

# Dual, Fast, Step-Down Controller's External Reference Input Enables Dynamic Voltage Scaling from 0.4V to 5.5V and 0.3% Total Combined Regulation Accuracy

Shuo Chen and Terry Groom

Low voltage, high current systems require accurate differential regulation. It is not uncommon for power supply rails at or below 0.9V to demand 25A or more, with fast transients that look like intermittent electrical shorts to the power supply rail. Such systems typically require power supply regulation accuracy of less than 1% regulated DC and 3% in the face of input transients.

Increasingly, core processors and other large scale digital ICs (such as ASICs and FPGAs) require dynamic voltage scaling—either multiple fixed levels, or a continuously adjusted reference voltage using a servo loop—to deliver power based on the processor demand. The goal is that the system can keep the applied power supply at the minimum voltage necessary for proper operation based on processing demand to conserve

PART NUMBER	REFERENCE VOLTAGE	OUTPUT VOLTAGE	TOTAL COMBINED ACCURACY (GROUND, LINE, LOAD & TEMP)*
LTC3838-1/-2 Ch.1 and LTC3838-1 Ch.2	0.6V Internal	0.6V to 5.5V	< $\pm 0.75\%$ ( $0^{\circ}\text{C} \leq T_A \leq 85^{\circ}\text{C}$ ) < $\pm 1\%$ ( $-40^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$ )
LTC3838-2 Ch.2 (e.g., with $\pm 0.1\%$ Linear Technology Voltage References)	0.6V External	0.6V to 5.5V	< $\pm 0.67\%$ ( $-40^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$ )
	1.5V External	1.5V to 5.5V	< $\pm 0.4\%$ ( $-40^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$ )
	2.5V External	2.5V to 5.5V	< $\pm 0.3\%$

\*external resistor divider error not included

**Table 1. Output voltage regulation accuracy over remote power ground deviation (up to  $\pm 200\text{mV}$ ), input voltage (4.5V to 38V), output current, and temperature**

energy. One example is LSI's adaptive voltage scaling & optimization (AVSO).

The LTC3838-2 is designed to meet the extreme accuracy requirements through precision differential output sensing, and offer dynamic output voltage scaling using the differential external reference voltage input.

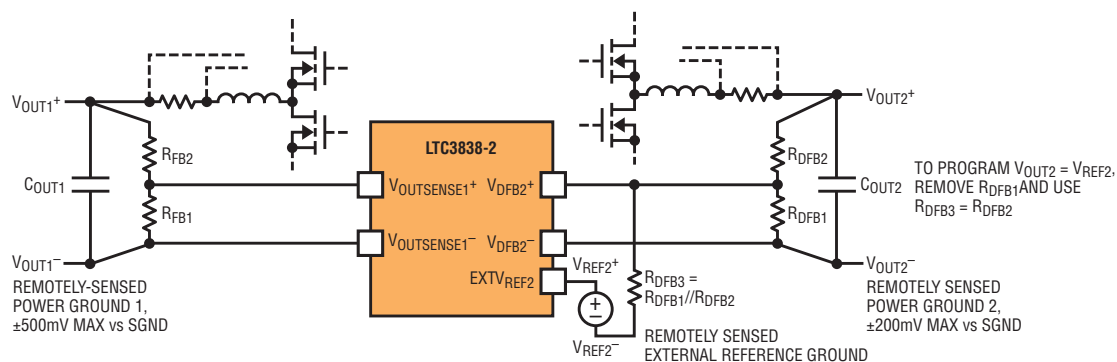
## DUAL DIFFERENTIAL $V_{\text{OUT}}$ ACCURACY THAT MATTERS

To obtain superior regulation accuracy, power supply designers sometimes bypass a controller's internal error amplifier and instead use a discrete precision reference and external op amps to control the power

stage. The problem is that soft-start and many common fault control features such as overvoltage protection might be sacrificed, depending on the technique used.

The LTC3838-2 avoids this trade-off by allowing the use of an external reference for accuracy while preserving valuable fault and protection features. With a precision voltage reference (such as LTC6652) from Linear Technology, or a DAC for programmability, the channel 2 output of the LTC3838-2 can be tightly regulated from 0.4V to 5.5V in applications with currents up to 25A per channel. At a very low 0.6V, the LTC3838-2 is able to achieve a total

**Figure 1. Channel 2 of the LTC3838-2 regulates to an external reference; channel 1 to an internal reference.  $V_{\text{OUT1}}$  and  $V_{\text{OUT2}}$  allow remote grounds up to  $\pm 500\text{mV}$  and  $\pm 200\text{mV}$ , respectively.  $V_{\text{REF2}}$  is also differentially sensed, but no separate pin for the remote ground of external reference is required.**



For differential external reference sensing, the LTC3838-2 has only one pin for external reference input. Channel 2 features a unique feedback amplifier configuration, which eliminates the need for a separate pin to sense the external reference's remote ground. Instead, one additional resistor, equal to the parallel of the two feedback resistors, is used to connect to the remote ground externally.

combined accuracy of  $\pm 4\text{mV}$ , or  $\pm 0.67\%$ , over all operating conditions including line, load, extreme temperature and remote ground deviation up to  $\pm 200\text{mV}$ .

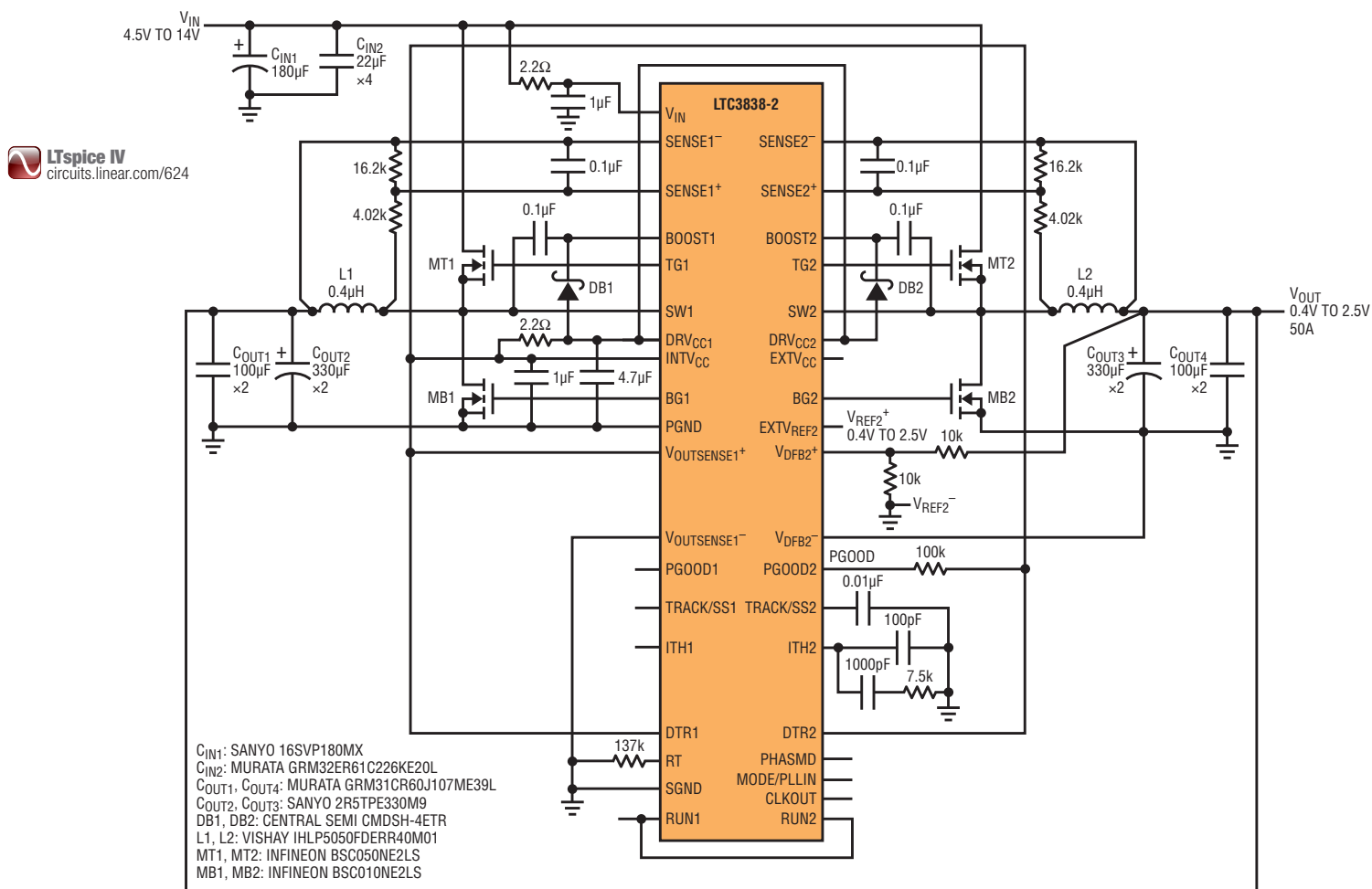
Relative accuracy improves as the reference increases because the absolute error is a smaller percentage out of a larger reference voltage. This contrasts with programming the output voltage

by scaling feedback with respect to a fixed lower reference voltage, where the percentage error does not change. For example, with an external reference of  $2.5\text{V}$ , the total relative tolerance is less than  $\pm 0.3\%$ . The LTC3838-2's dual channels can be configured to single-output applications using channel 2's external reference at such accuracy.

## TRACKING DYNAMIC DIFFERENTIAL EXTERNAL REFERENCE

For differential external reference sensing, the LTC3838-2 has only one pin for external reference input. Channel 2 features a unique feedback amplifier configuration, which eliminates the need for a separate pin to sense the external reference's remote ground. Instead, one

**Figure 2. A LTC3838-2, 300kHz, 2-phase single-output step-down converter with inductor-DCR sense. This application converts a 4.5V to 14V input to a dynamic 0.4V to 2.5V output at 50A.**



In addition to regulation accuracy, the LTC3838-2 offers wide-bandwidth tracking to a dynamic external reference. Tracking bandwidth is important in applications like dynamic voltage scaling because bandwidth determines how quickly the supply can respond to changes to the programmed external reference.

additional resistor equal to the parallel of the two feedback resistors is used to connect to the remote ground externally. See the LTC3838-2 data sheet for an explanation of how this configuration works.

Figure 2 shows a typical LTC3838-2 application with external reference input. This 2-phase converter is capable of producing 50A over a wide ranging output from 0.4V to 2.5V. For example, at 1.5V this application can achieve 0.4% total combined accuracy for all operating conditions. The high accuracy and superior transient performance make the LTC3838-2 well suited for the most demanding processor applications.

In addition to regulation accuracy, the LTC3838-2 offers wide-bandwidth tracking to a dynamic external reference. Tracking bandwidth is important in applications like dynamic voltage scaling because bandwidth determines how

quickly the supply can respond to changes to the programmed external reference.

Figure 3 shows Bode plots from a 350kHz LTC3838-2 step-down converter compensated to an aggressive bandwidth close to 1/3 of the switching frequency without sacrificing stability. This allows the LTC3838-2 to track an external sine wave of 3.5kHz or 1/100 switching frequency at full power, without any noticeable distortion even at the sine wave's very high bandwidth start and stop instants (Figure 4). Careful attention should be paid to the bandwidth requirements for any dynamic system. The wide-bandwidth external-reference-tracking capability, in addition to high speed transient performance, makes the LTC3838-2 ideally suited for the most dynamic supply applications.

### LT3838-1 CONTROLLER: INTERNAL REFERENCE ON BOTH CHANNELS

The LTC3838-1 shares the same functions as LTC3838-2, except channel 2 of the LTC3838-1 uses a 0.6V internal reference. Like its predecessors, the LTC3838 and LTC3839, both the LTC3838-1 and -2 use the controlled on-time, valley current mode architecture, which offers superior regulation during fast load transients without the typical switching period response delay of fixed frequency controllers, while still capable of constant frequency switching locked to an external 200kHz to 2MHz clock. They retain all features of the LTC3838, including the proprietary detect transient release (DTR), which improves the transient performance in low output voltage applications. Like the LTC3838, both LTC3838-1 and -2 include a full set of popular features, such as an external  $V_{CC}$  power pin,  $R_{SENSE}$  or inductor-DCR current sensing, selectable light load operating modes, overvoltage protection and current

Figure 3. Loop gain and closed-loop Bode plots taken with an OMICRON Lab network analyzer on  $V_{OUT2}$  of a 350kHz LTC3838-2 step-down converter with external reference (EXTV<sub>REF2</sub>).

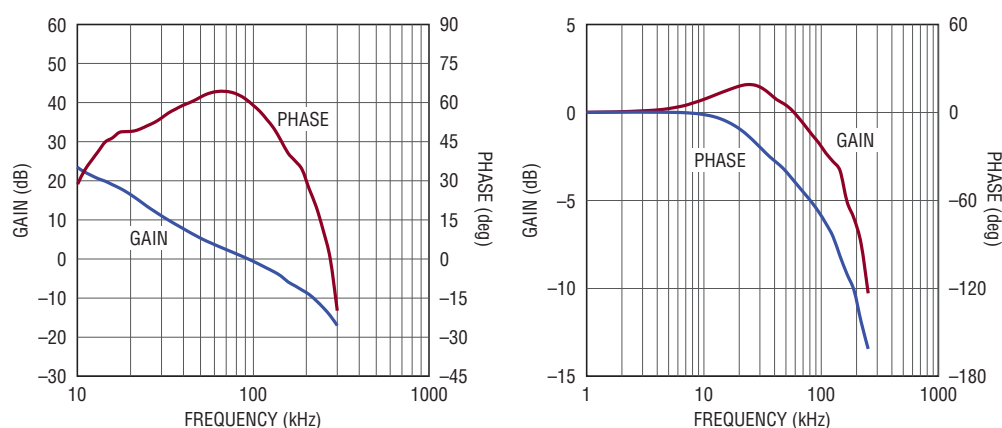
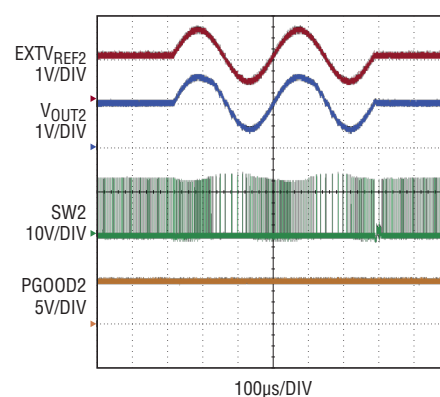


Figure 4. The LTC3838-2 tracks a 1V peak-to-peak, 3.5kHz sine wave external reference.



The LTC3838-1/-2 is the ideal choice for power in applications requiring fast transient performance, dual accurate differential output regulation, and external references for increased  $V_{OUT}$  accuracy and programmability down to 0.4V.

limit foldback, soft-start/rail tracking, and PGOOD and RUN pins for each channel.

In addition to the differential remote output sensing on both channels, a significant improvement of the LTC3838-1/-2 over the original LTC3838 is the maximum current sense threshold voltage (i.e., current limit) accuracy. Unlike the LTC3838, which has a continuously variable and two fixed current limit ranges ( $V_{RNG}$ ), the LTC3838-2 has a fixed  $V_{RNG}$  of 30mV (typical) and its tolerance over temperature is  $\pm 20\%$ ,

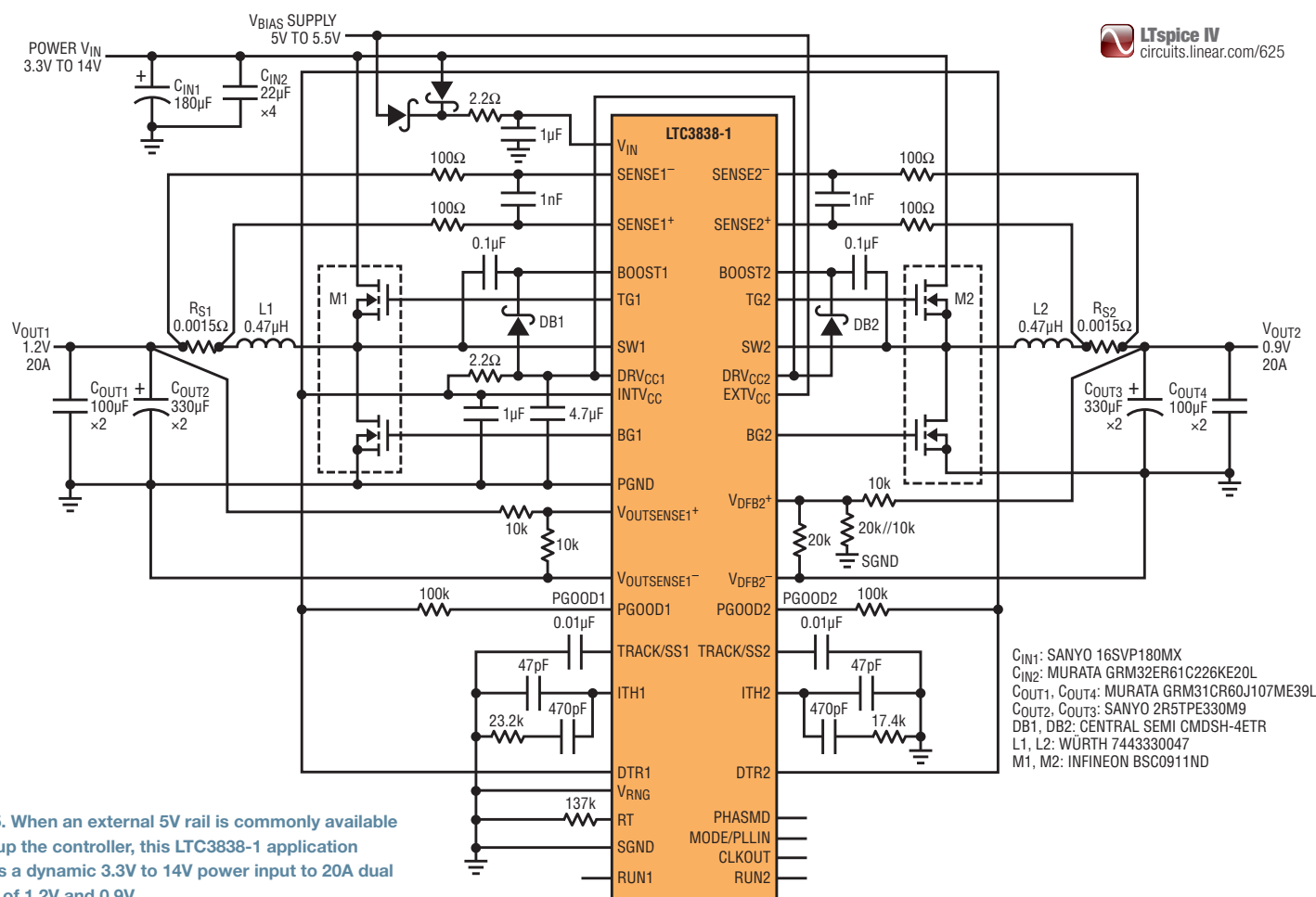
which is much improved. The LTC3838-1 has the same 30mV and an additional 60mV (typical)  $V_{RNG}$  setting whose tolerance is also significantly tighter. Refer to Table 2 for the comparison on the current limit tolerances and  $V_{RNG}$  controls of the LTC3838-series 2-channel controllers.

The LTC3838-1/-2 controllers require a minimum  $V_{IN}$  pin voltage of 4.5V, but this does not limit the power input to 4.5V. For example, many digital systems have an available regulated

5V rail, which can be used to bias the  $V_{IN}$  pin and gate drivers, and to efficiently step down inputs less than 4.5V.

Figure 5 shows the  $V_{IN}$  pin connected via diode-OR to the  $V_{BIAS}$  5V rail and to power  $V_{IN}$ , 3.3V–14V, rail. This allows the power  $V_{IN}$  rail to dynamically switch between a higher voltage and a minimum of 3.3V. When operating with the power  $V_{IN}$  supply below 5.5V, this application requires the  $V_{BIAS}$  supply to be present at  $EXTV_{CC}$  in order to maintain

LTspice IV  
circuits.linear.com/625



Using an external reference, the LTC3838-2 can achieve total accuracy levels as low as 0.3% under all operating conditions. The external reference feature is designed to accommodate dynamic voltage scaling and track fast external reference inputs with minimum distortion.

**Table 2. Maximum Current Sense Threshold Voltage Specifications and Range Controls**

PART	$V_{\text{RNG}} = \text{SGND}$	$V_{\text{RNG}} = \text{INTV}_{\text{CC}}$	$V_{\text{RNG}} \text{ CONTROL}$	$V_{\text{RNG}} \text{ PIN(s)}$
LTC3838 and LTC3839	21mV to 40mV	39mV to 61mV	30mV–200mV continuous & 30mV/50mV fixed	each per channel
LTC3838-1	24mV to 36mV	54mV to 69mV	30mV/60mV fixed	single
LTC3838-2	24mV to 36mV		30mV fixed only	no

$\text{DRV}_{\text{CC}}$ ,  $\text{INTV}_{\text{CC}}$  and  $V_{\text{IN}}$  pin voltages needed for the IC to function properly. The  $\text{EXTV}_{\text{CC}}$  supply is optional when the power  $V_{\text{IN}}$  supply is at or above 5.5V.

Note that the power input voltage range of this application cannot be generalized for other frequencies and output voltages, and each application that needs a power input voltage different from the  $V_{\text{IN}}$  pin voltage should be tested individually for margin of range in which the switching nodes (SW1, SW2) phase-lock to the clock output (CLKOUT).

## SUMMARY

The LTC3838-1/-2 is the ideal choice for power in applications requiring fast transient performance, dual accurate differential output regulation, and external references for increased  $V_{\text{OUT}}$  accuracy and programmability down to 0.4V. Compared to the original LTC3838, the LTC3838-1/LTC3838-2 offers differential output sensing on *both* channels, improved current limit accuracy, and the choice of internal/external reference. Using an external reference, the LTC3838-2 can achieve accuracy levels as low as 0.3% under all operating

conditions. The external reference feature is designed to accommodate dynamic voltage scaling and track fast external reference inputs with minimum distortion.

The LTC3838-1 and -2 are offered in 38-pin QFN (5mm × 7mm) packages with exposed pads for enhanced thermal performance.

Visit [www.linear.com/LTC3838-1](http://www.linear.com/LTC3838-1) and [/LTC3838-2](http://www.linear.com/LTC3838-2) for data sheets, demo boards, a variety of applications designs, and for more information about how:

- a 30ns minimum on-time enables high step-down ratios, e.g., from 38V to 0.8V at 350kHz
- 2MHz switching frequency enables applications with tiny power components
- 25A output becomes practical at 2MHz, with 95% peak efficiency (2V–5V  $V_{\text{OUT}}$ ). ■

## For More Information...

### THE LTC3838/LTC3839, PREDECESSOR TO THE LTC3838-1/-2:

See the article:

- **2MHz Dual DC/DC Controller Halves Settling Time of Load Release Transients, Features 0.67% Differential  $V_{\text{OUT}}$  Accuracy and is Primed for High Step-Down Ratios** in the *LT Journal of Analog Innovation*, April 2012 (Volume 22, Number 1).

### THE LTC3833 SINGLE-CHANNEL CONTROLLER

The LTC3838 series of dual controllers are based on and have all features of the single-channel controller LTC3833. For a full discussion of the features shared with LTC3833, refer to the cover article:

- **Fast, Accurate Step-Down DC/DC Controller Converts 24V Directly to 1.8V at 2MHz** in the *LT Journal of Analog Innovation*, October 2011 (Volume 21, Number 3).