The Future of Digital Power

A vital tool in the power-architect's repertoire

It is important to make a distinction between digital power management and digital power conversion. The former involves a microprocessor or microcontroller which monitors output parameters through an analog to digital converter (ADC) and modifies the reference, outside the control loop, through a digital to analog converter (DAC). This is often referred to as "digital assist". Digital power conversion on the other hand involves a digital PWM comparison in the regulator control loop.

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Several concerns are driving the adoption of digital power conversion. Stringent energy-saving requirements for data-processing and networking equipment, deep submicron CMOS technology and the lifetime requirement for high-performance computing and networking systems. Conventional and digital implementations of current mode control are shown in figures 1 and 2 respectively.

Figure1: Analog current mode control.

Figure2: Digital current mode control.

In 2006, during Digital Power Forum, two speakers in a conference session made statements that revealed the different perspectives of end-customers and those designing switch mode power supplies. The power-supply architect stated that "digital technology had already been deployed in all applications where it was prudent to do so". By this he was referring to digital assist and applications such as uninterruptible power supplies, multi-chemistry battery chargers and motion control; applications where the load time constants permit digital PWM techniques at modest clock rates.

Next, the high-performance computing architect spoke. His plea was for a digital power solution that was not merely a clone of analog control but a true adaptive solution capable of performance outside the realm of conventional analog techniques. A review of the capabilities and limitations of digital and analog signal processing can be seen in Table 1.

Analog Signal Processing	Digital Signal Processing
Computes with continuous values of physical variables in some range, typically voltages between the lower and upper power-supply voltages.	Computes with discrete values of physical variables, typically the lower and upper power-supply voltages, denoted by 0 and 1, respectively.
Primitives of computation arise from the physics of the computing devices: physical relations of transistors, capacitors, resistors, floating-gate devices, Kirchhoff's current and voltage laws, and so forth. The use of these primitives is an art form and does not lend itself to automation. The amount of computation squeezed out of a single transistor is high.	Primitives of computation arise from the mathematics of Boolean logic: logical relations like AND, OR, NOT, NAND, and XOR. The use of these primitives is a science and lends itself to automation. The transistor is used as a switch, and the amount of computation squeezed out of a single transistor is low.
Computation is offset prone since it is sensitive to mismatches in the parameters of the physical devices. The degradation in performance is graceful.	Computation is not offset prone since it is insensitive to mismatches in the parameters of the physical devices. However, a single bit error can have significant impact.
Noise is due to thermal fluctuations in physical devices.	Noise is due to round-off error.
Signal is not restored at each stage of the computation.	Signal is restored to 1 or 0 at each stage of the computation.
In a cascade of analog stages, noise starts to accumulate. Thus, complex systems with many stages are difficult to build.	Round-off error does not accumulate significantly for many computations. Thus, complex systems with many stages are easy to build.

Table 1.

An adaptive control system is defined as a form of control system in which parameters may be changed dynamically in order to adapt to a changing environment. For instance: changing power-source characteristics, changing load current profiles, ageing of components and ongoing system reconfiguration or enhancement. One unique benefit of digital power control is the ability to simultaneously optimize DC and AC parameters, for instance output voltage line/load regulation and load transient response/settling time.

Furthermore, CMOS load process technology is moving to smaller and smaller feature sizes below the point at which the transistors are useful from the analog performance point of view. Below 90nm the non-ideal VI and poor sub-threshold characteristics of the transistors are such that the analog peripherals have bad matching, low gain and poor common mode rejection. These analog blocks, particularly those in clock synthesis and recovery circuits are now very sensitive to supply voltage noise transients to the extent that supply voltage spikes or sags of the order of 10 to 20 mV cause spurious reset and data loss. In a deep-submicron CMOS process, time-domain resolution of a digital signal edge transition is superior to voltage resolution of an analog signal Consequently, the time will come when digital control and regulation is the only acceptable solution for certain types of load, specifically loads at the forefront of the inexorable reduction in feature size predicted by Moore's Law.

Efficiency is a key consideration, as advisory standards become legislation worldwide. Digital control can improve powertrain efficiency particularly in multiphase regulators for high current loads. The load current versus efficiency curve may be broadened and flattened by shedding phases at light loads and optimizing dead time for the full input voltage and load current range.

On the well-designed digitally controlled regulator an efficiency improvement of up to 2% is possible over the full load range. Bear in mind that the load current versus efficiency curve has three notable characteristics: a peak at the point of maximum efficiency, usually a duty ratio selected by the designer; a roll-off at light currents due to the effect of switching losses and the ratio of operating and drive power to load power and a decline after the peak at high loads due to resistances in the powertrain. Figure 3 shows the generic load current versus efficiency curve for a buck regulator with the characteristics identified.

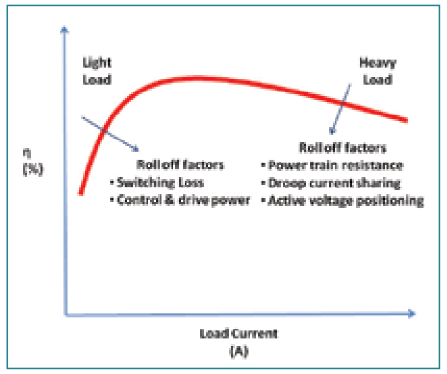

Figure3: Generic buck regulator efficiency characteristic.

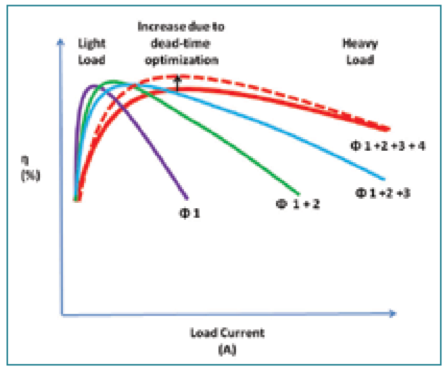

Figure4: Impact of load shedding & dead time optimization.

Figure 4 illustrates the impact of load shedding and dead time optimization. More dramatic efficiency improvements up to 30% may be achieved through a combination of power-saving techniques in the load with those in its power supply. Smart computing algorithms, adaptive supply voltage positioning, substrate biasing, internal supply and clock gating may all be used to good effect linked with the increasing sophistication that digital regulator control brings. As there is such compelling evidence in favor of the digital regulation of power supplies why have these techniques not been adopted so readily? One reason is that many power-supply designers are not completely familiar with digital techniques and terminology. Added to that challenge is the expectation on the part of some customers that digital technology is a commodity compared with high-performance analog.

This is not the case; in fact the real paradigm change is that the intellectual property migrates from the physical circuit to the software or algorithm therein. Furthermore, many customers have completely dispensed with their analog design expertise in favor of the new digital panacea. For these customers, a turnkey solution is required. Powervation has introduced the Auto-control™ technology to deal with these opportunities. With Auto-control, the controller acts as a frequency response analyzer, measuring the magnitude and phase characteristics of the load over a frequency range. To put it simply, the designer presses a key and the control loop is optimized for the load. This may be repeated at any time during operation of the equipment to establish optimal control and stable operation. This type of approach is useful for system designers and architects who, by necessity deal with their designs from a modular or black box perspective.

In order to maximize system availability data centers are considering practices adopted in national electrical power generation and distribution systems. These techniques are facilitated by the introduction of digital power control and regulation. The term "smart grid" refers to hardware and software added to the electrical power system to achieve a) responsiveness to events that impact the electrical power grid, and b) operational efficiency of electrical power delivery.

Among the events that impact the electrical power grid are outages, (scheduled and unscheduled), load balancing and peak shaving or sending power back to the grid when demand is high.

Smart grid hardware encompasses, a) metering and monitoring of the power system (telemetry), b) communicating the conditions of the grid in real time, and c) controlling the flow of power to maintain reliable service and stable direction. The term “smart grid” may also be applied to the power system feeding the racks and cards that make up a high-performance computing or networking system. Digital techniques can significantly improve availability, time-to-market and overall system efficiency.

Digital regulation employs comprehensive telemetry and real-time communication to be effective at the system level. Point of load regulator and load junction temperature measurement may be used to balance temperature rise in multiphase regulators or switch supplies off when overloaded. Failures may be predicted through temperature, ripple voltage or current logging. These measurements could have prevented the catastrophic failures in server systems in the past caused by the thermal ageing of iron powder cores. When a system determines that a card rack may likely fail due to excessive temperature rise or other factors, it can take measures to shed or balance loads, switch off such circuits and inform maintenance.

Time-to-market is reduced as the development and commissioning time of complex systems is reduced, especially in developments where ASICs are used. ASIC power, sequencing and noise immunity requirements are only available when first silicon is evaluated, late in the system development. Highly configurable power architecture is complementary to this approach, potentially eliminating months of cut and try. In-service upgrades may be applied by remotely programming the power system rather than servicing cards or racks.

Digital power conversion is here to stay. Many techniques that are commonplace in industrial and process control may now be applied to power supplies. Powering deep submicron CMOS loads may be the exclusive domain of digital power conversion in the future as analog performance degrades with feature size. Power consumed by a router or switch will vary in real time proportional to the traffic at the network’s edge. Once power management is treated from the whole system point of view, digital power conversion becomes a necessary tool in the power-architect’s repertoire.

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