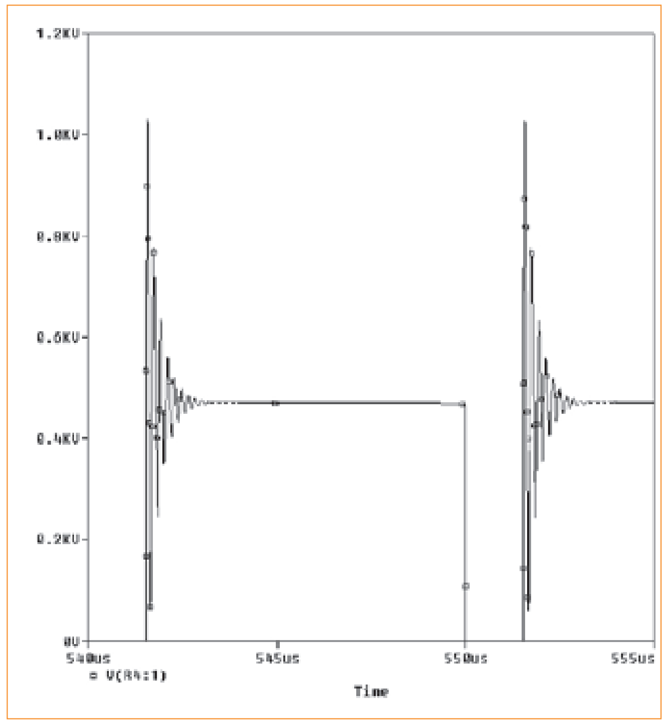



*Figure 1: Drain node switching transients generated by leakage inductance*

**How the clamp works**

A clamp circuit is used to limit the maximum voltage across the MOSFET to a specified value. Once the voltage across the MOSFET reaches the threshold, all additional leakage energy is diverted into the clamp circuit where it is either stored and slowly dissipated or recycled back into the circuit. One disadvantage of a clamp is that it dissipates power and can reduce efficiency. For this reason, there are many different types of clamp circuits (Figure 2). Several use Zener diodes to minimize power consumption, but also increase EMI generation from the sharp turn-on of the Zener. The RCD clamp provides a good balance of efficiency, EMI generation and cost and, as a result, is the most common.

The RCD clamp operates as follows: Immediately after the MOSFET turns off, the secondary diode remains reverse biased, and magnetizing current charges the drain capacitance (Figure 3a). When the voltage across the primary winding reaches the output reflected voltage ($V_{OR}$) defined by the turns ratio of the transformer, the secondary diode

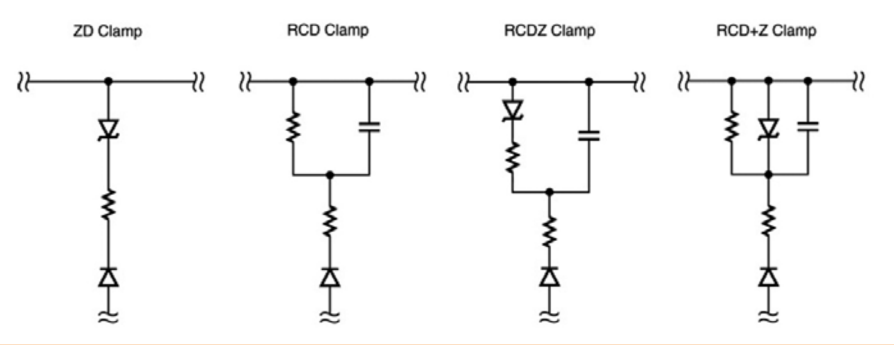
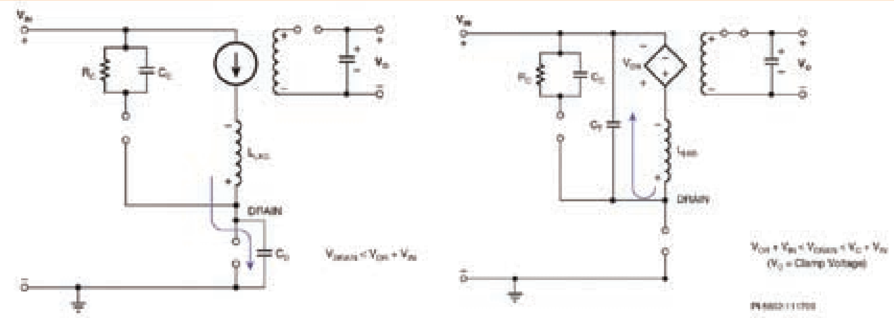
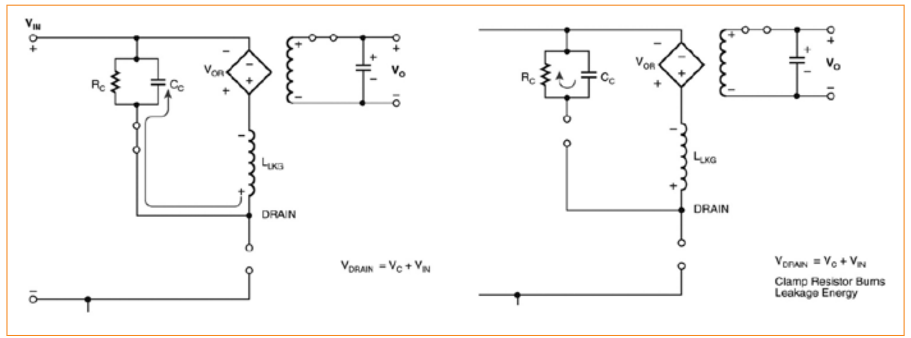



*Figure 2: Clamp types*




*Figures 3a (left) and 3b (right): Primary side clamp*




*Figures 4a (left) and 4b (right): Clamp operation*

turns on and magnetizing energy is transferred to the secondary. Leakage energy continues charging the transformer and drain capacitance until the voltage across the primary winding equals the voltage across the clamp capacitor (Figure 3b).

At this point, the blocking diode turns on and leakage energy is diverted into the clamp capacitor (Figure 4a). The charging current drawn through the capacitor clamps the peak voltage seen on the drain node to $V_{IN(MAX)}$ + $V_{C(MAX)}$. After the leakage energy is fully transferred, the blocking diode turns off and the clamp capacitor discharges into the clamp resistor until the next cycle (Figure 4b). A small resistor is often added in series with the blocking diode to dampen any ringing between the transformer inductance and clamp capacitor at the end of the charging cycle. This complete cycle causes the voltage ripple seen across the clamp circuit referred to as VDELTA, with the amplitude controlled by the sizing of the parallel capacitor and resistor (Figure 5).

The RCDZ clamp is identical in operation to the RCD clamp except that the Zener diode in series with the resistor shares the dissipation (Figure 2). The Zener diode prevents the capacitor from discharging below the Zener blocking voltage. This limits power dissipation and improves efficiency, particularly at light loads. The ZD clamp provides a hard clamp of the MOSFET voltage specified by the blocking voltage of the Zener. Finally, the RCD+Z clamp operates in the same way as an RCD clamp, with the added Zener providing a fail-safe hard clamp for the MOSFET voltage during transient conditions, along with the EMI generation characteristic of the RCD during normal operation.

Clamp design must take into consideration the characteristics of both the transformer and MOSFET. If the minimum clamping voltage is below the VOR of the transformer, the clamp will act as a load, dissipating more than just leakage energy and reducing efficiency. If the clamp components are undersized, they may overheat, fail to prevent dangerous voltages and create unnecessary EMI. Most importantly, the clamp must protect the MOSFET under all conditions of supply input voltage, load current, and component tolerances.

A Clamp Sizing Design Guide (PI-DG-101) published by Power Integrations, Inc., provides a step-by-step procedure for sizing components in each of the four major clamp type circuits for a flyback power supply. The Design Guide is intended to be used together with *PI Expert*™design software. PI Expert is an interactive program that takes a user's power supply specifications and automatically determines the critical components (including transformer specifications) needed to generate a working switch mode power supply. PI Expert will create a clamp design automatically, but the result will be slightly more conservative than that generated by following the algorithms in the Clamp Sizing Design Guide.

**Sizing an RCD clamp**

Below is a summary of the steps to follow when designing an RCD clamp. For complete details, please refer to the Clamp Sizing Design Guide. All values mentioned below not measured or defined by the user should be found in the PI Expert Design Results tab.





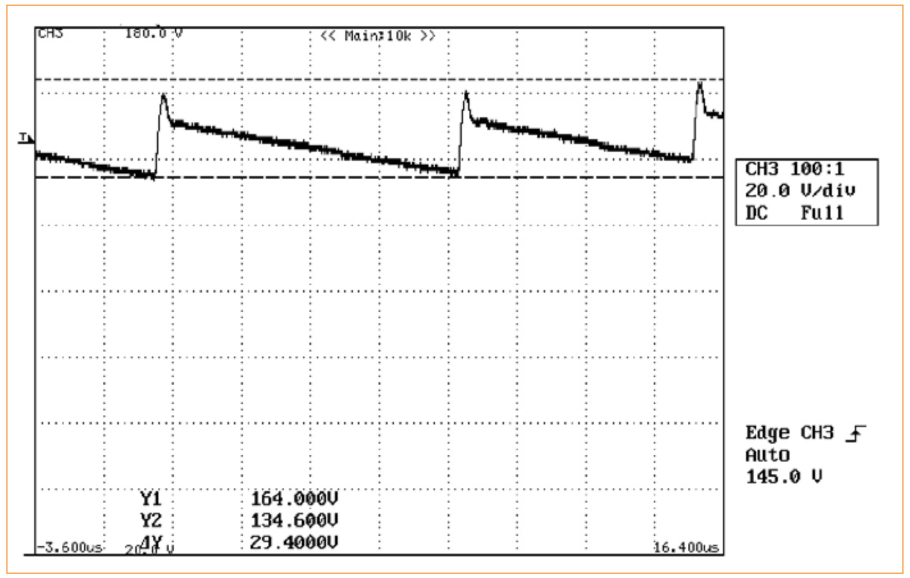



*Figure 5: Bench measurement of RCD clamp voltage*

1. Measure the primary leakage inductance of your transformer, $L_L$
2. Check the switching frequency of your design, $f_s$
3. Determine the correct primary current, $I_P$, as follows:
   a. If your design uses power limit programming, $I_P = I_{LIMITEXT}$
   b. If your design uses external current limit programming, $I_P = I_{LIMITEXT}$
   c. For all other designs, $I_P = I_{LIMITEXT}$
4. Determine the total voltage allowed across the primary MOSFET and calculate $V_{maxclamp}$ as:

$$V_{MOSFETmax} = (VAC_{HighLine} * \sqrt{2}) + V_{maxclamp}$$

   (Note: It is recommended that at least a 50V margin be maintained below BVDSS for a MOSFET, with an additional 30 to 50V margin to acount for transient voltages.)
5. Determine the voltage ripple across the clamp circuit, $V_{delta}$
6. Calculate the minimum voltage across the clamp circuit as:

$$V_{minclamp} = V_{maxclamp} - V_{delta}$$

7. Calculate the average voltage across the clamp circuit, $V_{clamp}$ as:

$$V_{clamp} = V_{maxclamp} - \frac{V_{delta}}{2}$$

8. Calculate energy stored in leakage reactance as:

$$E_{LL} = \frac{1}{2} * L_L * I_P^2$$

9. Estimate energy dissipated in the clamp, $E_{clamp}$, as:

$$1.5\,W \le P_{out} \le 50\,W \qquad E_{clamp} = 0.8 * E_{LL}$$
$$50\,W < P_{out} \le 90\,W \qquad E_{clamp} = E_{LL}$$
$$90\,W < P_{out} \qquad E_{clamp} = E_{LL} * \left(\frac{V_{clamp}}{V_{clamp} - VOR}\right)$$

10. Calculate the clamp resistor value as:

$$R_{clamp} = \frac{V_{clamp}^2}{E_{clamp} * f_s}$$

11. The clamp resistor power rating should be more than:

$$\frac{V_{clamp}^2}{R_{clamp}}$$

12. Calculate the clamp capacitor value as:

$$C_{clamp} = \frac{E_{clamp}}{\frac{1}{2} * [V_{maxclamp}^2 - V_{minclamp}^2]}$$

13. The clamp capacitor voltage rating should be more than: 1.5*$V_{maxclamp}$
14. A fast or ultra-fast recovery diode should be used as the blocking diode in a clamp circuit.
15. The Peak Inverse Voltage of the blocking diode should be more than: 1.5*$V_{maxclamp}$
16. The forward peak repetitive current rating of the blocking diode should be more than: $I_P$ IF this parameter is not listed in the datasheet, the average forward current rating should be more than:0.5*$I_P$
17. Size the damping resistor (if used) as:

$$\frac{20}{0.8 * I_p}\,\Omega \le R_{damp} \le 100\,\Omega$$

18. The damping resistor power rating should be more than:

$$I_P^2 * R_{damp}$$

After the initial design, a prototype should be constructed to verify power supply performance, as transformer leakage inductance can vary significantly according to winding techniques. In particular, the average voltage $V_{clamp}$ should be measured and compared with that calculated in Step 7 (Figure 5). Any significant deviation may be corrected by adjusting the value of $R_{clamp}$. If the results are significantly different from expected, the design must be iterated.

The procedures for sizing the other clamp types follow the same process, with steps for each additional component. Care must be taken in diode and Zener selection to ensure their power ratings are not exceeded. In almost all cases where a Zener function is required, a transient voltage suppressor type should be used to provide the necessary instantaneous peak power rating.

The power ratings of components should be verified by measuring body temperatures while the power supply is running at full load and lowest input voltage. If any component is operating above the manufacturer's recommended temperature limits, it should be resized and the design carefully evaluated against prototype results.

Following the steps detailed in the Clamp Sizing Design Guide will result in a highly optimized and effective clamp design. Further information may be obtained and questions answered by posting an inquiry on the PI Power Supply Design Forum.

www.powerint.com

Power Systems Design

# Special Report- Supplying the Power Grid

Special Report - Supplying the Power Grid

# PLC for the Smart Grid

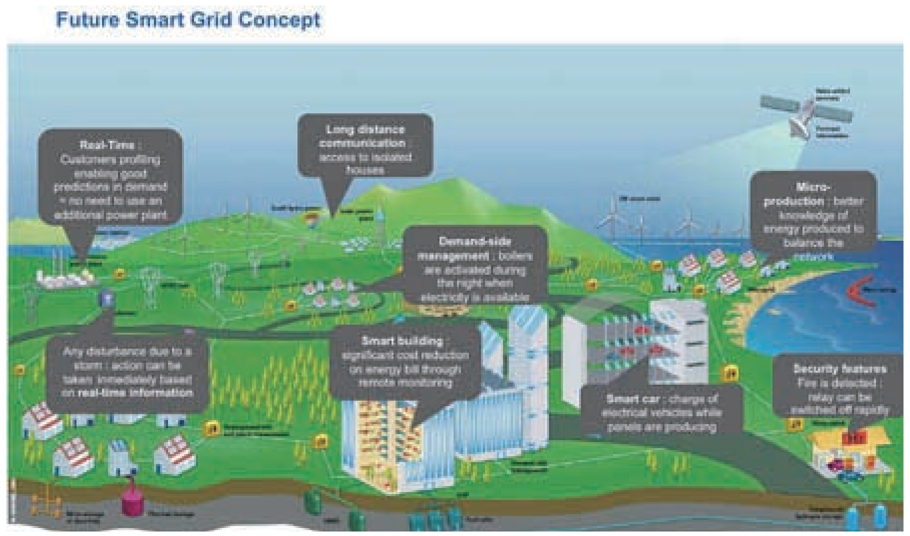
## *Laying down the driving technologies and standards*

*The evolution from the traditional electrical grid to the new smart grid introduces many challenges. One of these main challenges is the need for a good communication network to receive information and control the loads of each customer in real time. The most proven and robust solution for this is the use of Power Line Communication (PLC) technology that uses the grid as the communication medium. Here we discuss the technology and its evolution and compare the traditional narrow band single carrier FSK modulation with the new solutions based in OFDM which are known as PRIME and G3.*

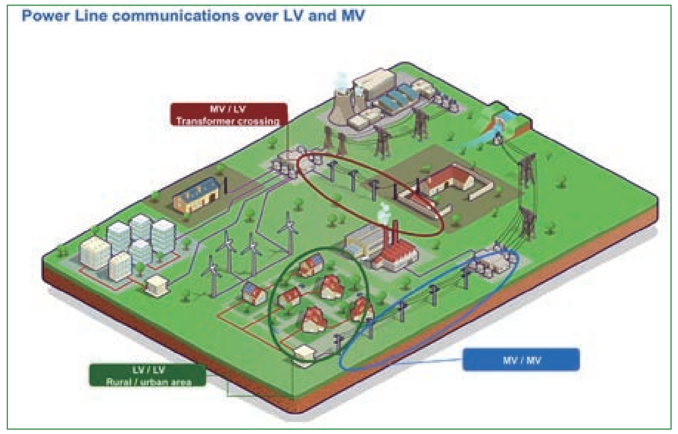
*By Alfredo Sanz, COO, ADD Semiconductors, Advanced Digital Design S.A., Zaragoza, Spain*

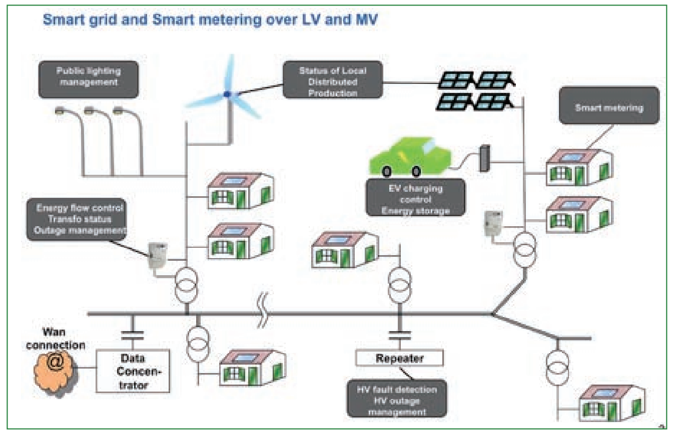
THE traditional electrical grid is changing. In the last century the electrical grid was a system designed to distribute the energy produced from a relatively small number of generation points to an enormous number of customers of different sizes in terms of usage. The criterion to design and to operate the grid was to transport the energy in an efficient way from the centres of generation to millions of customers. The capability to store energy in this system was very limited and therefore the capability to forecast the energy consumption was critical. The control of the grid was based on a daily forecast and the flow of the energy was from centres of production, via the transport grid, to the distribution grid. Most of the production was under the control of a regulator.

Now in some countries, and certainly more in the near future, the contribution of green energies to the electrical grid is a highly significant and important factor. The contribution of so-called green energies to the electrical grid is moving from 5% of hydroelectric production to nearly 40%, made up mainly of solar and wind energy. For the majority of this green energy the regulator normally has a limited control. Additionally, to compound the issue, the electrical vehicle (EV) is becoming a reality and will, for sure, change the scenario. The predicted massive deployment of EV will potentially double the energy consumption in the grid and will as a by-product introduce a large capability to store energy in a distributed structure. This predicted rise in energy consumption, the spreading of green and uncontrolled generation together with the storage capability of EV has been defined as the 'perfect storm' for the electric grid. The solution to this threat was defined as the smart grid. It is a combination of embedded intelligence and real time communication and control capability with enough capillarity to control and communicate to any of the millions or hundreds of millions of users in real time. To achieve this capability of communication it is necessary to actually utilize the electrical grid as the main communication medium using PLC technology.




PLC technology has been used in MV to control the electrical grid for over 20 years. But the massive use of PLC on the LV side of the grid is more recent. A huge success story here is the massive




deployment of an AMM (Automatic Meter Management) system of 35 million meters in Italy by the ENEL utility using a narrow band PLC system based on FSK and BPSK modulation. This system provides the capability to perform accurate bimonthly reading of the 35 million meters, but unfortunately the average baud rate is limited which prevents more real time information and control. Future applications will be based in protocols such as IPv6.

To support more real time information, control and future applications based on protocols as IPv6, makes it necessary for a new generation of PLC technology based in OFDM modulation schemes to be utilized. The two main OFDM proposed solutions are now G3 and PRIME. G3 is a solution promoted by the French utility, EDF, and developed by MAXIM and SAGEMCOM. This solution has been made public from 2009 and EDF plans to test 2000 meters utilizing G3 by 2013.

PRIME is an open and multi provider solution promoted by the PRIME Alliance which includes more than 30 companies such as utilities, meter manufactures, and silicon providers such as ADD Semiconductors, FUJITSU, STM, and TI. Meter manufactures involved in the PRIME Alliance include SAGEMCOM, ITRON, LANDIS+GYR, ISKRA-MECO, ZIV, SOGECAM. IBERDROLA was the initial utility promoter but now EDP, CEZ MERENI and ITRI are also members.

IBERDROLA was the company that started the deployment of 100,000 me-

transmits and receives MPDUs (MAC protocol data units) between neighbouring nodes. The average transmission rate of the PHY layer is around 70kbps and the maximum is 120kbps using a frequency bandwidth of 47.363kHz located on the high frequencies of the European Committee for Electrotechnical Standardization, CENELEC, A-Band. In 92% of cases there is direct visibility of the nodes of the network. In all other cases the routing assures 100% connectivity.

The MAC layer provides core MAC functionalities of system access, bandwidth allocation, and connection establishment/maintenance and topology resolution.

The service-specific Convergence Layer (CL) classifies traffic associating it with its proper MAC connection. This layer performs the mapping of any kind of traffic to be properly included in MAC Service Data Units (SDUs). It may also include payload header suppression functions. Multiple Convergence sublayers are defined to accommodate different kinds of traffic into MAC SDUs.

In the basic FSK or BPSK the information is transported in a single carrier. The baud rate used is proportional to the bandwidth, but the noise and selective attenuation can limit the communication. In OFDM solutions the information is transported in several subcarriers. The baud rate used is proportional to the bandwidth and the complexity of modulation of the subcarriers; DBPSK, DQPSK or D8PSK. The uses of several subcarriers, the coding and error correction used provide more robustness for

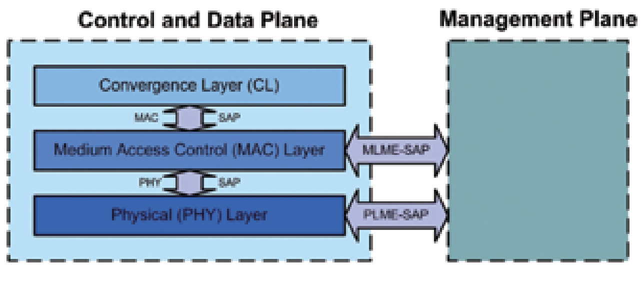

*Prime Alliance meeting of affiliate members*

**Top European Utilities**

Providing Solutions

| # | WW rank | Company | Country | Subs [million] | | Smart meter tech (PLC) |
|---|---|---|---|---|---|---|
| 1 | 1 | EDF | France | 42 | | G3 / SFSK |
| 2 | 2 | Enel | Italy | 30 | | FSK/BPSK |
| 3 | 4 | Iberdrola | Spain | 11 | | PRIME |
| 4 | 5 | Endesa | Spain | 13 | | BPSK |
| 5 | 6 | Vattenfall | Sweden | | | x |
| 6 | 7 | E ON | Germany | | | x |
| 7 | 8 | EnBW | Germany | | | x |
| 8 | 9 | CEZ | Czech | 7 | | PRIME |
| 9 | 12 | EDP | Portugal | 1.4 | | PRIME |
| 10 | 14 | Fortum | Finland | | | x |
| 11 | 16 | Union Fenosa | Spain | 9+ | | PRIME |

**PRIME Protocol Stack**




Based on IEEE Std. 802.16 protocol layering

**PRIME Physical Layer Specifications**

| | | |
|---|---|---|
| Number of data subcarriers | 84 (header) | 96 (payload) |
| Number of pilot subcarriers | 13 (header) | 1 (payload) |
| Subcarrier spacing | 488,28125 Hz | |
| Frequency Band | 42 – 89 KHz (CENELEC A) | |

| | DBPSK | | DQPSK | | D8PSK | |
|---|---|---|---|---|---|---|
| Convolutional Code (1/2) | On | Off | On | Off | On | Off |
| Info bits per subcarrier | 0,5 | 1 | 1 | 2 | 1,5 | 3 |
| Info bits per OFDM symbol | 48 | 96 | 96 | 192 | 144 | 288 |
| Raw data rate (kbps approx) | 21,4 | 42,9 | 42,9 | 85,7 | 64,3 | 128,6 |
| MAX MSDU length with 63 symbols (bits) | 3016 | 6048 | 6040 | 12096 | 9064 | 18144 |

ters in 2010, and the company is now planning a new tender for 1 million meters by the end of 2010 and to complete the full deployment of 10 million meters in Spain within 3 to 5 years. Other utilities are also starting to introduce PRIME.

G3 and PRIME are both OFDM solutions but with a different history. G3 initially used a chip designed by MAXIM that provided the PHY layers and some available software layers as in IEEE 802.15.4 2006, using 6LowPAN for the MAC layer and IPv6 for the Network layer.

PRIME is the result of the collaboration of a multi-disciplinary consortium including utilities, industrial and university partners to design a new OFDM-based power line technology open standard. The consortium used a systematic process of design for the PHY layer starting from basic requirements. The next step was the characterization of the physical medium in terms of noise level, noise patterns, attenuation characteristics and models of impedances. The industrial partners developed new automatic equipment specific for these tasks and several records were accumulated in collaboration with the utility. This process delivered a large database of noise level, noise patterns, attenuation characteristics and models of impedances that provided a statistically accurate model of the grid.

In a second step, this model was used to evaluate, by simulation, several alternative combinations of parameters of the OFDM technology including header implementation, bandwidth allocation, number of subcarriers, subcarrier modulation and error correction. The best alternatives were evaluated in the field using the new equipment. After several iterations and a massive field test, the best combination of parameters was selected according the condition of the European grid and the specification of the utility. Also the MAC and upper layers are the result of a collaborative consortium including silicon providers, meter manufactures and utilities.

The net result of these combined efforts is the finalization of the PHY, MAC and Convergence layers. The PHY the noise and selective attenuation in the communication.

Size of the data transmitted (symbol) is proportional to the sampling frequency and the number of sub-carriers. The size of the symbol increases the robustness for impulsive noise. Coding increases the robustness but also increases the complexity and power consumption. It is the number of sub-carriers that provides more robustness, not a higher baud rate.

The G3 solution uses 36 subcarriers and sort symbols of 0.735ms, preamble of 6.79ms, headers of 9.5ms and need repetition and Reed Solomon (cyclic error-correcting codes) error correction to increase robustness.

The PRIME solution uses 97 subcarriers and long symbols of 2.24ms, preamble of 2ms, headers of 4.48ms. To avoid the need for repetition and the complexity of Reed Solomon error correction Prime uses symbols with 3 times more energy to increase robustness. This is a more cost effective solution to increase robustness.

In conclusion, the electrical grid is evolving into a smart grid which needs greatly improved communication capabilities. PLC technology is the most convenient technology to achieve the necessary capillarity and robustness. The PLC technology is evolving to OFDM solutions with G3 and PRIME as the main alternatives.

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Special Report - Supplying the Power Grid

# Driving Public Lighting

## *Pulse Frequency Modulation High-Brightness LED power driver*

*Increasingly, with the development and refurbishment of Power Grid systems, more efficient street and public lighting systems are becoming ever higher on a government's agenda. Over the last years, the significant improvements in the field of solid-state lighting technology have been paving the way for the possibility of replacing conventional light sources (such as halogen and fluorescent lamps) with high-brightness LEDs (HBLEDs). They offer significant advantages; extremely long lifetime, low maintenance, robustness, low-voltage operation and good colour-rendering properties.*

*By Silvio Baccari, Massimo Tipaldi, Francesco Vasca, Luigi Iannelli, Department of Engineering, University of Sannio, Benevento, Italy*

The main barrier to universal adoption is the cost of a complete LED light system, which includes the LED itself and the auxiliary control circuitry. This justifies the efforts of the research institutes and the industry in improving the overall system efficiency so that the energy and maintenance cost savings can cover up the installation expenses.

It is well-known that the LED emission intensity increases linearly with increasing small forward currents. On the other hand, for high forward currents, the emission intensity deviates from this linear behaviour and shows a tendency to saturate. Recently, the two commonly used driving solutions for LEDs are the analog and the pulse width modulation (PWM)/dimming techniques. The former stems from a simple concept that is the direct regulation of the forward current. The latter is carried out by switching on and off the LEDs repeatedly while the LED string current, during its on-phase, is forced to its nominal value. The so-called dimming frequency is usually set so that the dimming effect is not critical to the human perception.

That said, it is often discussed in the literature that, due to the above-mentioned nonlinearity, the efficacy of the LEDs driven by a PWM will be lower than that driven by dc for the same average current, since a larger current amplitude exists in the average-equivalent PWM case. In other words, the light output obtained from a LED is strongly dependent on the actual current flowing

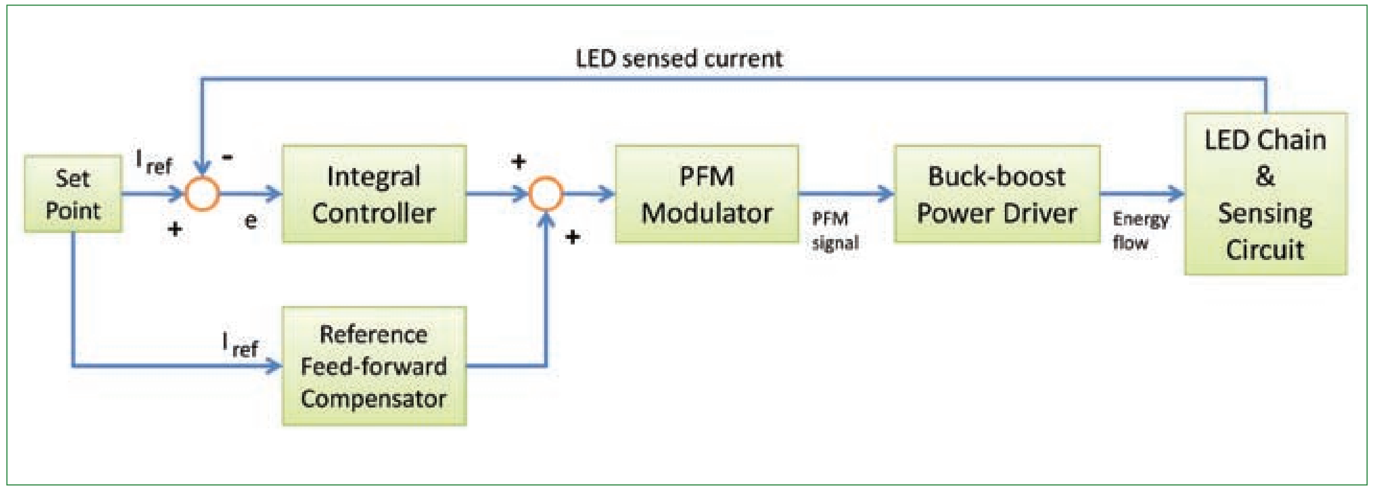


*Figure 1: Block diagram of the PFM based HBLED power driver*

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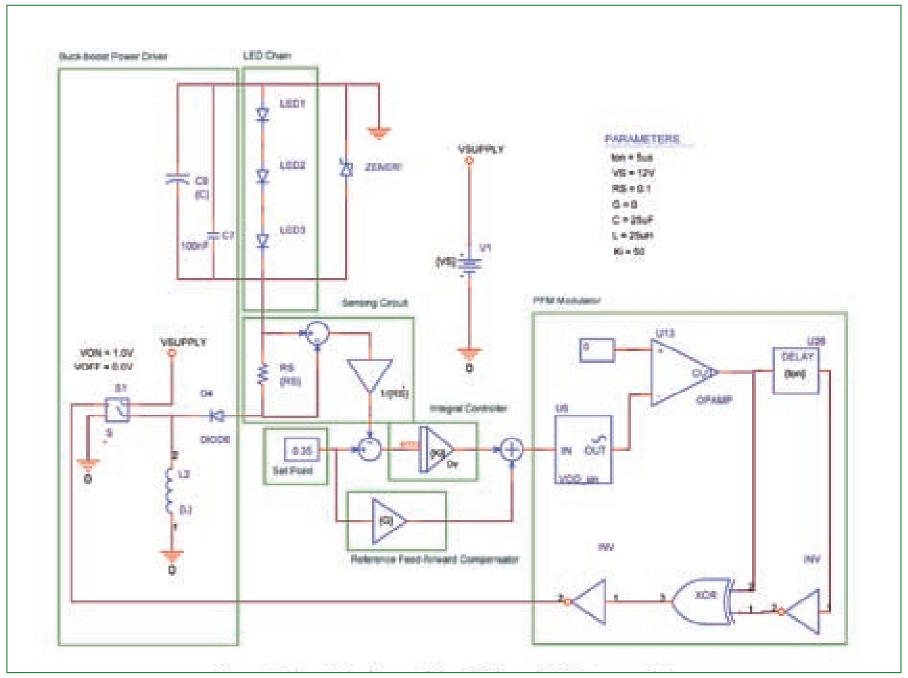


*Figure 2: Electrical scheme of the PFM based HBLED power driver*

through it.

**Block Diagram Description and Control Approach**

The control solution proposed here is focused on the LED efficiency rather than on the auxiliary control circuitry. The underlying principle of the proposed solution is to set and to regulate the LED dc current value by means of a driving circuit based on Pulse Frequency Modulation (PFM). A block diagram of the proposed circuit is shown in

Figure 1 and is made up of:

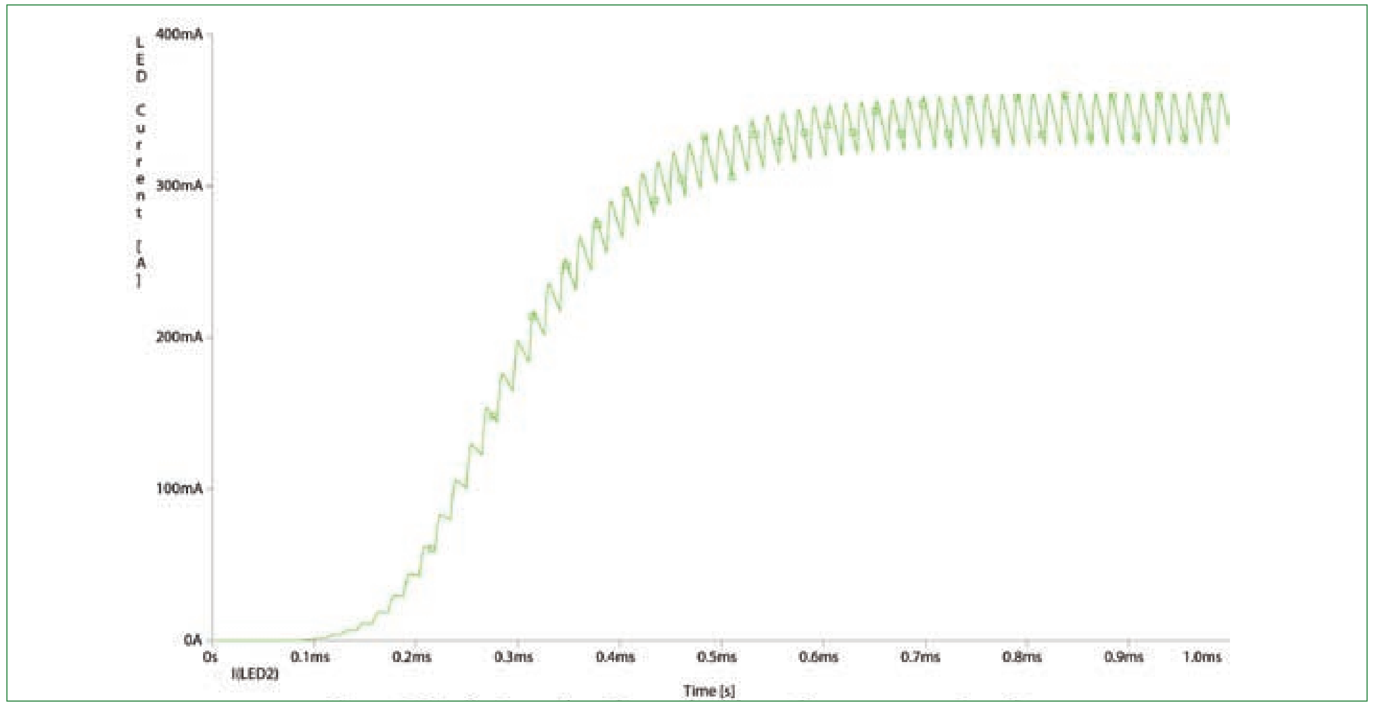
- The controller
- PFM based actuator
- Buck-boost power driver
- The plant, i.e. the LED chain

Unlike PWM, in which the width of square pulses is varied at constant frequency, PFM is accomplished by using fixed-duration pulses and varying the repetition rate. The controller determines the frequency of the PFM. The controller is essentially based on the combined action of a feed-back error integral control and a reference feed-forward control. The error is calculated by subtracting the LED current reference from the measured LED current. From control theory it is well-known that, thanks to the integral action, the reference steady-state error can be eliminated, although this comes at the expense of deterioration in the dynamic response. The purpose of the reference feed-forward compensator is just to make up for the delay induced by the integral action.

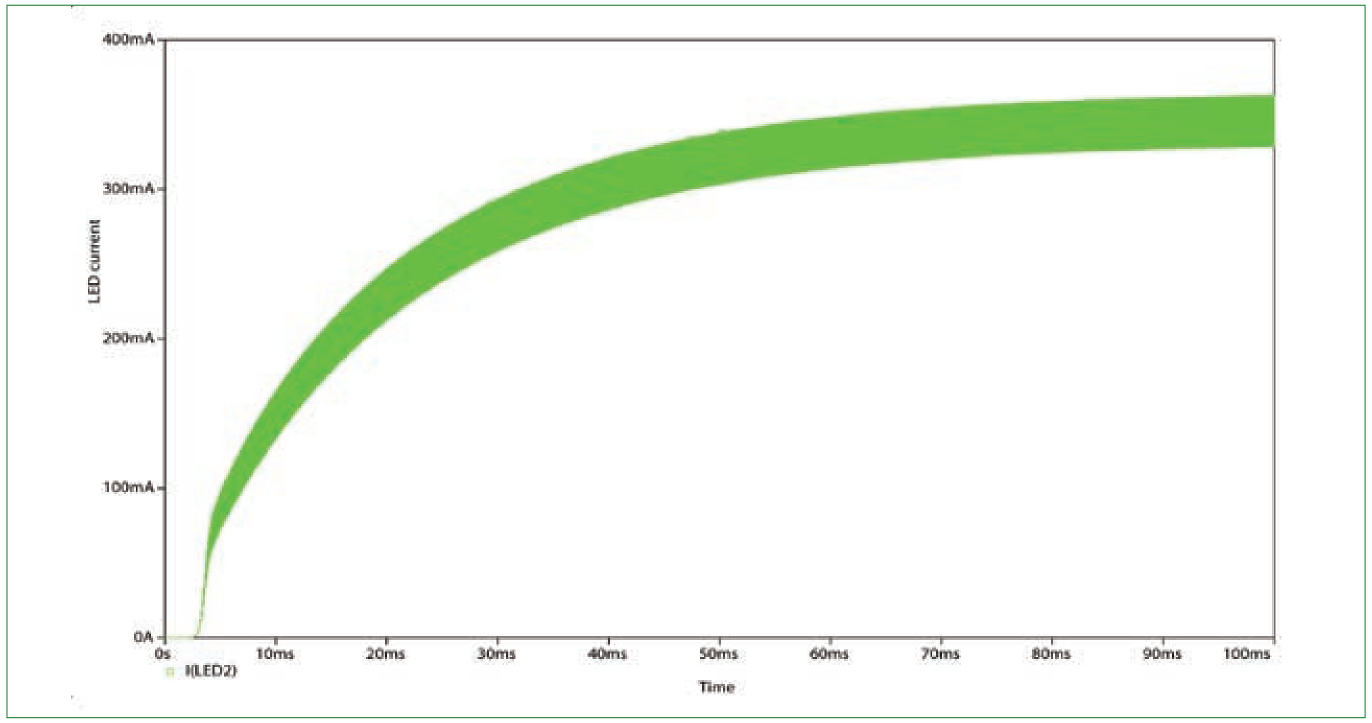
The output of the controller regulates the frequency of the PFM pulse train, and then the flow of energy driven by the buck-boost power driver towards the LEDs. An accurate choice of the circuit parameters can guarantee an acceptable current ripple value.

**Circuit Description and Simulation Results**

Figure 2 shows the electrical scheme of the PFM based high brightness LED power driver with the design details of the afore-mentioned blocks.




*Simulation results: reference feed-forward compensator activated*




*Simulation results: reference feed-forward compensator disabled*

A DC/DC buck-boost converter with an output capacitor is used. It has cyclic changes in topology due to the switching action of the semiconductor devices. During a cycle of operation, the main power switch (driven in our case by the PFM actuator output) is turned on and off.

When the switch is closed:

- the inductor receives energy from the source and is charged up
- the diode is in the reverse region (that is, it is an open circuit)
- the capacitor is discharged into the output load (i.e., the LEDs) and the LED current decreases.

On the other hand, when the switch is open:

- the inductor maintains the current flow in the same direction and the diode is forward-biased
- the inductor transfers the accumulated energy into the capacitor and, as soon as the LED forward drop voltage is reached, into the LEDs as well
- the output voltage/current rises.

The LED chain current is measured by means of a sensing resistor and compared with a specific set-point. The error signal is integrated and, along with the appropriately amplified set-point (please note that this is nothing but the feed-forward action), supplies the PFM actuator input. The feed-forward controller gain has been fixed in function of the power driver load, i.e. the number of LEDs. It means that, in case of a lower number of LEDs, the LED current can exceed its nominal value, but only for a brief lapse of time.

The PFM block has been implemented by a voltage-controlled oscillator, which generates an output signal whose frequency depends proportionally on the input magnitude.

A dedicated circuit is in charge of converting it into a train of fixed-duration pulses. An impulse is generated for each period of the VCO output signal. This circuit is based on a XOR port, which avoids failures in case the VCO output period is lower than the duration of a generated pulse (fixed by the delay component).

Some simulation results, obtained by using PSPICE, are shown in Figure 3 and Figure 4. The simulations allow summarizing the following advantages of the proposed solution:

- the LED current flows in continuous mode thus guaranteeing a better efficiency for what concerns the LED emission intensity
- the current set point is reached, showing also an acceptable ripple
- the frequency of the PFM actuator (not shown in the figures) is lower during the transients
- the reference feed-forward compensator reduces quite considerably the transient duration.

With the increase in efficiency and subsequent low maintenance that can be achieved with advanced driving system concepts, power utilities can justify the initial start-up costs associated with HBLED lighting systems, to use energy more wisely and to gain the advantages of lifetime cost for indoor as well as outdoor applications. In this article, an ad-hoc solution based on a Pulse Frequency Modulation power driver is presented. Its main idea is to set and regulate the LED dc current to a specific analog value. By doing so, a higher level in terms of LED efficiency can be reached since this technique deals with the nonlinearity behavior of the LED emission intensity with the related forward current.

www.grace.ing.unisannio.it

# Grid Tie Inverter Design

## *Generation 7, 1200V ultrafast trench IGBTs for high efficiency*

*In order to achieve higher efficiency in a grid tie inverter, the correct choice of power semiconductor devices becomes very important. For grid tie inverters, the bus voltage is in the order of a few hundred volts. IGBTs are the most suitable power device choice from the point of view of cost and efficiency.*

*By Wibawa T.Chou, Senior Application Engineer, International Rectifier Corporation*

Grid tie inverters typically operate at 20kHz switching frequency and therefore, require ultrafast IGBTs with balanced switching and conduction losses.

A typical schematic for DC to AC sinusoidal inverters used for grid tie application is shown in Figure 1. The inverter bus voltage is typically derived directly from a series connected PV arrays or through an intermediate boost converter that is not shown here.

For a 230Vac output inverter for instance, the DC bus voltage is typically +/- 400Vdc. Figure 1 shows IGBT current flow in the forward direction when IGBT Q1 is turned on and the inverter is delivering positive current. When IGBT Q1 is turned off, the current in the inductor has to continue and flows in the copack diode of IGBT Q2. The voltage stress across Q1 is the sum of the DC bus which is 800V. Including voltage spike due to parasitic inductance and rate of current change (di/dt), 1200V IGBTs are typically selected for Q1 and Q2. The same analysis can be done when the inverter is delivering negative current when IGBT Q2 is turned on. In this case, the freewheeling current path is through the copack diode of IGBT Q1.

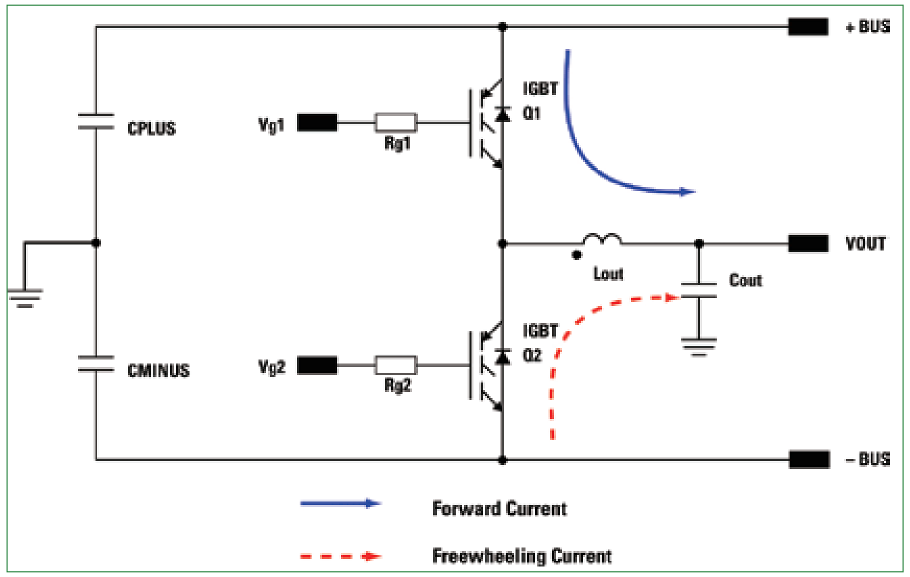



*Figure 1: Typical schematic of a half bridge grid tie inverter with IGBT copacks*

| P/N | $Ic_{(nom)}$ | $V_{CEON}$ @ 25°C | $Rth_{(j-c)}$ | Package |
|---|---|---|---|---|
| IRG7PH35UDPBF<br>IRG7PH35UPBF | 20A | 1.8V | 0.70 °C/W | TO247 |
| IRG7PH42UDPBF<br>IRG7PH42UPBF | 30A | 1.7V | 0.39 °C/W | TO247 |
| IRG7PH46UDPBF<br>IRG7PH46UPBF | 40A | 1.7V | 0.32 °C/W | TO247 |
| IRG7PH50UDPBF<br>IRG7PH50UPBF | 50A | 1.7V | 0.27 °C/W | Super TO247<br>TO247 (discrete) |

*Figure 2: 1200V Ultrafast Trench IGBTs are available in four current ratings*

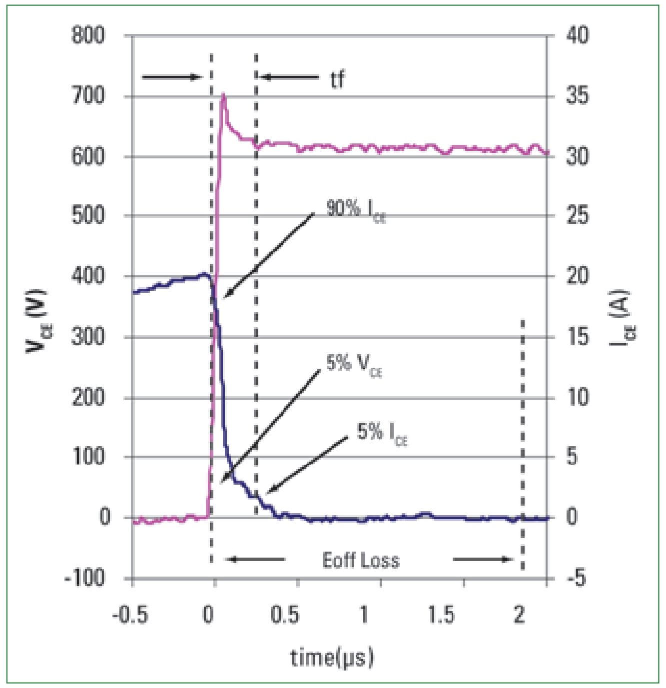



*Figure 3: Turn off transition of IRG7PH35UDPBF at Vce = 600Vdc, Ice = 20A, Vge = 15V and $T_{junction}$ = 150℃*

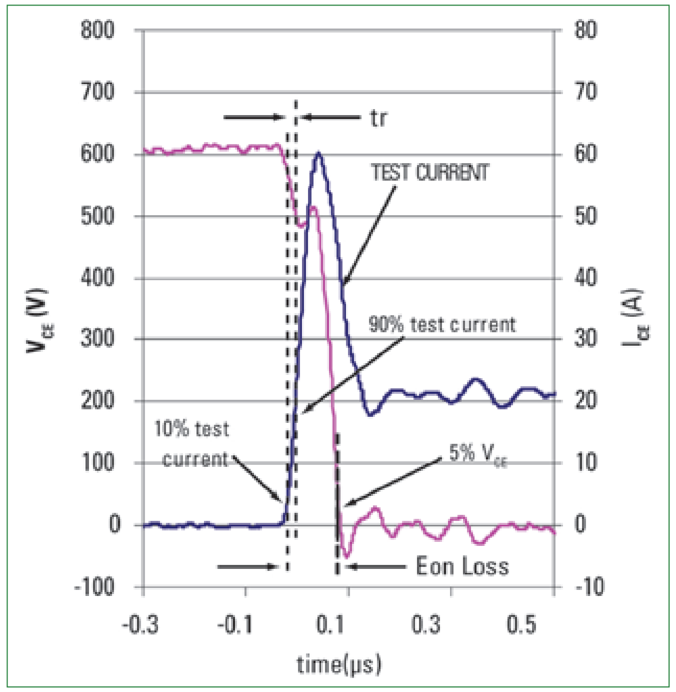



*Figure 4: Turn on transition of IRG7PH35UDPBF at Vce = 600Vdc, Ice = 20A, Vge = 15V and $T_{junction}$ = 150℃*

International Rectifier recently released a series of Generation 7, 1200V ultrafast trench IGBTs intended for high frequency applications. These IGBTs are the extension of IR's previously launched 600V trench IGBTs that have become industry de-facto in high frequency inverter applications. By utilizing thin wafer technology, these 1200V IGBTs are able to achieve typical voltage drop (Vceon) of 1.7V and typical fall time of less than 100nsec at their nominal current ratings. They also exhibit a positive Vceon temperature coefficient which allows for easy paralleling. Another benefit of thin wafer technology is the reduction in junction to case thermal resistance ($Rth_{(j-c)}$) and improvement in the transient thermal response of the IGBT.

Four die sizes representing current ratings of 20A, 30A, 40A and 50A are available in popular lead-free packages: TO247/Super TO247 discrete and copack versions and are shown in Figure 2. The IGBT dies are also available in wafer forms for engineers designing power modules. The package versions are switched at four times the nominal current with 960VDC bus voltage at final test. This ensures all weak IGBTs are screened before they leave the factory. The parts without diodes are introduced to give design engineers flexibility to choose their own diodes either for cost or performance reasons. An example of an application that does not require a copack diode is power factor correction or boost converter. Here, the function of the diode across the IGBT is only as protection in case there is current flowing from Emitter to Collector of the IGBT. A small external diode will be sufficient as oppose to a high performance copack diode which saves the cost of the overall system.

Figure 3 shows a typical turn off event of the 1200V/20A, IRG7PH35UDPBF, ultrafast trench IGBT at junction temperature of 150℃ .

It can be seen from Figure 3 that the cross over between voltage and current during turn off transition contributes to switching loss and needs to be minimized by making the fall time and tail current as small as possible. This generation IGBT is able to achieve a balance loss between conduction and switching at 20kHz by utilizing both IR's trench gate and thin wafer technologies. Another important feature is the low rate of current change (di/dt) which results in lower voltage spike at turn off. It can be seen that with a bus voltage of 600Vdc, the voltage overshoot across the IGBT is only slightly more than 700V which is much lower than the breakdown capability of the device. Also, there is lack of voltage ringing at turn off which might contribute to overall system EMI reduction.

The diodes in the copack IGBT versions are 1200V fast recovery low Qrr diodes which provide lower total power dissipation compare to high Qrr diodes typically found in motor drive IGBTs. Having a fast recovery diode is important in minimizing turn on transition loss of the IGBT. As the IGBT Q1 turns back on, the current on the output inductor of Figure 1 will flow again in the forward direction. This current is the combination of load current and reverse recovery current of diode copack IGBT Q2. The shorter the turn on transition, the lower IGBT turn on loss will be. The turn on transition of the IGBT at 600Vdc, 20A and at junction temperature of 150℃ is presented in Figure 4.

Although the trade-off of low Qrr diode is in its higher voltage drop

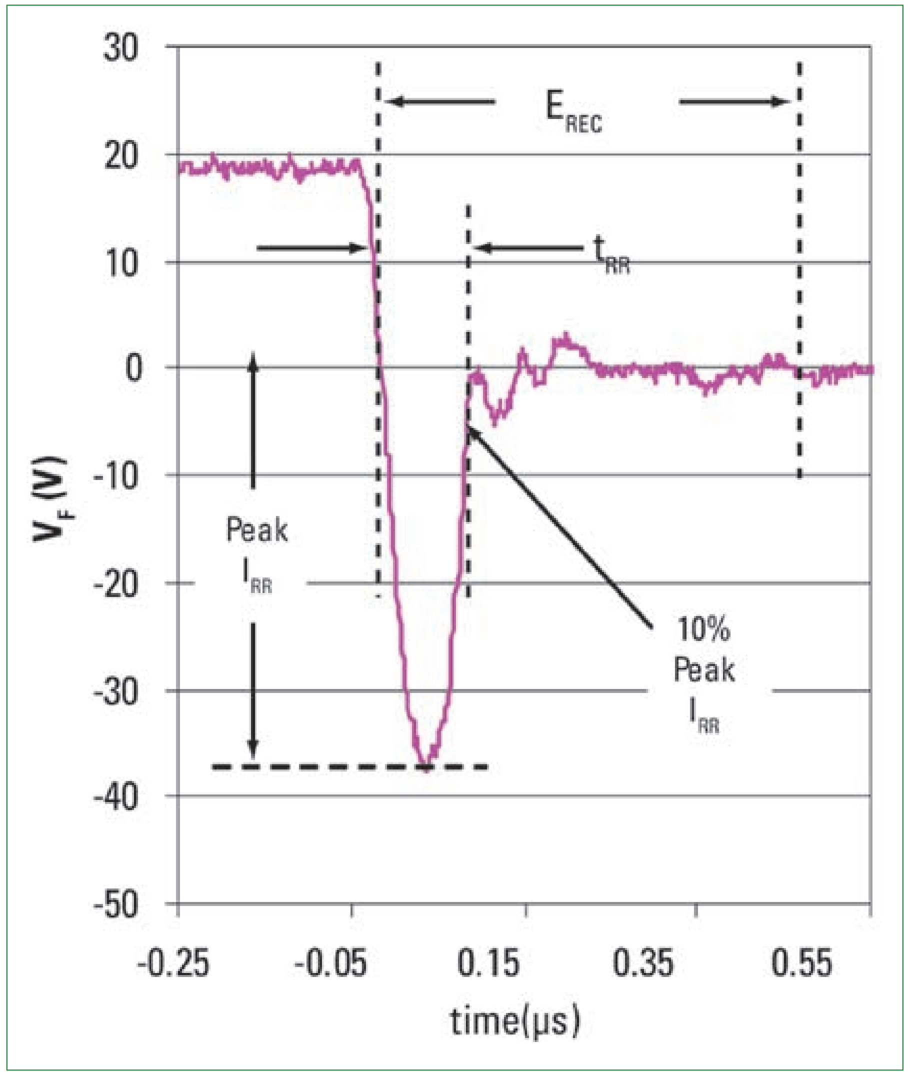



*Figure 5: Reverse recovery of IRG7PH35UDPBF copack diode at Vce = 600Vdc, Ice = 20A, Vge = 15V and $T_{junction}$ = 150℃.*

(Vf), the benefit of having low Qrr still outweighs it. On a grid tie inverter the copack diode will have to take the same IGBT peak current during the freewheeling period when the IGBT is turned off. However, the duty cycle is opposite to that of the IGBT. Therefore the conduction loss of the diode is a much smaller portion of its reverse recovery loss and is typically within a 1 to 3 ratio. Figure 5 shows a typical IRG7PH35UDPBF copack diode recovery waveform at 600V, 20A at $T_{junction}$ = 150℃ . Here, it can be seen, the recovery of the diode is very fast and the recovery current decays to zero and transfers to the IGBT in about 100nsec.

By selecting the right power device for a grid tie inverter, design engineers can achieve the highest efficiency possible. Recently released Generation 7, 1200V ultrafast trench IGBTs offer balanced conduction and switching losses at 20kHz by reduction in Vceon, fall time and tail current. Copackage with low Qrr diodes, the package part version will reduce power dissipation further. This generation is also available as stand alone discrete device without copack diode for cost or performance improvement. In addition, the die version is available in wafer forms for engineers designing for power module applications.

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# Smart Grid Integrity

## *Advanced secure smart metering transformers*

*Every day we can read and see on news statements like: "A series of agreements to collaborate on four smart grid projects signed.", "International Smart Grid Action Network launched.", "Beyond the hype: making smart grids happen", "Building a smarter Electric grid.", but what are the real needs?*

*By Helmut Dönges, Dipl -Ing., MBA, Sales Director, Inductive Components, Magnetec GmbH, Germany*

Many countries all over the world are looking forward to replace, extend or modernize their grid infrastructure. In many cases, this is going along with new and intelligent smart metering devices to make smart grids overall reliable and efficient. Current Transformers made -of nanocrystalline soft magnetic materials, provided by MAGNETEC GMBH are providing the ideal transducer principle.

**Why use current transformers**

The increasing demand for smart meters in new, modern smart grids requires highly qualified and reliable current transducer technologies. The main question is, whether or not the current transducers are able to meet all requirements from the consumer side, from the energy supplier side and the metrology?

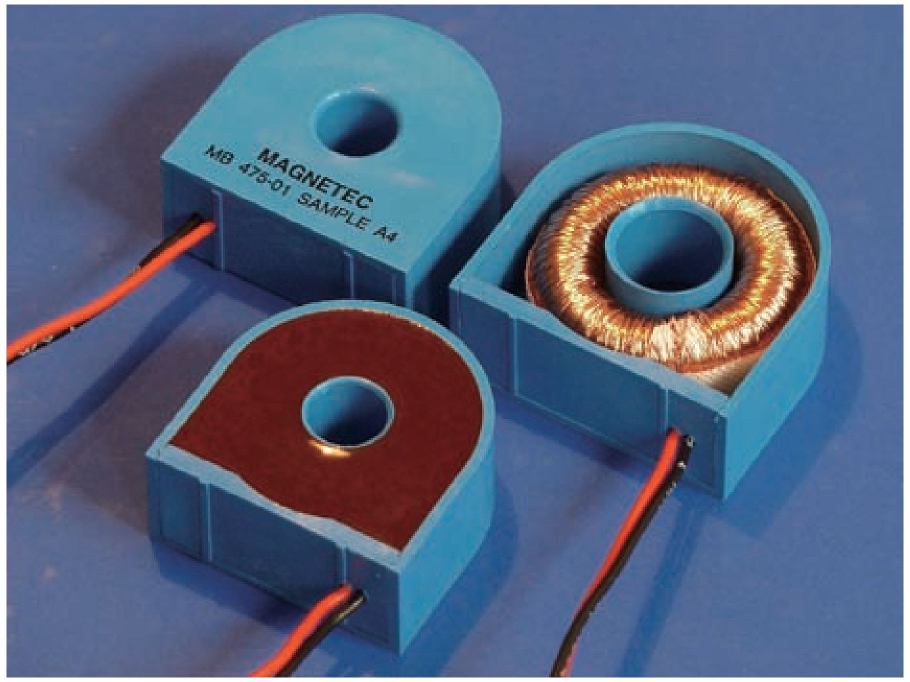



*Figure 1: Current transformers for electronic energy metering*

Consumers are mainly looking for actual consumption measurement, transparency of energy demand and energy savings without any doubts

Energy suppliers are looking for tamper-proof metering, secure remote readout and an increased accuracy for efficient data collection, control and billing

The metrology bodies have to consolidate all needs and in line with the standards, to insure long lasting quality of the energy measurement to avoid financial losses for distributors and consumers of electric energy.

A highly developed transducer principle such as the current transformer is an innovative technology and helps to ensure a consistently a high quality level on all the mentioned "user sides" explained above.

Of course, it is easier to use existing transducer principles in meter solutions without any changes to promote a new product for smart grid technology. But new and innovative products offer a huge potential and high level of safety and reliability in terms of a consumer friendly energy measurement. Such innovations are developed with close communication of all needs between utilities and meter manufacturers, and also between the utilities and the consumer. It is important that the solution is not only driven by price, but also driven by the quality and the attractiveness of the product innovation. This means more security and reliability in the energy measurement within the smart grid and will be a good argument to penetrate the smart grid business.

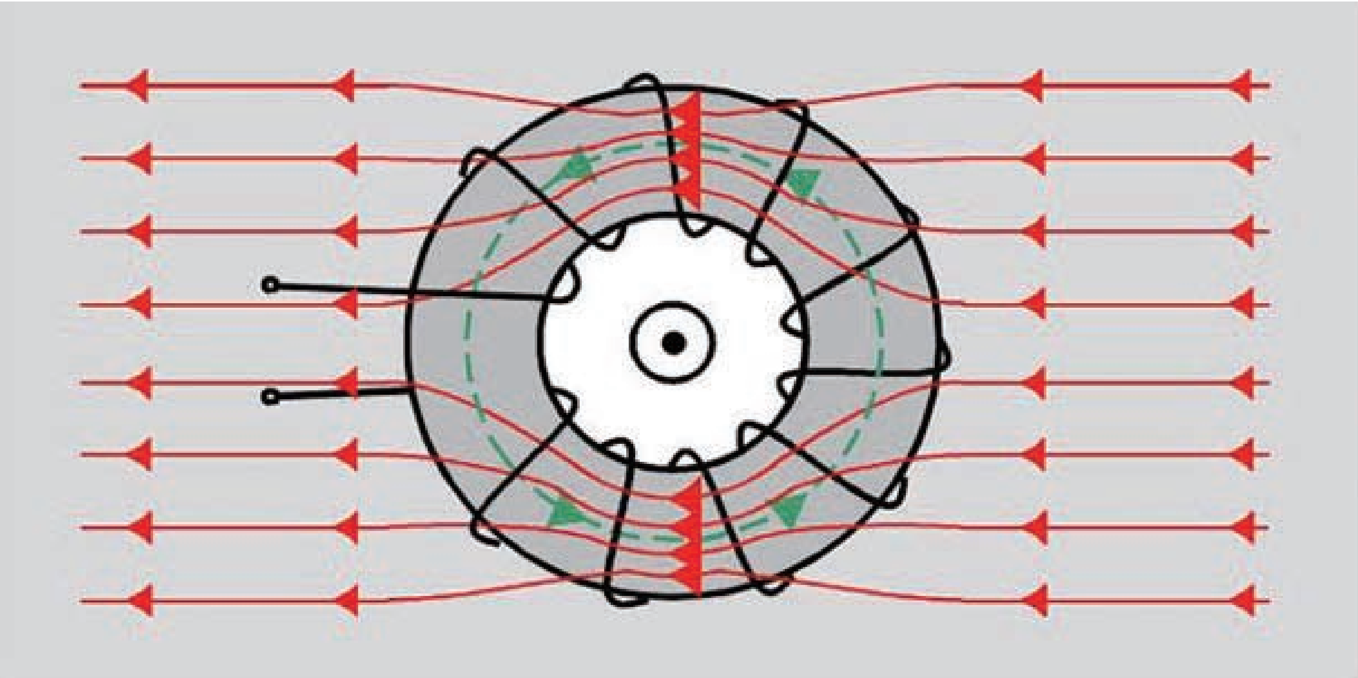


*Figure 2: Virtual field gradients in a toroidal current transformer*

As is well known in the market, an increasing number of electronic energy meter devices for the smart grid use advanced current transformers compared to meters made with shunt solutions and Rogowski coils. The magnetic properties of current transformers from MAGNETEC are highly linear and stable throughout a wide range of temperature and comply with the dc-immunity requirement from the IEC standard 62053-21, providing high reliability for metering devices for the smart grid despite the sometimes non-ideal environment.

**Current transformer with integrated shielding – Recipe for a high-grade smart grid**

Although all technologies used in smart metering are susceptible to magnetic influence to some degree, the superior performance of current transformers should be considered carefully from the very beginning of any smart meter design. Without the use of current transformer technology, strong magnetic fields can cause distortion in billable counting. In recent times a huge increase in manipulation attempts has been observed worldwide whether in developing regions or highly-industrialized countries. The reason almost certainly is to reduce the apparent energy consumption for lower billing. Here the utilities have to detect revenue losses and continue billing accurately when tampering of energy metering equipment has occurred.

Therefore, in general, many transducer principles in electronic meter devices show sensitivity to external magnetic fields when tampering attempts occur. These do not always necessarily need be produced with malicious intention, they can also occur from a stray field of electrical equipment or lines in the vicinity of the meter. To understand and to evaluate the influence external magnetic fields, a series of experiments should be made during the evaluation process and during the field tests of the energy meter.

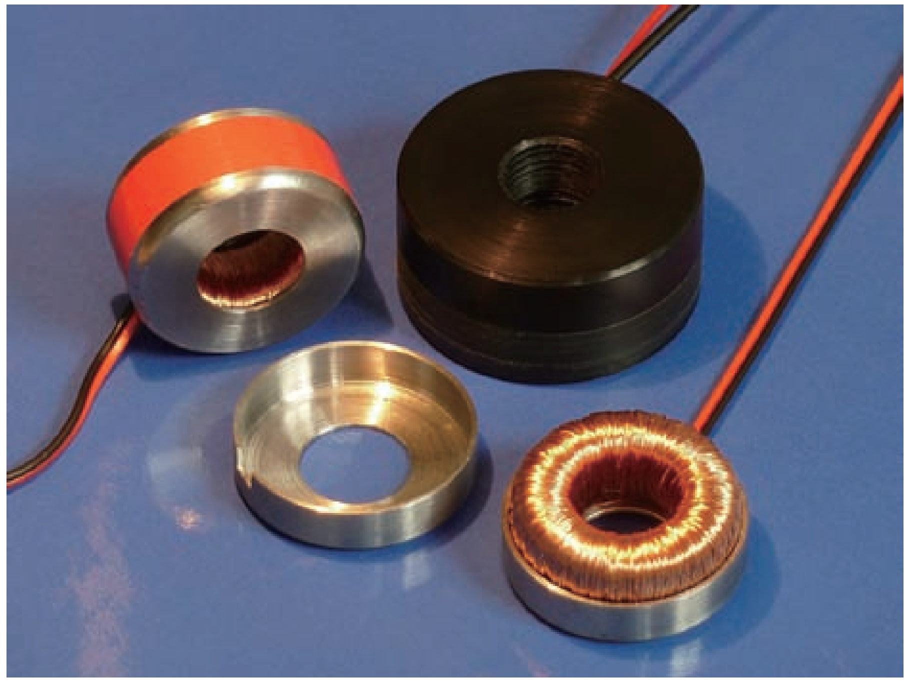
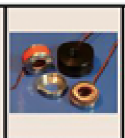
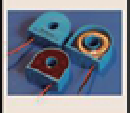
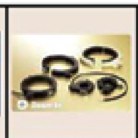
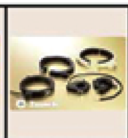


*Figure 3: Shielded current transformers for electronic energy metering*

**Consideration of different measuring principles**

| Measuring principle |  |  |  |  |  |
|---|---|---|---|---|---|
| Testing parameters | CT with magnetic shielding | CT without magnetic shielding | coil with magnetic shielding | coil without magnetic shielding | shunt magnetic shielding |
| Accuracy at minimum load | 😊 | 😊 | 😐 | ☹ | ☹ |
| Accuracy at maximum load | 😊 | 😊 | 😊 | 😊 | 😊 |
| Immunity against external AC magnetic field | 😊 | 😊 | 😐 | ☹ | ☹ |
| Immunity against external DC magnetic field | 😊 | 😐 | 😊 | 😊 | 😊 |
| Immunity against ext. AC and DC fields | 😊 | 😐 | ☹ | ☹ | ☹ |
| Size | 😊 | 😊 | ☹ | ☹ | 😊 |
| Cost | 😐 | 😐 | ☹ | 😐 | 😊 |

In the case of the influence of an alternating field with an electromagnet (e.g. 50 Hz transformer with I – Core), the sensitive input circuits of the meter with a shunt and with a Rogowski coil can be influenced very strongly. As an example, because of the absence of a magnetic core, the Rogowski coil is immune to magnetic interference caused by external permanent magnets. There is no need to shield the coil by a steel housing as is used for other technologies. On the other hand, the Rogowski coil is extremely sensitive to the external alternating fields mentioned above and has to be magnetically disconnected from its environment. For this purpose a magnetic shielding using a highly permeable material is needed and this needs to be very efficient at any time - even at low field intensities.

The possibility to influence a current transformer is much lower because of the closed loop principle of the magnetic circuitry. Measurements with an external alternating field do not show significant effects. This application advantage is based on the rotational symmetry of the CT (magnetic core and the winding). Figure 2 shows the virtual field lines of the primary current (green line) and the field lines of an external stray field (red) in the current transformer with a toroidal magnetic core. The primary current induces via the field lines a voltage into the secondary winding, which is available at the terminals.

Generally speaking, it seems to be that for all the different measurement principles used in smart electronic energy meters, metallic shields are needed to make any attempts at tampering ineffective. In any case, it can be demonstrated that the current transformer with suitable screening and placement within the meter design can, in economic terms, be designed to be largely insensitive to both types of magnetic fields. Figure 3 shows two types with such an integrated shielding.

### What can we learn from the example?

The development and understanding of current transformers in electronic energy metering applications needs more than just a simple testing of different transducer solutions. This must be taken into consideration in the development of meters from the beginning to avoid later adjustments in a finalized design of the meter. It could be too late.

More and more meter manufacturers and customers are embarking on the development of smart meters for use in a modern smart grid. Current transformer-based technology differs greatly from the many other offerings in transducer technology that exist in this application field where, except for standard functions, they offer no real advantage. In the long run, they usually disappear from the market because they are simply not suitable for future demands and requirements within a modern power grid system. Table 1 shows a broad overview of different measuring principles under specific testing parameters.

### Conclusion

The smart grid will, in the future, replace the old grid infrastructure. The requirements for this new generation of smart grid are increased significantly and require high-precision and safe measurement technology and in line with reliable components. Current transformers from MAGNETEC offer a combination of desirable properties from a technical and commercial perspective.

The new combination of the current transformer with integrated shielding presents an excellent new opportunity to supply complete high-quality solutions to the global market for electronic energy meters. The new current transformer series, especially for 60A and 100A metering devices in particular can now compete on a cost basis with all widespread transducer systems such as Hall-effect transformers, Rogowski systems or shunts.

### MAGNETEC – European experts for current transformers

For over 25 years MAGNETEC GmbH has developed, produced and marketed high performance soft magnetic core products for many applications within electrical installation technology and industrial automation. The company has developed soft magnetic cores for current transformers, based on nanocrystalline alloys, over a number of years. Additionally, MAGNETEC is pursuing new technologies and applications in the renewable energy sector (photovoltaic and wind energy) and specializing in inductive components for EMC applications.

www.magnetec.de.irf.com





# Power-Grid Monitoring Systems

## *High-performance simultaneous-sampling ADCs collect sensor signals*

*Many advanced industrial applications use high-performance multichannel data acquisition systems (DASs) to manage real-time information from precision industrial sensors. These complex systems require the use of high-performance, simultaneous-sampling, multichannel ADCs.*

*By Joseph Shtargot, Strategic Applications Engineer, Maxim Integrated Products Inc., Sunnyvale, California*

Consider an advanced three-phase power-line monitoring/measurement system shown in Figure 1. Such a system requires accurate simultaneous, multichannel measurement over a wide dynamic range – up to 90dB (depending on the application) – at a typical sample rate of up to 64k samples/s. To optimize system precision, signals from the sensors (CT and PT transformers in Figure 1) should be properly conditioned to meet the ADC's input ranges and ensure that the DAS's characteristics will enable measurements that comply with international standards.

### Role of the SAR ADCs in an industrial DAS

As Figure 1 illustrates, devices such as the MAX11046, MAX1320, or MAX1308 (or similar devices from other vendors) simultaneously measure the three phases and a neutral (voltages and currents). Each of these ADCs is based on a successive-approximation-register (SAR) architecture. These ADCs offer both a fast conversion time (up to 250ksps per channel for up to 8 channels) that allows the system to perform instantaneous measurements, and flexible input interfaces of ±10V, ±

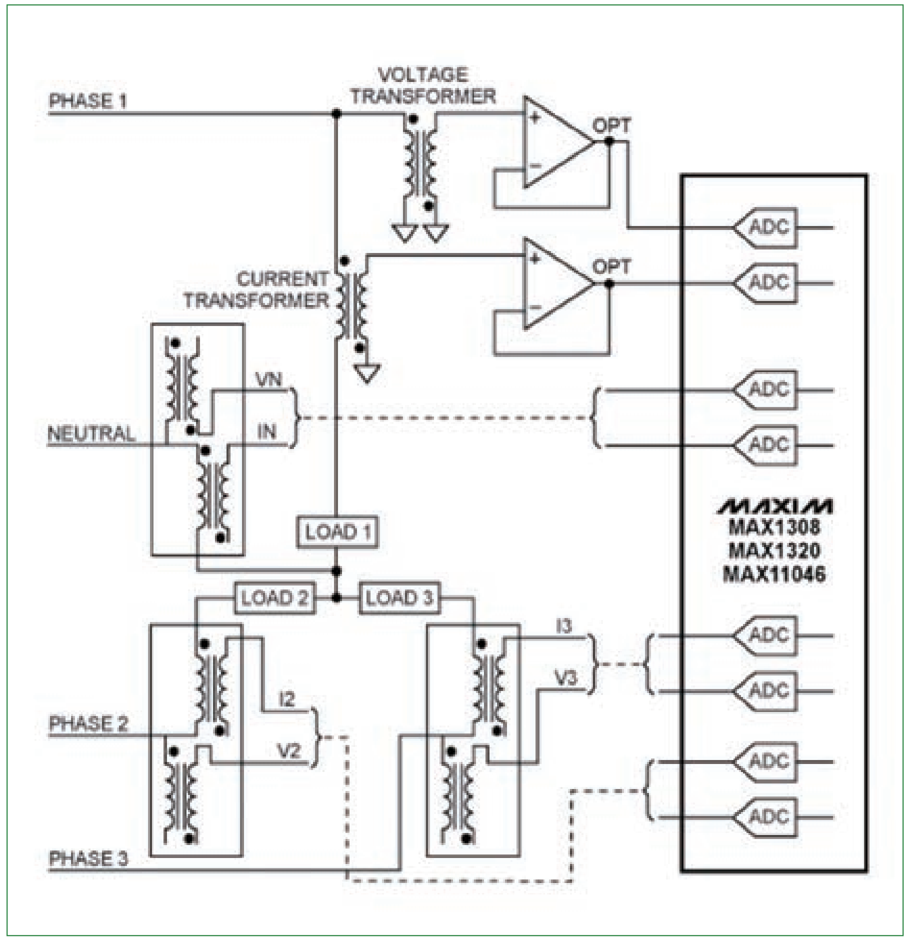



*Figure 1: Typical power-grid monitoring application for a MAX11046-, MAX1320-, MAX1308-based DAS*

Special Report - Supplying the Power Grid

*Table 1: Important typical characteristics of high-performance multichannel SAR ADCs*

| Part | Channels | Input Range - (V) | Resolution (Bits) | Speed (ksps, max) | SINAD (dB) | Input Impedance |
|---|---|---|---|---|---|---|
| MAX1304 | | 0 to 5 | | | | |
| MAX1308 | | ±5 | 12 | 456 | 71 | |
| MAX1312 | | ±10 | | | | Medium, |
| MAX1316 | 8 | 0 to 5 | | | | (approx.2kΩ) |
| MAX1320 | | ±5 | 14 | 250 | 76.5 | |
| MAX1324 | | ±10 | | | | |
| MAX11046 | | ±5 | 16 | 250 | 91.4 | Very high (in 10s of MΩ); mostly capacitive |

5V, or 0 to 5V to meet multiple application requirements. Some key typical characteristics of Maxim's SAR ADC families are shown in Table 1; competitive solutions from other vendors offer similar characteristics.

Typically, the outputs of the CT and PT (sensor) transformers are ±10VP-P or ±5VP-P. As Table 1 shows, the MAX130x and MAX132x ADCs cover these ranges well. The MAX11046's input range covers only one of the transformers' popular input ranges, ±5V.

The MAX130x and MAX132x ADCs have relatively low-impedance input circuitry. Consequently, for a power-grid monitoring system, these devices require an input buffer and low-pass filter (Figure 2a) to achieve 12-bit to 14-bit accuracy.

Active low-pass filters are required to interface to CT and PT transformers. An active-input buffer/low-pass filter is optional for MAX11046. The very high input-impedance values of the MAX11046 devices allow direct connection to specific sensors (see Table 1). The CT and PT measurement transformers, for example, represent relatively low-impedance sensors (i.e., effective impedance, RTRANS, is in the order of 10Ω to 100Ω) and, therefore, could be connected directly to the MAX11046 inputs using a simple RC analog front-end (AFE). If the 50Hz/60Hz signal in the measurement

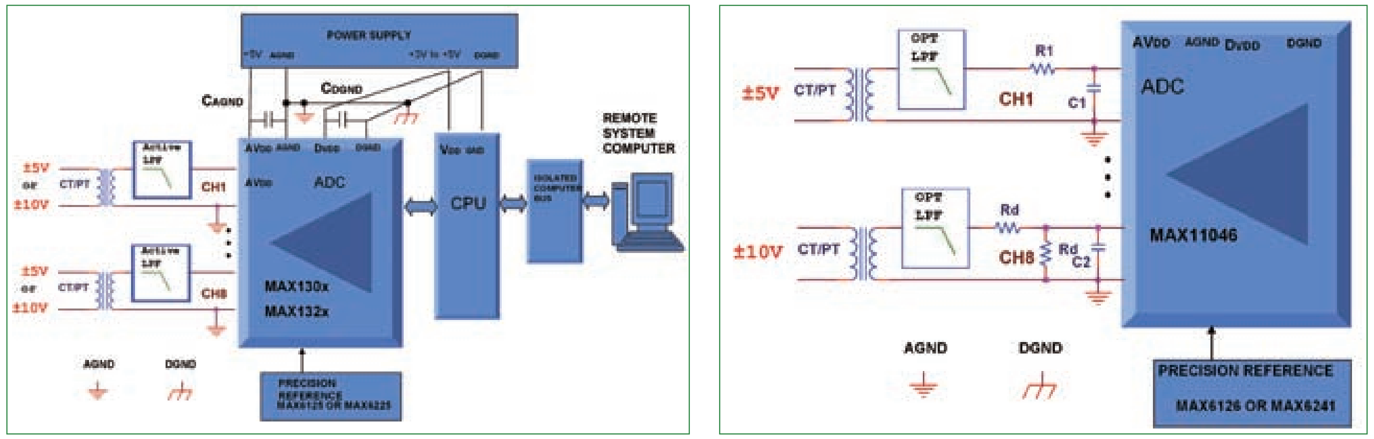



*Figure 2: Board-level block diagram of a typical power-line monitoring application using the MAX130x and MAX132x families (a). Changes in the front end for an application using the MAX11046. A ±5V transformer interface is used for channel 1 and ±10V interface is set up for channel 8 (b)*

*Table 2: Effect of the resistance values on the gain error*

| $R_{TRANS}$ (Ω) | Rd (Ω) | Gain Error (%) | Resistor Tolerance (%) |
|---|---|---|---|
| 50 | 20000 | 0.12 | 0.05 |
| 50 | 15000 | 0.17 | 0.05 |
| 50 | 10000 | 0.25 | 0.10 |
| 50 | 6980 | 0.36 | 0.10 |
| 50 | 4990 | 0.50 | 0.10 |

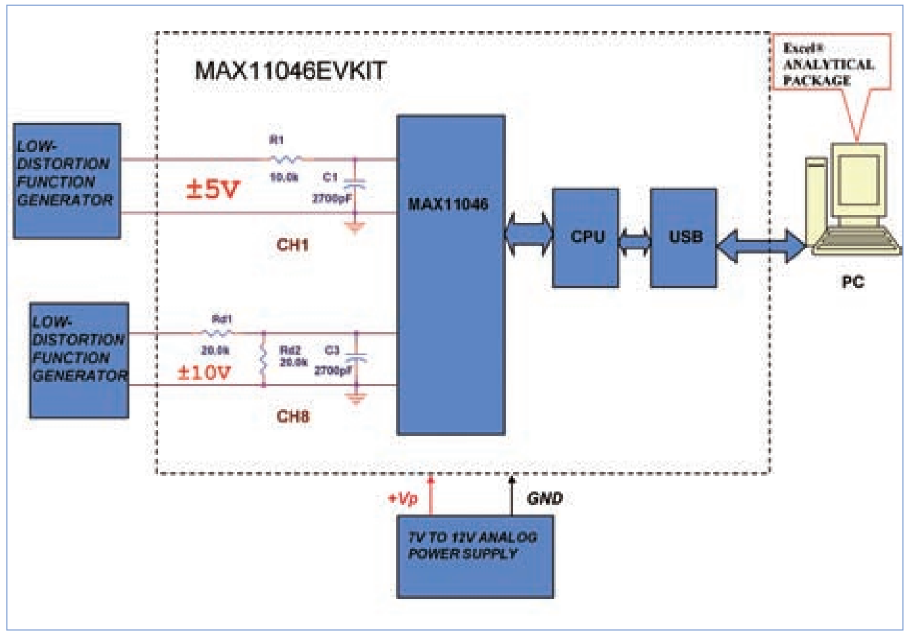



*Figure 3: Block diagram of a MAX11046 EVKIT-based development system shows that precision measurement can be accomplished using a minimal number of additional components. Measurement results are transferred though the USB port to a PC and are converted to Excel® files for further processing*

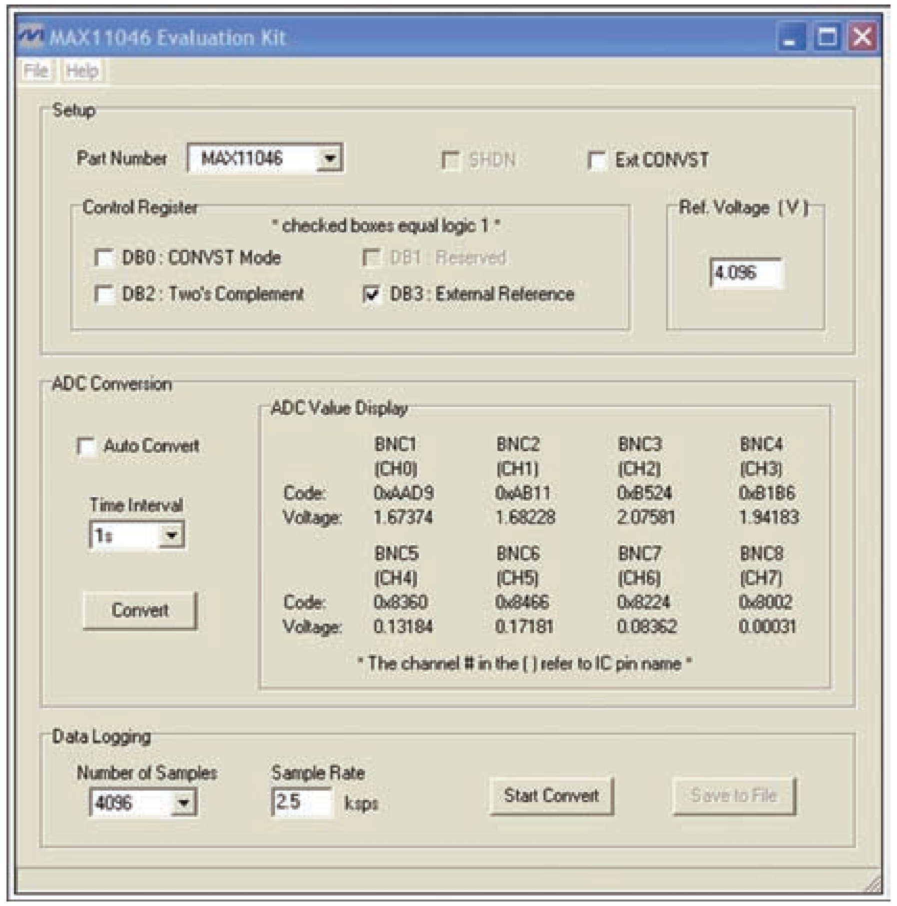



*Figure 4: The MAX11046EVKIT's GUI allows the designer to conveniently set various measurement conditions, in this case 2.5ksps and 4096 samples*

bandwidth has low levels of aliasing interferences, then a filter created by an input RC circuit can suffice.

A simple and cost-effective approach to accommodate ±5V or ±10V ranges for the MAX11046 is shown in Figure 2b. Let's examine the input circuit in Figure 2b. You should pay special attention when selecting the values for R1, C1, Rd and C2. The 1:1 ratio resistive divider (Rd1 = Rd2 = Rd) represents a load for the PT and CT transformers, which will cause gain error. This gain error can be calculated using Equation 1:

Gain error % = (1 - 2 × Rd/(2 × Rd + RTRANS)) × 100 (Eq. 1)

Where:
Rd is the divider impedance;
RTRANS is the transfer impedance;

The effects of the resistance values on the gain error are shown in Table 2.

Data from Table 2 demonstrate that to maintain low gain error, the designer must use precision resistors. The resistors should be metal-film type, have the tolerances defined in Table 2, and offer a low temperature coefficient (tempco). It is preferable for the designer to acquire components from reputable sources like Tyco or Vishay. An elegant resistor-divider solution can be implemented using the MAX5491 which consists of two accurately matched resistors connected in series with a center-tap connection in a single package.

The resistors in the MAX5491 have an extremely low resistance-ratio temperature drift of 2ppm/°C over -40°C to +85°C and an end-to-end resistance of 30kΩ, which yields and maintains a 0.17% gain error (see Table 2).

To demonstrate this, a MAX11046 evaluation (EV) kit, which offers a fully-functional 8-channel DAS can help designers expedite development and verify circuit performance of the solution suggested in Figure 2b. Measurements performed on the MAX-

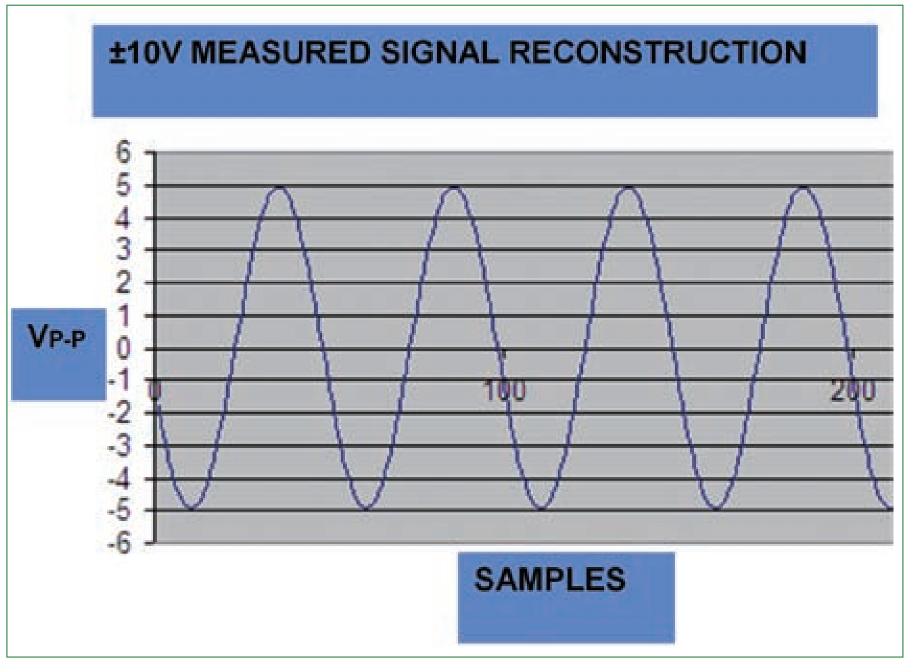



*Figure 5: Simulated with Excel software, these oscilloscope images show the reconstructed conditioned (divided and filtered) ±10V input signal from a function generator (see schematic in Figure 3)*

*Table 3: Measured parameters from data gathered for the Figure 3 circuit*

| Generator | Measured Parameters from Processed Excel Files | | | |
|---|---|---|---|---|
| Signal | RMS (gen, | RMS(meas) | RMS Error | Req |
| ($V_{P-P}$) | $V_{RMS}$) | $V_{RMS}$) | (%) | (%) |
| Channel 1, ±4.950 | 3.50018 | 3.49704 | 0.08961 | 0.20 |
| Channel 8, ±9.900 | 7.00036 | 3.49695 | 0.09227 | 0.20 |

11046EVKIT development system are shown in Figure 3.

In Figure 3 the ±5V signals from a function generator are connected to the MAX11046's channel 1 input by R1 and C1. The values of R1 and C1 must meet the ADC's acquisition time requirements and can be derived from Equation 2:

R1MAX = (1/FSAMPLE - TCONV)/ k(C1 + CSAMPLE) (Eq. 2)

Where:
R1MAX is the maximum source impedance; FSAMPLE is the sample rate; TCONV is the ADC's conversion time (e.g., 3µs for the MAX11046); K is the number of RC time constants needed to meet the ADC's required resolution (i.e., 12 time constants for a 16-bit ADC); and CSAMPLE is the internal sample capacitor (e.g., around 20pF for the MAX11046).

From Equation 2, R1MAX is around 12.1kΩ at 2.5ksps and C1 = 2700pF. Therefore, the selected value of R1 = 10kΩ is within the design limits. The value of C1 = 2700pF is more than 100 times larger than CSAMPLE and, therefore, supplies more than sufficient charge to the internal sampling capacitor. The ±10V signals from the function generator in Figure 4 are connected to the MAX11046's input channel 8 by the Rd divider and C2. Rd = 20kΩ and, therefore, according Table 2 should provide gain error around 0.12%. This performance meets the standard 0.2% accuracy measurement mandated by the popular European Union (EU) standard IEC 62053 for precision energy-metering equipment.

The EV kit settings used for the above measurements are shown Figure 4.

Results of the precision measurement using the settings required for the circuit in Figure 3 are shown in Table 3.

From Table 3, the measured RMS (meas) represents the measured and processed results of the generator's input RMS (gen). Results confirm that the measured RMS error of the conditioned circuits is approximately 0.09%, which comfortably meets the EU standard IEC 62053 precision requirement of 0.2% for energy-metering equipment.

**Conclusion**

High-performance multichannel, simultaneous-sampling ADCs like the MAX130x, MAX132x, and MAX11046 devices are especially useful in new DAS industrial applications. With properly selected signal conditioning, an interface circuit can exceed the EU standard requirements and advanced specifications for "smart" power-grid monitoring systems.

For additional reading, see Maxim application notes, AN4639 and AN4595

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# Global Companies Expand Power Electronics R&D To Develop Grid Technologies And More

*By David G. Morrison, Editor, How2Power.com*

As the world struggles to meet growing demands for energy in environmentally and economically responsible ways, we're witnessing a global effort to harness renewable energy sources, and to use all existing sources of energy more efficiently. These efforts are driving the development of renewable energy systems that connect to the electric power grid, as well as a variety of smart grid technologies that will more efficiently control the distribution of electrical energy. Power electronics (PE) plays a critical role in both renewable energy systems and in emerging smart grid technologies such as high-voltage dc (HVDC) transmission systems and flexible ac transmission systems (FACTS).

At present, there are numerous openings for PE engineers at the companies who produce these types of equipment. The tables that accompany the online version of this article list many of the recent PE job postings at global companies such as General Electric (GE), Siemens, and ABB, which are deeply involved in energy-related businesses.

It's intriguing to see the large number of postings for PE engineering positions related to renewable energy and smart grid technologies. But perhaps equally important to potential job applicants is the fact that these companies also have numerous other openings for PE engineers in traditional energy-related businesses like oil and gas, as well as other businesses such as industrial automation, transportation, and aviation.

Naturally, this diversity of application areas requiring power electronics expertise means more opportunities overall for PE engineers. However, it also means that some PE specialists who work at the research and development level will find themselves developing power conversion technologies for a wide range of applications that include, but aren't limited to renewable energy and the smart grid.

This broad scope influences the types of candidates that are sought to work in power electronics R&D, their roles within their companies, and the ways these companies recruit PE engineers to develop new technologies for the power grid. Recently I spoke with leaders of the power electronics R&D groups at GE and Siemens, who shared some insights on these issues.

**Addressing Diverse Power Requirements**

Juan de Bedout is the Global Technology Leader for the power conversion group within GE's Global Research Center (GRC), which is based in Niskayuna, New York, but also has operations in Munich, Shanghai, and Bangalore with additional sites planned in Detroit and Brazil. In this role, de Bedout runs all of the engineering laboratories that develop advanced technology in electric power for GE's infrastructure businesses.

The GRC is separate from the company's infrastructure businesses, which include GE's Energy, Oil and Gas, Aviation, Healthcare, and Transportation businesses. This is worth noting because those businesses, while they are supported by the GRC's power electronics team, also have their own power electronics engineers.

By itself, GE Energy includes a broad portfolio of power generation and energy delivery technologies. These include wind and solar power, gas and steam turbines, nuclear power, and smart controls and communications technologies that span the grid from generation through end use. For a variety of reasons, the demand for power electronics expertise is growing across all of the company's infrastructure businesses.

Although PE engineers in the GRC work collaboratively with their counterparts in these infrastructure businesses, the nature of their work is different.

"For example, someone within the energy business that's hired for power electronics may dedicate themselves to either wind energy or solar energy," says de Bedout. "But at the research center someone who's hired for power electronics could find themselves working one year on wind turbines, another on a healthcare MRI scanner power supply, and a third year on transportation traction drive systems. So engineers at the research center have to be more flexible in terms of their skills, but with this comes the opportunity to apply and grow these skills for a variety of applications."

According to de Bedout, within the businesses, the company is looking for engineers with a fundamental understanding of power electronics plus a good understanding of manufacturing processes, controls, software, and simulation. These engineers can be recent graduates, but preferably enter the company with prior industry experience. For these positions, the tendency is to hire engineers with masters degrees in power electronics.

However, at the research center, the PE engineering positions require "a much stronger foundation in mathematics. We do a lot of work here conceptualizing next-generation power converters. And there's a strong need for a very good controls background, very good modeling and simulation background, and dynamic systems background," says de Bedout. As a result, the research center tends to hire more PhDs.

## A Global Approach to Recruiting

The biggest challenge for de Bedout is not finding power electronics engineers with a particular skill set—such as controls, thermal management, or packaging—all skills are needed. Rather, the difficulty is in meeting the growing overall demand for PE engineers, particularly in the U.S. That is at least part of the reason why half of GRC's ten power electronics labs are located outside the U.S. In countries such as Germany and China, there are more PE engineers available, says de Bedout.

"Within the United States, it's very difficult to find the applicants that we need. If I look at the few universities that have good power electronics programs, they're not producing enough in terms of our needs. We'd like to see more programs throughout the country focusing on power electronics," says de Bedout. "When I go to the universities to recruit, I'm always on point, saying 'If you want good job security going forward, work in power electronics and develop some capability there because you'll have a job with a company like GE or many others."

## Serving Multiple Roles in the Organization

Siemens is another company with requirements for power electronics engineers that cut across a number of markets including energy, industrial drives (automation), healthcare, and security. Madhav Manjrekar, heads the power electronics team within Siemens' research and development center, which is based in Princeton, New Jersey. His group consists of engineers specialized in power electronics, power conversion, and power systems, as well as several energy-related application areas such as power converters for photovoltaic and wind power systems.

The applications also include various forms of connected energy storage such as stationary energy storage and mobile energy storage (for example, electric vehicles). Another important application area for this R&D group is smart-grid communications systems such as those using synchrophaser technologies and charging stations for electric vehicle applications.

Siemens currently has job postings related to power electronics engineering positions across the company. One of these positions is in the R&D group in Princeton, New Jersey.

The power electronics R&D group supports other organizations within the company such as Siemens' Energy Sector and Industry Sector businesses. Some of the grid-related technologies such as smart grid cut across both these sectors since Siemens' work in Smart Grid involves all aspects of the technology, including communications, power electronics, and demand response.

Engineers in Siemens' power electronics R&D are focused on specific engineering tasks, but are also expected to serve in another capacity as technology leaders within the company. Learning how to accomplish both roles is something that the company expects to teach new hires. Using photovoltaic inverters as an example, Manjrekar makes this point.

"There are projects where we are designing and actually implementing a photovoltaic power converter one day and the next day we are participating in a senior management team meeting where we are the experts discussing what's on the technology horizon for photovoltaic power converters. We have to look beyond 5 years or 10 years and try to understand where the technology is headed."

"What we would expect to share with the new hire is basically how to put on these different hats," says Manjrekar.

## Seeking Well-Rounded Applicants

For Manjrekar, the challenge is not so much finding enough candidates with power electronics engineering background, but rather finding the right candidates.

"Basically, there are several engineers coming from very good schools with the background that we are looking for. But in addition to the technology background and the university background, we are looking for someone who has practiced this technology," says Manjrekar. For example, the candidate who has studied photovoltaic power converter technology in a university, would be expected to have designed and implemented a PV power converter at some power level, if not commercially, at least on a laboratory scale.

In addition to recruiting recent graduates from power electronics programs, Siemens also seeks candidates with several years of industry experience.

For potential job candidates, having a degree from a power electronics engineering program provides them with essential preparation for positions within Siemens' power electronics R&D team. However, Manjrekar stresses it's important for candidates to also have a technically well-rounded background.

"Power systems are very eclectic," says Manjrekar. "Of course, power electronics would be the core of these systems. But this area migrates into communications technology, IT, controls, and embedded controls. It even migrates into applied math and sometimes pure math as well. So rather than putting the walls around and saying, 'I'm just going to do power electronics and I'm just going to be involved with pulse width modulation' I would definitely recommend that potential applicants expose themselves to as many different aspects of power systems as possible."

## About the Author

David G. Morrison is the editor of How2Power.com, a site designed to speed your search for power supply design information. Morrison is also the editor of How2Power Today, a free monthly newsletter presenting design techniques for power conversion, new power components, and career opportunities in power electronics. Subscribe to the newsletter by visiting

www.how2power.com/newsletters.

# Power Grid Overhaul

*Reported by Cliff Keys, Editor-in-Chief, PSDE*

An increasing number of governments and authorities in Europe have embarked on programs to expand and update their aging electricity systems by developing and deploying smart grid technologies - with hard funding pledged from some to accelerate the process.

European energy leaders join forces with their worldwide counterparts to participate in the GridWise® Global Forum, in Washington, DC. The GridWise Alliance is a coalition of public and private stakeholders advocating a smarter grid for the public good, in partnership with the U.S. Department of Energy and business and government leaders from 19 countries.

Smart Grid deployment requirements are boosting research, effort and development into PLC (power line communications) modems. With more than 200 million smart meters to be utilized in Europe alone, electricity meter manufacturers are looking for cost effective, reliable and flexible communication solutions for the move to smart electricity meters. These smart E-meters are capable of two-way communication outside of the home back to the utilities, and inside the home to monitor devices such as thermostats, in-home displays and smart appliances.

**PV Inverter Shipments Hit 5 GW in Q2'10**

Solar inverter shipments reached 4.9GW in Q2'10, growing by 2.8x according to IMS Research. More than half of these shipments were for installations in Germany, which grew by 3.9x in Q2, driving total shipments up to more than 8GW for the first six months of 2010 – a three-fold increase over the same period last year.

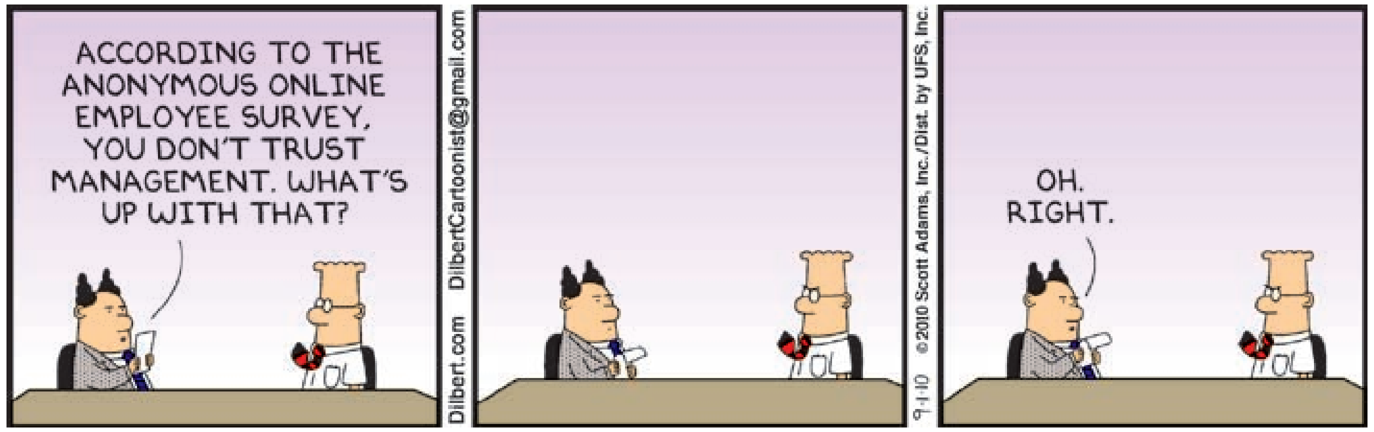
EMEA accounted for around 90% of inverter shipments in Q2'10, growing by more than 3x over the previous year; further, but also of note, the Americas market has doubled in size. Indeed, all regions recorded impressive growth, generating around €1.5 billion in revenues for inverter suppliers. The inverter shipments of more than 8GW in H1'10 were similar to shipments for the whole of 2009.

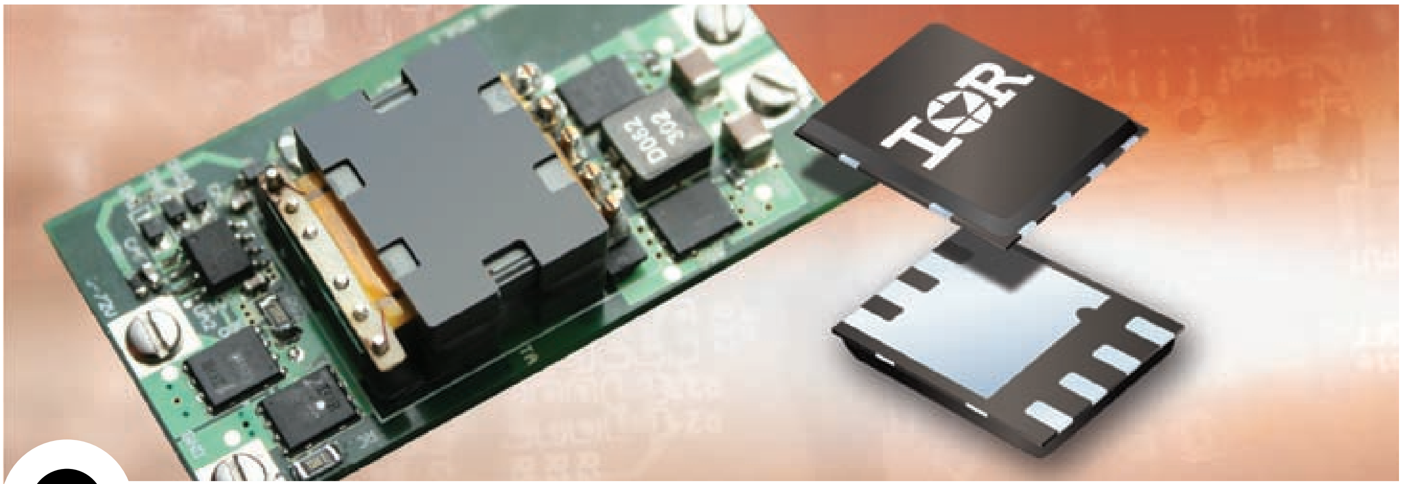
Shipments of 8GW in the first six months of the year appear to support the prediction of close to 15GW of new PV installations in 2010; with Q3 and Q4 both expected to be strong quarters for suppliers.

Whilst MW shipments grew by 2.8x in Q2, revenues only grew by 1.65x due to a 30% fall in inverter prices. Despite extraordinarily high demand amidst tight supply, inverter prices fell for the fifth consecutive quarter in Q2'10. Much of this can be attributed to a continuing shift towards larger inverters, which have an inherently lower price per Watt.

One thing is quite clear; there is a desire, funding availability, the technology, and certainly the vital engineering skill in our power community to implement a new, more efficient energy system. It will of course, not happen overnight, but engineering in all its forms will play the pivotal role in making it happen.

www.powersystemsdesign.com/greenpage.htm





# Introducing 40 V – 250 V MOSFETs in High Current Package

## Offering Optimized Performance and Cost for a Given Application

**Standard Gate Drive**

| Part Number | Package | Voltage | Current | $R_{DS(on)}$ Max. @10V | $Q_G$ Typ @10V |
|---|---|---|---|---|---|
| IRFH5004TRPBF | PQFN 5x6mm | 40 V | 100A | 2.6 mΩ | 73 nC |
| IRFH5006TRPBF | PQFN 5x6mm | 60 V | 100A | 4.1 mΩ | 67 nC |
| IRFH5106TRPBF | PQFN 5x6mm | 60 V | 100A | 5.6 mΩ | 50 nC |
| IRFH5206TRPBF | PQFN 5x6mm | 60 V | 98A | 6.7 mΩ | 40 nC |
| IRFH5406TRPBF | PQFN 5x6mm | 60 V | 40A | 14.4 mΩ | 23 nC |
| IRFH5007TRPBF | PQFN 5x6mm | 75 V | 100A | 5.9 mΩ | 65 nC |
| IRFH5207TRPBF | PQFN 5x6mm | 75 V | 71A | 9.6 mΩ | 39 nC |
| IRFH5010TRPBF | PQFN 5x6mm | 100 V | 100A | 9.0 mΩ | 65 nC |
| IRFH5110TRPBF | PQFN 5x6mm | 100 V | 63A | 12.4 mΩ | 48 nC |
| IRFH5210TRPBF | PQFN 5x6mm | 100 V | 55A | 14.9 mΩ | 39 nC |
| IRFH5015TRPBF | PQFN 5x6mm | 150 V | 56A | 31 mΩ | 33 nC |
| IRFH5020TRPBF | PQFN 5x6mm | 200 V | 41A | 59 mΩ | 36 nC |
| IRFH5025TRPBF | PQFN 5x6mm | 250 V | 32A | 100 mΩ | 37 nC |

**Logic Level Gate Drive**

| Part Number | Package | Voltage | Current | $R_{DS(on)}$ Max. @4.5V | $Q_G$ Typ @4.5V |
|---|---|---|---|---|---|
| IRLH5034TRPBF | PQFN 5x6mm | 40 V | 100A | 2.4 mΩ | 43 nC |
| IRLH5036TRPBF | PQFN 5x6mm | 60 V | 100A | 4.4 mΩ | 44 nC |
| IRLH5030TRPBF | PQFN 5x6mm | 100 V | 100A | 9.0 mΩ | 44 nC |

**Features**

- Low thermal resistance to PCB (down to <0.5°C/W)
- High Current Package – up to 100A continuous
- 100% RG tested
- Low profile (<0.9 mm)
- Industry-standard pinout
- Compatible with existing surface mount techniques
- RoHS compliant containing no lead, no bromide and no halogen
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