SAM DAVIS, Editor in Chief

Adaptive Control IC Creates Self-Adjusting DC-DC Converters

Unique IC adds true adaptive control to dc-dc power conversion, providing automatic loop compensation that accommodates a broad range of load variations.

A **DC-DC CONVERTER** with fixed compensation parameters cannot perform well if load dynamics vary widely. A better approach is adaptive control, which can handle a broad range of parameter variations with the ability to change the loop compensation in response to load variability.

In addition, adaptive control provides better disturbance rejection than a fixed compensation converter. Thus, adaptive techniques can keep a dc-dc converter optimized under most operating conditions. To be effective, however, the adaptive-control system must employ an IC that uses minimal external components and still provides all the necessary functions.

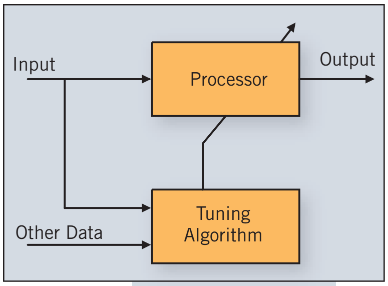

Fig. 1. With open-loop adaptation, a tuning algorithm adjusts the converter by applying predefined rules or formulae to the input signal or other data.

An adaptive control IC can be used in an open-loop system, as shown in *Fig. 1*. Here, a tuning algorithm adjusts the converter by applying predefined rules or formulae to the input signal or other data.

In such a system, the tuning algorithm does not analyze the adjustment results so it does not ensure system optimization. Examples in dc-dc conversion include phase-add and drop-in multiphase dc-dc converters, and switching between DCM and CCM control modes at a predefined point.

Fig. 2 shows a closed-loop adaptation scheme, where the output feedback applied to the tuning algorithm allows a dc-dc converter to optimize its performance. The closed-loop adaptive approach sets the converter's parameters automatically for the exact load dynamics seen in the system. A controller IC based on these principles is portable across various use scenarios, allowing a single controller IC to be used in a wide variety of applications.

Therefore, a suitable working definition of a true adaptive controller IC for power conversion is: An adaptive controller IC has a mechanism for adjusting operating parameters in a way that optimizes dc-dc converter performance regardless of load conditions.

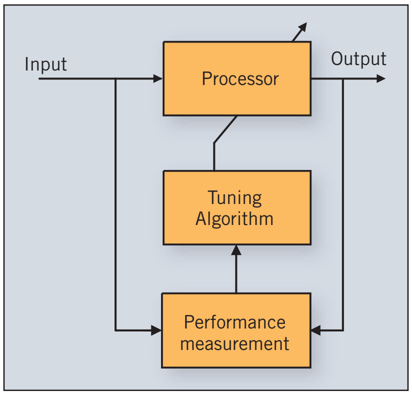

Fig. 2. In closed-loop adaptation, the output feedback applied to the tuning algorithm allows a dc-dc converter to optimize its performance.

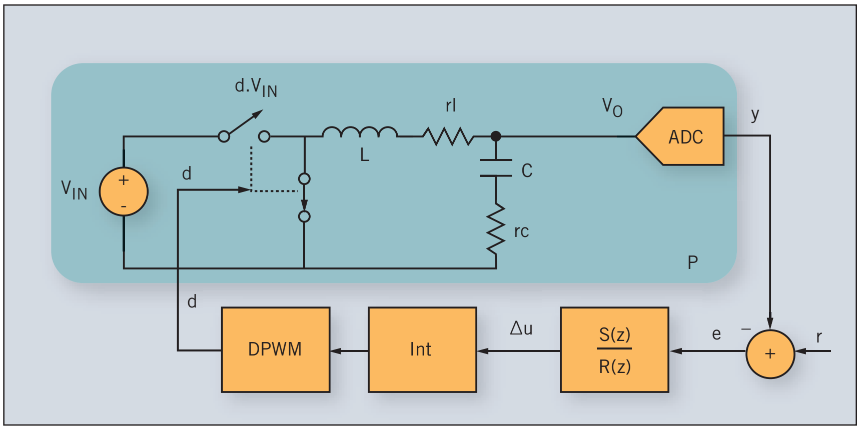

Fig. 3. The digitally controlled buck converter incorporates the power-stage transfer function that is known with a reasonable degree of precision.

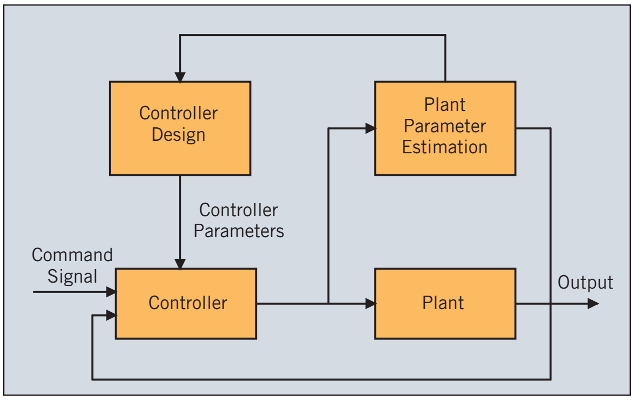

Fig. 4. Parameters of a typical adaptive controller are estimated by the 'plant parameter estimation' block and the controller meets some predetermined requirements, such as closed-loop bandwidth.

Powervation's Auto-control™ controller IC satisfies this definition. Designing the controller parameters to meet the desired objective usually requires knowledge of the plant transfer function. In dc-dc conversion, for example, it is very useful for an adaptive controller to use closed-loop bandwidth as a user-defined design objective.

Because closed-loop bandwidth is a function of plant and controller dynamics, adaptive control techniques allow the controller parameters to be selected for the desired closed-loop bandwidth without prior knowledge of the plant dynamics. This simplifies the design process.

ADAPTIVE DC-DC CONVERTER

Consider the dc-dc converter shown in *Fig. 3*, where the controller is represented by its numerator and denominator polynomials, S and R respectively, which specify the zeros and poles of the controller. It is well known that the transient response of a buck converter can be estimated as the product of the load-step current and the peak closed-loop output impedance of the converter:

$$V_{TRANS} = \Delta I_{LOAD} \times |Z_{OUT}|_{MAX}$$

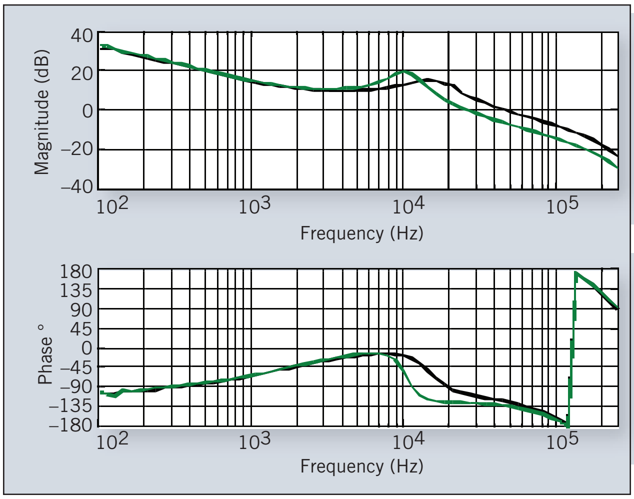

Fig. 6. Bode plot of multiphase buck converter in two-phase (full line) and one-phase (dotted line) configuration.

Also, the closed-loop output impedance tends to peak in the vicinity of the closed-loop bandwidth. Therefore, you can determine the transient response from the expected closed-loop system bandwidth and the output-capacitor impedance[2].

In addition, there are Nyquist limitations. This implies that the transient voltage is only a function of the regulator's response, which is only true up to a point, where gain is about zero; after that, the inductances and capacitances determine the response.

However, the closed-loop bandwidth of the buck converter is not a simple function of the controller transfer function. It also incorporates the power-stage transfer function which, at worst, may be unknown and, at best, is known with a reasonable degree of precision. With an adaptive system a controller may be designed automatically to achieve a closed-loop bandwidth selected by the designer. *Fig. 4* shows a typical adaptive controller, whereby the parameters of the plant are estimated by the 'plant parameter estimation' block and the controller is designed on-the-fly by the 'controller design' block to meet some pre-determined requirements, such as closed-loop bandwidth.

Because this automatically maintains closed-loop bandwidth you can achieve optimized transient response over a wide range of power-stage component values and conditions. The Auto-control™ IC achieves this.

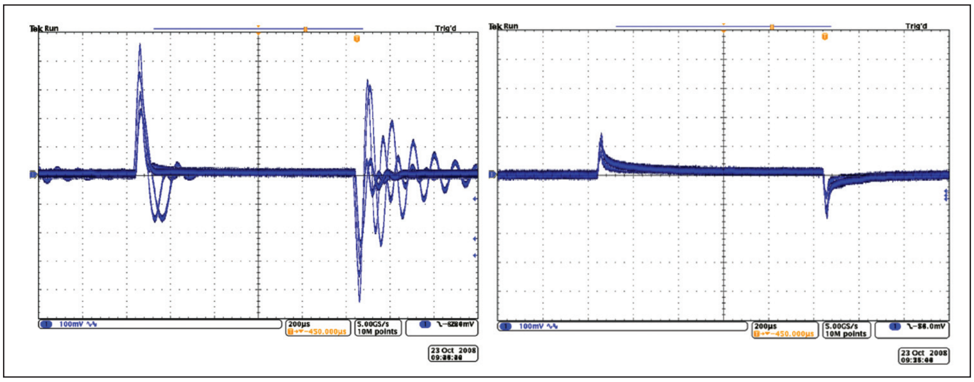

Fig. 5. Transient response to load steps: (a - left side) as power-stage L and C values vary with fixed control; (b - right side) when controlled with Auto-control technology.

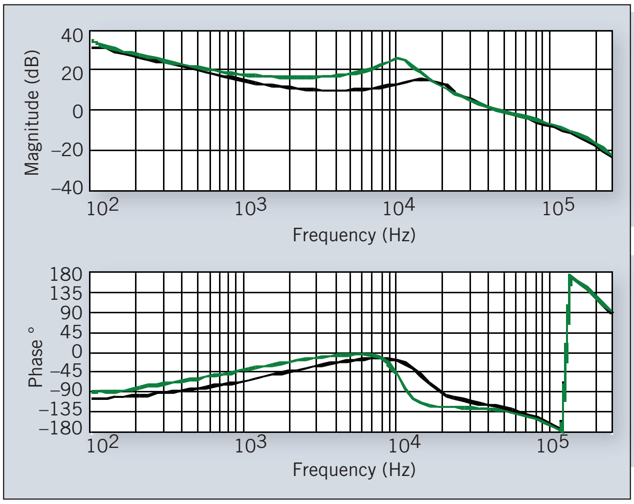

Fig. 7. Bode plot of multiphase buck converter in two-phase (full line) and one-phase (dotted line) configuration with Auto-control.

AUTO-CONTROL

Historically, adaptive control has had a very large toolbox to draw upon; from gain scheduling (mode switching), to model-reference adaptive systems, to self-tuning regulators and stochastic regulators. This gives designers a wide scope from which to apply adaptive control.

The challenge is to apply those techniques with minimal computational complexity. Adaptive control techniques in process control and robotics are not suited to power control, which requires fast computation in very little silicon area. Therefore, adaptive control of power converters requires new operational algorithms.

To this end, Powervation's Auto-control technology brings true adaptive control to dc-dc conversion. The benefits of Auto-control—such as improved robustness, maximum performance and ease of design—are all possible with this technology.

Fig. 5 illustrates the transient responses to load steps with various power-stage L and C values with fixed control (*Fig. 5a*), and Auto-control (*Fig. 5b*). Therefore, Auto-control provides greater robustness than a fixed controller.

The loop-gain and bandwidth of a multi-phase dc-dc converter change dramatically for one-phase or two-phase operation (*Fig. 6*), making energy-efficient design techniques difficult to implement. *Fig. 7* shows how the closed-loop bandwidth remains constant with Auto-control technology, allowing energy-efficient design techniques to be implemented in a way that fixed controllers or open-loop adaptive techniques cannot achieve.

With Auto-control at its core, the PV3002 IC is intended for applications where a more efficient power supply is a key competitive differentiator. True adaptive control allows the PV3002 to distribute power intelligently, enabling a system to consistently operate at peak efficiency.

The PV3002 represents a fundamental shift in power-supply design and solves the most pressing performance, reliability and cost challenges facing designers. It reliably adapts power conversion to cases of changing system behavior and unpredictable variations.

Thus, it guarantees stability over a wide range of conditions throughout the system's lifetime. Auto-control allows designers to

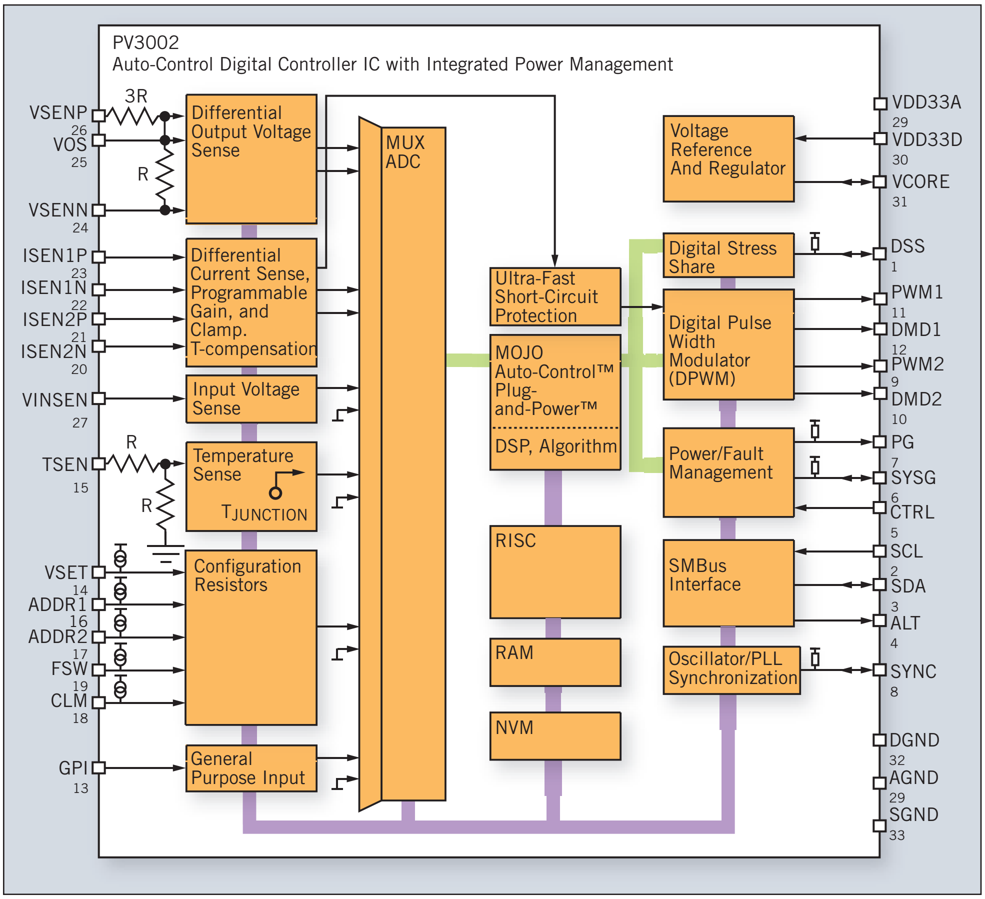

Fig. 8. Simplified diagram of the PV3002, including both a DSP and RISC processor.

breach the performance barriers that have limited traditional digital power technologies.

The PV3002 controller delivers performance that enables higher efficiency, better transient response and ease of use across a broad range of voltage-regulator designs. Auto-control works in real time, ensuring stability for the system's entire life.

The PV3002 adaptive control IC delivers performance that enables higher efficiency, better transient response, and ease of use across a broad range of voltage-regulator designs

Fig. 8 shows a simplified diagram of the PV3002. It includes a DSP, a RISC processor and traditional analog blocks. This dual-core architecture produces a voltage regulator for applications that demand high stability and high efficiency.

Here, control-loop optimization circuits are separate from general housekeeping fault-management and configuration tasks. This permits the DSP core to be optimized for high performance and minimal power.

The RISC processor can set operating parameters and monitor operating conditions via the SMBus™. Settings can be stored in on-chip non-volatile memory (NVM).

You can disable the SMBus to allow the controller to act as a stand-alone device, or the SMBus can remain active to interface with an external power manager. Alternately, you can set the startup mode, output voltage and current limit with external resistors.

You can configure this IC to provide one- or two-phase operation, and you can parallel multiple controllers to provide load sharing. For systems where load current can vary widely, the PV3002 has an option to automatically shift between single-and dual-phase operation, which ensures the highest efficiency over the full range of load current.

The PV3002 moves the control loop stabilization from external components to the DSP core. A fast analog-digital converter (ADC) monitors output voltage and inductor current.

The results are passed to the DSP, which calculates the Auto-control algorithm and adjusts the pulse-width-modulator (PWM) output on a cycle-by-cycle basis. The digital PWM has a duty cycle resolution of less than 1 ns, which ensures loop stability and improves transient response.

To complement the digital loop control, the PV3002 provides versatile analog inputs. The output voltage and

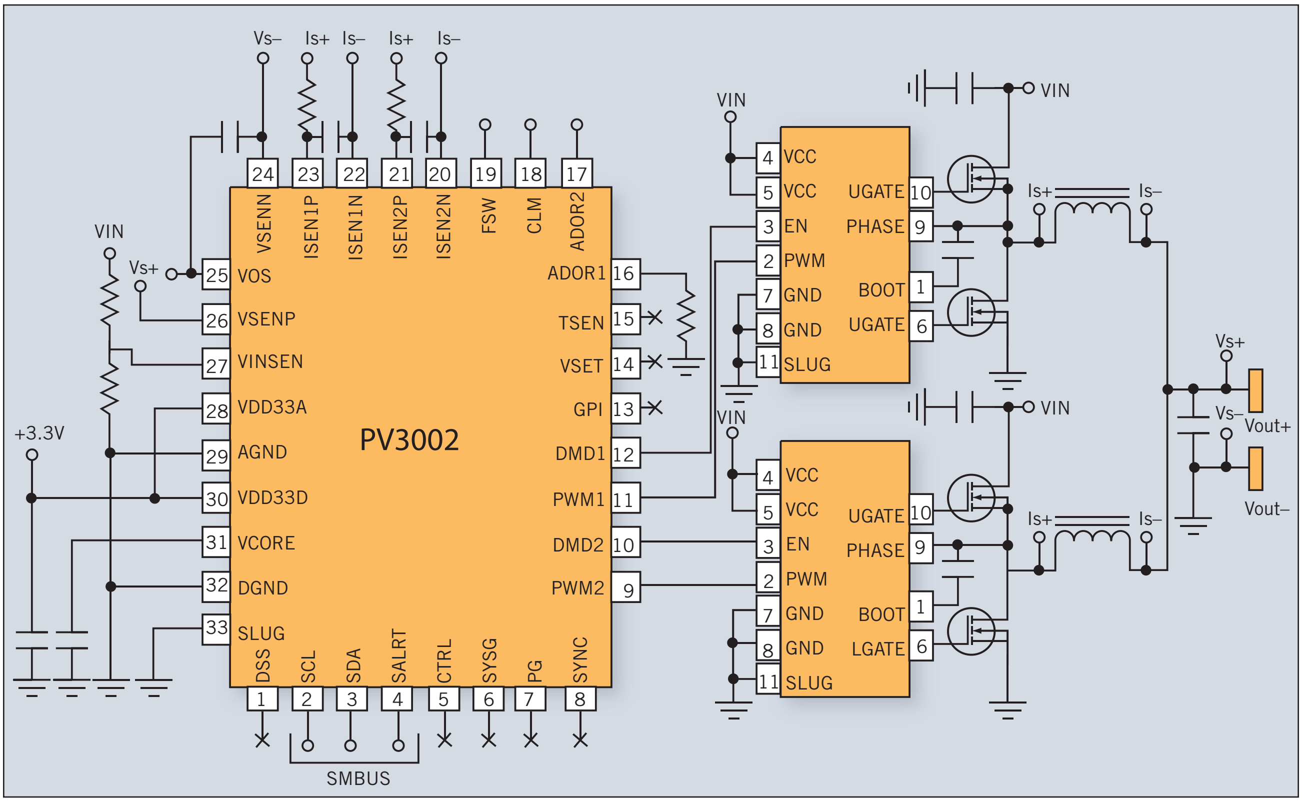

Fig. 9. PV3002 in a buck converter configuration. Output voltage and current are applied to PV3002's differential ±Vs and ±Is inputs, respectively.

PV3002 SUMMARY OF FEATURES

- Automatic compensation adjustment
- Guaranteed stability
- Improved transient response
- Improved efficiency
- One- or two-phase operation
- 10-mV set-point accuracy
- Digital current sharing
- Phase add-and-drop with auto-compensation monitoring
- Precise current monitoring
- Internal and external temperature sensing
- Wide output and input voltage range
- Differential voltage sense
- Precise voltage set-point accuracy (±10mV)
- Fault detection (OVP, OTP, UVLO)
- High-reliability non-volatile memory (fuse-based OTP)
- Single 3.3-V-supply operation
- Available in RoHS 5- x 5-mm QFN package
- Fully specified over the –40° to 85°C range

inductor current-sensing inputs are differential for maximum accuracy, and inductor current can be sensed via inductor dc resistance or an external resistor.

The PV3002 monitors fault conditions to protect the system, including undervoltage and overvoltage conditions on both input and output. Two overcurrent monitors—one fast analog for protecting external circuits and the other calculated from ADC readings for system use—provide additional protection. Temperature monitoring, either from an included on-chip sensor or via an external sensor, is also available.

Fig. 9 shows the PV3002 in a buck converter configuration. Here, its outputs connect to external gate drivers that drive external power MOSFETs.

REFERENCES

1. Astrom, K.J. and B. Wittenmark, Adaptive Control. 2nd ed. Vol. 2nd ed. 1995: Addison-Wesley.

2. Betten, J. and R.Kollman, 2005,“Easy Calculation Yields Load Transient Response”, Power Electronics Technology Magazine, Feb. 2005