White Paper

Simplifying Advanced Power Systems Design

Digital power is one of the most important technologies available today to reduce power consumption and also manage the growing power complexity in modern electronic systems in information and communications technology markets and in today's smart handheld or portable consumer electronics products. Digital power management and control provide real-time intelligence that enables system developers to build power systems that automatically adapt to their environment and optimize efficiency. The use of intelligent digital power ICs means automatic compensation for changes in load and system temperature, enabling energy savings with adaptive dead-time control, dynamic voltage scaling, frequency shifting, phase dropping and discontinuous switching modes.

The power supply's ability to enable these modes to optimize system efficiency is especially important, especially when energy consumption is reaching increasing levels of sensitivity worldwide. Key aspects of power management include voltage and current monitoring, voltage sequencing, voltage tracking, fault detection and fault management. Additionally, thermal management includes monitoring temperature throughout a system and responding to conditions by controlling fans or shutting down parts of the system. Also important is integrating the power and thermal management with the power conversion, thereby removing the need for further power and thermal management ICs.

Market

According to market analyst IMS Research[1], the digital power market is currently one of the fastest-growing segments of the power management industry. The global markets for digital power supplies and digital power ICs are projected to boom from 2013 to 2017 with increasing use in IT infrastructure and further expansion into markets such as lighting and consumer applications. In particular, the server market is the largest for digital power supplies and is predicted to grow at a compound annual growth rate (CAGR) of 44.8 percent from 2012 to 2017. And markets that currently account for considerably smaller shares, such as lighting along with notebooks and tablets, are predicted to grow even faster at 126, 92 and 88 percent, respectively, over the same period. Rapid growth for digital power ICs is, therefore, expected from this potential in digital power supplies, and this does not include the significant market for their deployment in equipment at the board level. The analyst forecasts digital power IC revenues to increase by more than five times from 2013 to reach $2.6 billion in 2017.

One obstacle to the rapid adoption of digital power has been its perceived expense, but this is fast becoming a myth. Digital power efficiency and cost is now equaling or bettering comparable analog power-conversion solutions. However, power conversion is only part of the overall solution. Having the digital controller in a highly integrated mixed-signal silicon technology process allows the integration of power management with power conversion. There are significant performance, cost and space benefits made possible by this high level of integration. A digital power solution differs from an analog solution in a number of ways. Most importantly, the pulse width modulation (PWM), loop control and feedback are implemented digitally. Analog signals are converted to digital using analog-to-digital converters (ADCs) and once the signals are digital, microcontrollers, digital-signal processors or computational state machines control the digital PWM and the feedback loop.

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[1] *'The World Market for Digital Power', IMS Research (now part of IHS), 2013*

For the most part, the early adopters of digital power have been in IT infrastructure markets, such as servers and telecommunications or data-communications equipment, although analog-based power-management systems still occupy an enviable share in the market at present. However, increasing number of equipment makers are migrating to digital technology because of its flexibility and programmability, delivering overall increased performance and reliability.

Design Flexibility of Digital Power

An increasingly complex yet reliable power distribution system will need many voltage rails, which are required to sequence or track other rails to properly bias microprocessors, microcontrollers, ASICs, FPGAs and any other digital logic ICs that are present in the system and will likely require differing voltages for operation. As a product design moves through various phases, changes in the design can occur including the addition of a power rail, more current on a rail, or the requirement for a tighter transient response. Normally, this would require the redesign of the power distribution, whereas a digital power solution is flexible and can adapt with changing requirements. A new voltage rail can easily be added to the power-management system using the industry-standard System Management Bus (SMBus). The digital power ICs communicate with each other via the SMBus using the Power Management Bus (PMBus) protocol, the standard protocol for communicating with power conversion systems using a digital communications bus. Using PMBus and PMBus-enabled devices for power conversion provides flexibility and control that is not possible with traditional analog power systems. Adding a new rail is integrated into the monitoring, sequencing, margining and fault detection schemes. The digital power IC for the new rail is provided with its own SMBus address and is added to the system and there is no need to reprogram or add more stand-alone power-management ICs because of the additional voltage rail.

In addition, for system monitoring, a digital power solution provides multiple methods of reacting to a fault. Over-current and under-current, over-voltage and under-voltage, and over-temperature faults and warning thresholds can be configured and adjusted throughout the lifecycle of the product. Digital power solutions can also reduce cost–the lower component count makes a more reliable and longer-lived system. Digital power enables designers to use the same device for each voltage rail and make changes to the operation of the device without having to make costly hardware changes. Digital power solutions can be more efficient by meeting increasing thermal demands, an increasingly common challenge as boards become denser and generate more heat.

Digital Power Heritage

The definition of digital power varies according to which silicon or power-conversion vendor is asked: some may consider it as having an analog-based control loop with a digital interface, simply adding digital power functionality via the PMBus; while others may implement a fully digital control loop in a microcontroller or digital signal processor solution. This latter solution comes with the inherent implication that the user may need to do a significant amount of software coding, in addition to which an MCU or DSP is not a power-centric product and does not address the element of managing the currents and voltages of a power supply.

The first Intersil digital power device was launched in 2005 by Zilker Labs, which was acquired by Intersil in early 2009. The ZL2005 was the industry’s first fully digital controller with PMBus interface. It implemented a traditional digital PID (proportional-integral-derivative) control loop along with a compact and efficient buck controller, high-current adaptive drivers and full power and thermal management functions in a single package. The device provided sequencing, telemetry read back and basic control of the device. However, the PMBus interface can be fairly slow and does not allow truly accurate sequencing due to delay times. The second-generation device, launched in 2008, added Zilker Labs’ patented Digital-DC™ (DDC) technology–a proprietary single-wire interface to overcome the limitations of the previous generation. The third generation controller delivered significantly better digital control, fully leveraging the digital capabilities of the device to make a better power supply. One of the biggest challenges in reducing design complexity in power systems is compensation and the third generation used auto-compensation to deliver self-stability.

Over three generations, the company has adapted each generation to meet customer demands and is now fully realizing the potential of digital power technology. The new ZL8800 represents the fourth-generation of Intersil's digital power platform and is now significantly surpassing the capabilities of analog control. A key problem with analog is engineers have to work within the 'poles and zeros' of the frequency domain to maintain device stability. The ZL8800 offers a fully digital compensation-free control loop – if an event occurs in a system and the output capacitance is changing dynamically, the device will continue to remain stable, while delivering a faster transient response than is achievable with an analog control loop. This advanced compensation loop technology, coupled with state-of-the-art silicon power IC design and an intuitive easy-to-use GUI-based software, delivers a complete system overview for power system architects and designers.

ZL8800 – Architecture and Power Management Overview

The ZL8800 is an innovative mixed-signal power conversion and power management IC. Based on Intersil Zilker Labs Digital-DC technology, the ZL8800 dual-channel dual-phase controller integrates a high-performance step-down converter for a wide variety of power supply applications. The device provides best-in-class transient response for digital Point of Load (POL) converters, saving on output capacitors and board space. Designed for use in advanced power systems found in the latest generation of base-stations, routers and other data-communications infrastructure designs, the device enables designers to fully control and monitor, via the PMBus interface, every power rail to maximize reliability, and use monitors and sequencers to provide added functionality around the POL converters. The use of Intersil's proprietary single-wire DDC (Digital-DC) serial bus also enables the ZL8800 to communicate between other Zilker Labs ICs. By using the DDC, the ZL8800 achieves complex functions such as inter-IC phase-current balancing, sequencing and fault spreading, eliminating complicated power supply managers with numerous external discrete components.

The ZL8800 is based on an architecture that enables fast transient response without the need for loop compensation. Adaptive algorithms enable the power converter to automatically change the operating state to increase efficiency and overall performance with no user interaction needed. The device's fully digital loop achieves precise control of the entire power conversion process with no software required resulting in a very flexible device that is also very easy to use. The chip's unique ChargeMode control algorithm is implemented to respond to output current changes within a single PWM switching cycle, achieving a smaller total output voltage variation with less output capacitance than traditional PWM controllers.

An extensive set of power management functions is fully integrated and can be configured using simple pin connections. The user configuration can be saved in internal non-volatile Flash memory. Additionally, allowing ultimate flexibility, all functions can be configured and monitored via the SMBus hardware interface using standard PMBus commands. Once enabled, the ZL8800 is immediately ready to regulate power and perform power management tasks with no programming required. Advanced configuration options and real-time configuration changes are available via PMBus commands if desired, and continuous monitoring of multiple operating parameters is possible with minimal interaction from a host controller. Integrated sub-regulation circuitry enables single supply operation from any power supply between 4.5V and 14V without the requirement for bias supplies.

Supporting output voltages from 0.54V to 5.5V, each ZL8800 output can operate independently or together in a dual-phase configuration for high current applications. The ZL8800 also incorporates a wide range of configurable power management features that are simple to implement with no external components. The integration of Low Drop-Out (LDO) regulators allows the ZL8800 to be operated from a single input supply eliminating the need for additional linear regulators. The LDO output can be used to power external drivers or DrMOS (Driver plus MOSFET) devices. Additionally, the ZL8800 includes circuit protection features that continuously safeguard the device and load from damage due to unexpected system faults. The ZL8800 can continuously monitor input voltage and current, output voltage and current, including cycle-by-cycle output overcurrent protection, internal temperature, and the temperature of two external thermal diodes. A Power Good output signal is also included to enable power-on reset functionality for an external processor. All power management functions can be configured using pin-configuration techniques or via the SMBus interface using PMBus commands. Monitoring parameters can also be pre-configured to provide alerts for specific conditions.

ZL8800 – ChargeMode Control Technology

The key element of the ZL8800 is the integration of the Company's proprietary digital modulation technology, called ChargeMode control. Today, a leading-edge digital controller designed for use in information and communications technology power supplies needs to meet three key requirements: it should support sufficiently high bandwidth; ideally it should be compensation free, or at the very least, a user should spend little to no amount of time compensating the control loop; and it should support fixed frequency switching. The ZL8800 achieves all of these with its unique digital modulator and compensation technique.

Fundamentally, the ZL8800 uses a digital modulation technology that allows the controller to react to voltage deviation in a single PWM switching cycle. ChargeMode control is digital voltage-mode control with the ability to achieve high bandwidth using the single cycle response technology. Traditionally, voltage- or current-mode hysteretic controllers have offered the best loop response, but these come with the drawback of switching with variable frequencies. Modern telecommunication equipment that uses digital power controllers requires fixed frequency operation, allowing tight control of the noise spectrum in end-user applications.

At the heart of ZL8800's ChargeMode control technology is its PWM modulator. The ZL8800 uses the flexibility of digital control to implement a modulator that corrects for voltage deviation within a single cycle, assuming that the slew rate of the inductor allows for such a correction. One switching cycle represents the smallest quantum of control in a PWM and thus represents the upper limit in terms of speed in responding to a transient.

Traditional digital PWM controllers are uniformly sampled, the controller samples error and compute the modulation signal once per switching cycle. The downside of uniformly sampled controller is the latency or group delay, which is a significant portion of the switching cycle. The group delay translates to phase lag, which increases with frequency and places an upper bound on the achievable closed-loop bandwidth. However, the ZL8800 uses a mixture of uniform and multi-rate sampling techniques, which samples the error and computes the modulation signal multiple times during a switching period. This technique significantly reduces group delay and therefore supports very high bandwidth operation. The phase lag is significantly reduced due to the reduction of group delay. The ZL8800 also uses a dual-edge modulator, which outperforms competitive and so-called 'leading-edge' modulators in terms of total group delay.

Figure 1 shows ZL8800's sampling technique. The total delay (t_{delay}) is the sum of ADC conversion delay and computation delay (including pipeline/filter delays). Figure 1 also clearly demonstrates the reduction of t_{delay} in the ZL8800 compared to a uniformly sampled PWM modulator.

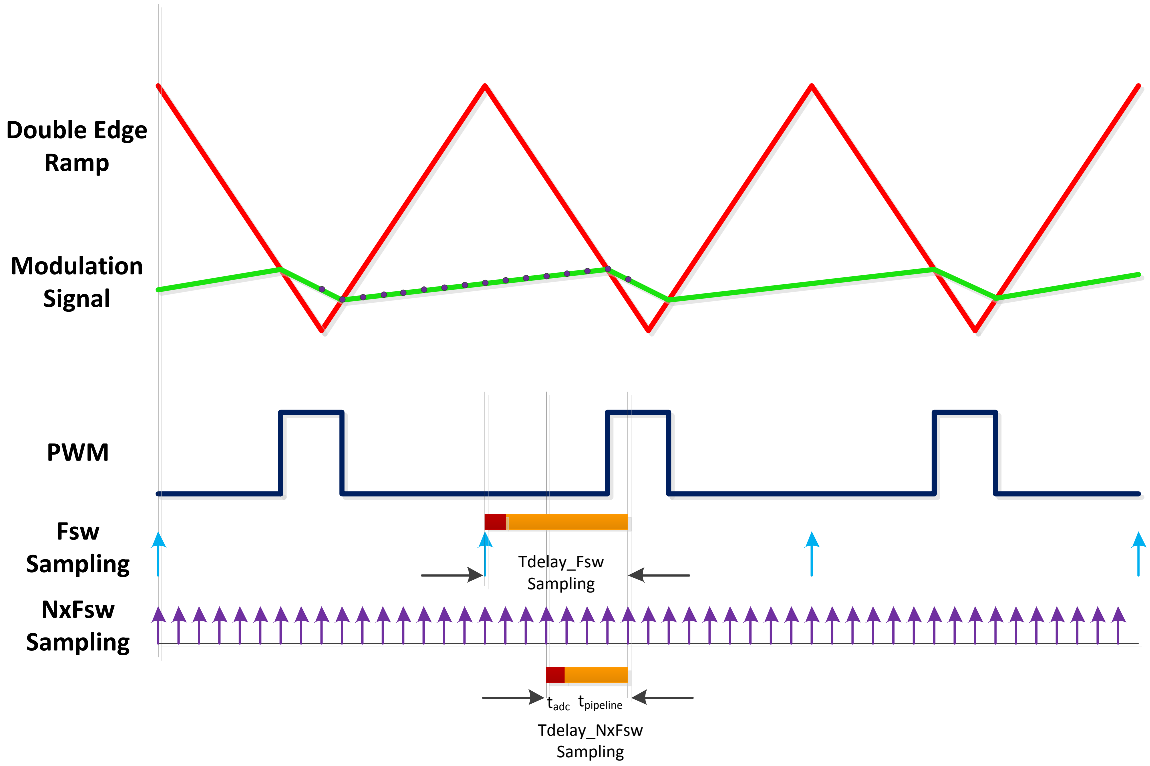

Figure 1 – ZL8800 Digital PWM Modulation

ZL8800 – ASCR (A Single Cycle Response) Digital Compensator

The ZL8800 digital compensator processes the quantized error signal and generates duty cycle command for the PWM modulator. The control loop is designed to react to a voltage deviation in a single cycle. This can be achieved by a proportionate gain that is linear to the error voltage deviation. Using only a proportionate gain it is possible to achieve single cycle reaction using fixed-frequency switching but it does not guarantee stability. The controller knows what is done to the duty cycle in one cycle and attempts to localize its effect to one or a few cycles. If the duty-cycle effect propagates to the next few cycles, then it may lead to the point of instability. What is done to the duty cycle within the ZL8800 to correct for a voltage deviation in one switching cycle is undone within the next switching cycle or next few cycles, hence ASCR (A Single Cycle Response).

The compensator block diagram, shown in Figure 2, has many similarities to a traditional digital PID (proportional-integral-derivative) controller, but it also has significant differences. The diagram indicates how the multi-rate sampling technique is integrated within the compensator. The compensator has two parallel paths for processing the quantized error voltage. One is called the ‘fast path,’ which samples error voltage more frequently than the ‘slow path.’ In this unique compensator structure, the duty cycle command is fed back to determine the effect of the fast path and to nullify the fast path effect in the following cycles.

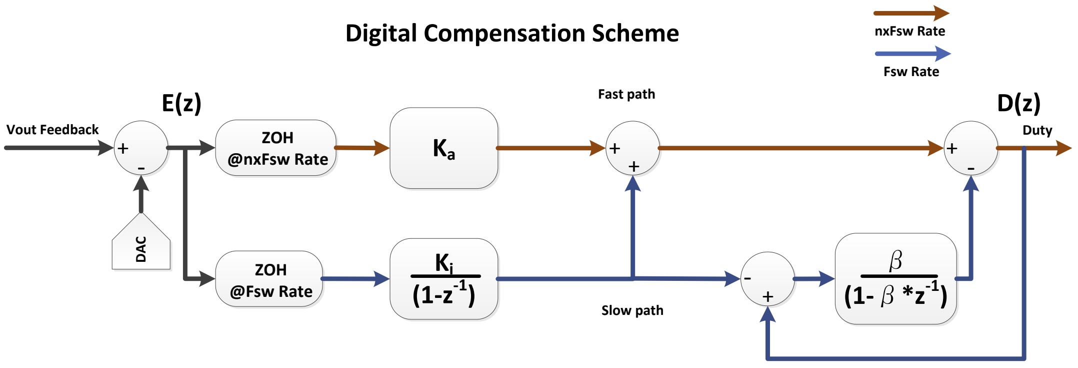

Figure 2 – ASCR Digital Compensator

The fast path consists of the proportional gain (ASCR gain) Ka, which samples the error and processes the duty cycle at NxFsw (N times the switching frequency rate). The slow path samples error at Fsw rate and processes duty cycle only once per switching cycle. The fast path responds to voltage deviation in proportion to the error voltage. The slow path consists of the Integrator function with Ki as its gain used for low frequency gain and duty cycle reset function with β as its gain. The duty cycle reset function nullifies the effect of the fast path during a transient event as it feeds back the duty cycle change due to fast path and also the steady state duty cycle from the integral function. The z-domain or frequency-domain transfer function is shown in Figure 3. The compensator simplifies down to a two-pole, two-zero filter, which enables the stability of the closed-loop system.

$$\mathbf{D}(\mathbf{z}) := \mathbf{E}(\mathbf{z})\cdot\mathbf{Ka} + \frac{\mathbf{E}(\mathbf{z})\cdot\mathbf{Ki}}{1 - \mathbf{z}^{-1}} - \left(\mathbf{D}(\mathbf{z}) - \mathbf{E}(\mathbf{z})\cdot\frac{\mathbf{Ki}}{1 - \mathbf{z}^{-1}}\right)\cdot\frac{\beta}{1 - \beta\cdot\mathbf{z}^{-1}}$$

Figure 3 – Digital Compensator z- domain

The ZL8800 compensator structure has reduced delays between the error sampling instant and the duty cycle decision. This translates to a natural phase boost at high frequencies, which brings stability and makes it possible for high-bandwidth designs (see Figure 4).

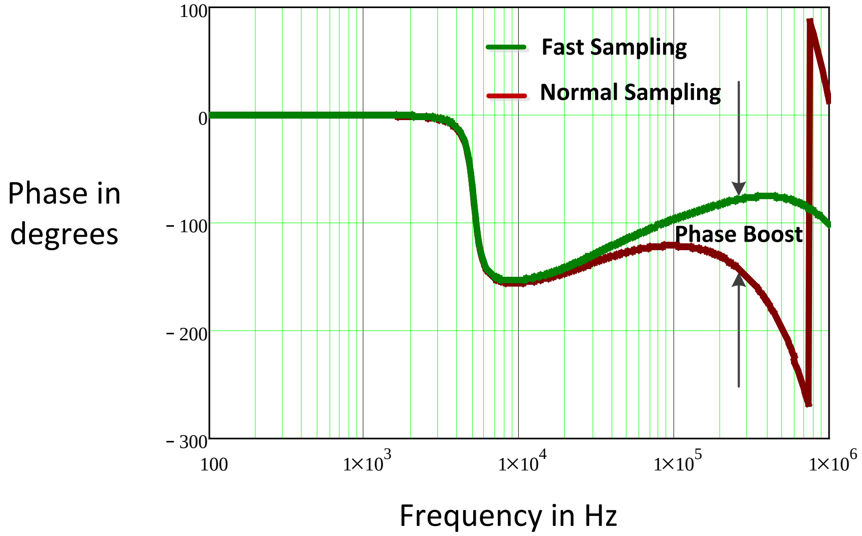

Figure 4 – Phase boost at high frequencies

Thus the ASCR compensator can achieve an inherently stable control loop, which only needs to be tuned for bandwidth specification. In a wide range of output filter configurations, only ASCR gain needs to be varied to reach the desired closed-loop bandwidth operation. In fact, there are actually two inputs to the ASCR block: gain setting and a residual. Gain sets up the overall transient response speed, whereas the residual is a dampening factor, essentially setting the response rate of the loop, which could be important to bring out the last ounce of performance. However, the ZL8800 default setting for the residual value will be suitable for most systems.

The major drawback of multi-rate sampling technique is the injection of switching frequency harmonics into the feedback loop due to over sampling of the error. In the ZL8800, a low-latency ripple filter is engaged in the fast path, so that all the repetitive elements of ripple are totally rejected. All that remains are the non-periodic elements in the waveform including transient steps with little or no delay, resulting in more than 20db of ripple reduction without a significant time delay allowing high gains and higher bandwidths.

PowerNavigator™ Software and Evaluation Boards

The remaining element that ties the Intersil approach together is the company’s PowerNavigator™ software. While some advanced power systems may require extensive programming and coding experience from users to set up the commands and functionality required to access the capabilities of digital power management devices, PowerNavigator enables the simple configuration and monitoring of multiple Intersil Digital-DC devices using a PC or Mac via the USB interface. The tool makes it easy to change all features and functions of a digital power supply design using a simple graphical user interface. Through simple drag-and-drop graphics users can simplify and create an entire power management environment without having to write a single line of code. In addition, and to help users become familiar with the ZL8800, two evaluation kits are available, the ZL8800-2CH-DEMO1Z two-output board and the ZL8800-2PH-DEMO1Z 60A two-phase demo board.

Digital Power Leadership

Building upon the heritage of Zilker Labs, the evolution of Intersil’s know-how in the development of power conversion architectures, power management logic and advanced auto-compensation techniques, together with its world-class mixed-signal silicon-integration capabilities, has culminated in the launch of the fourth-generation ZL8800 DC/DC controller. The device extends the company's cutting-edge Digital-DC digital power platform and further consolidates its technology leadership in this field. The ZL8800 simplifies life for power system designers, reducing the risk, cost and footprint of highly advanced power control and management solutions. Very simply, the ZL8800 makes digital power easy to use.

Next Steps

- Find out more about the ZL8800 digital power controller
- Get the ZL8800 datasheet
- Learn more about the ZL8800-2CH-DEMO1Z and ZL8800-2PH-DEMO1Z demo boards
- Download the PowerNavigator software
- Learn more about Renesas' digital power solutions
- Search for digital power parts using our parametric search

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