LINEAR TECHNOLOGY

Journal of
Analog Innovation

October 2011 Volume 21 Number 3

IN THIS ISSUE



# Fast, Accurate Step-Down DC/DC Controller Converts 24V Directly to 1.8V at 2MHz

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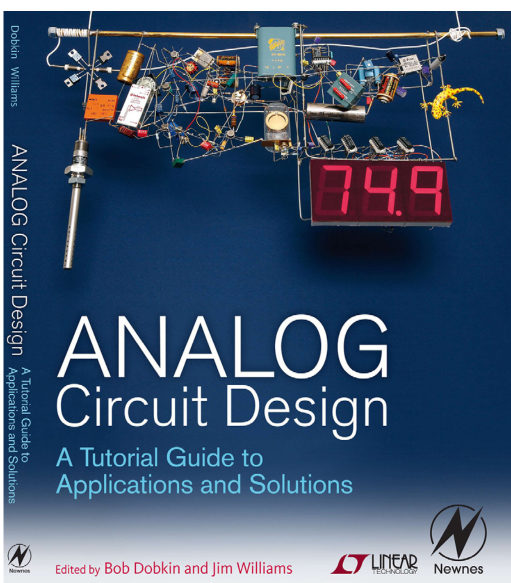
The continuous march in electronics toward lower supply voltages and higher load currents puts tremendous pressure on point-of-load DC/DC converters to maintain a fast pace of performance improvements. For instance, a lower supply voltage means a regulator must support a higher step-down ratio from a 12V or 24V power rail while maintaining high efficiency. Regulation accuracy also becomes more important as supply voltages drop—and accuracy must be maintained in the presence of parasitic IR drops and dynamic load transients. EMI generated by switching converters is also of concern, especially in RF applications.




Published September 2011 and now available. See page 2.

Some applications require that their power supplies meet all of these stringent requirements: high power, high efficiency, high accuracy, high step-down ratio, fast transient performance and low EMI—and that they do it in a small footprint. The LTC®3833 is a high performance synchronous step-down DC/DC controller that steps up to the challenge. Figure 1 shows a typical application. The LTC3833 accepts an unregulated input voltage between 4.5V and 38V (40V abs max) and downconverts it to 0.67% accurate output voltage between 0.6V and 5.5V (6V abs max).

It features a 20ns minimum on-time, enabling a high step-down ratio (high $V_{IN}$ to low $V_{OUT}$) at high frequency (up to 2MHz), and its control architecture is primed for fast transient performance. The LTC3833 is offered in 20-pin QFN (3mm × 4mm) and TSSOP packages with exposed pads for enhanced thermal performance.

*(continued on page 4)*

The LTC3833 is a high performance synchronous step-down DC/DC controller that regulates to 0.67% output accuracy, operates up to 2MHz switching frequency and has a 20ns minimum on-time.

*(LTC3833, continued from page 1)*

## FAST TRANSIENT PERFORMANCE AND CONSTANT FREQUENCY

The LTC3833 uses a new, sophisticated *controlled*-on-time architecture—a variant of the *constant* on-time control architecture with the distinction that the on-time is controlled so that the switching frequency remains constant over steady state conditions under line and load. This architecture takes advantage of all the benefits of a constant on-time controller, namely fast transient response and small on-times for high step-down ratios, while imitating the behaviors of a constant frequency controller.

The LTC3833 can respond to a load step immediately without waiting until the next switching cycle as in a conventional constant frequency controller. During a load step, the LTC3833 increases its switching frequency to respond faster and reduce the droop on the output. Similarly, during a load release, the LTC3833 reduces the switching frequency in order to prevent the input rail from charging the output capacitor any further. Once the transient condition subsides, the LTC3833 brings the switching frequency back to the nominal programmed value, or to the external clock frequency if it is being synchronized.

| EFFICIENCY ↘ | | FREQUENCY, INDUCTANCE | | | |
|---|---|---|---|---|---|
| | | 200kHz, 2.00µH | 500kHz, 0.82µH | 1MHz, 0.47µH | 2MHz, 0.20µH |
| $V_{IN}$ | 6V | 91% | 92% | 91% | 87% |
| | 12V | 92% | 92% | 89% | 84% |
| | 15V | 92% | 91% | 87% | 81% |
| | 24V | 91% | 88% | 83% | 73% |

Table 1: Example of efficiency variation over input and frequency. Higher frequencies have lower efficiencies but allow smaller component size for compact solutions. $V_{OUT}$ = 1.8V $I_{LOAD}$ = 10A.

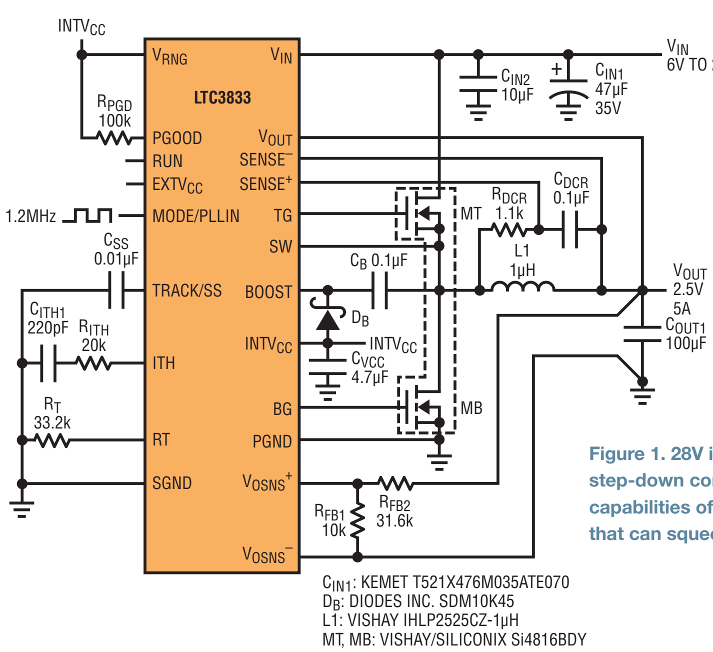



Figure 1. 28V input, 2.5V output, 5A, 1.2MHz step-down converter. The high frequency capabilities of the LTC3833 enable designs that can squeeze into tight spaces.

The LTC3833's low minimum off-time of 90ns allows it to achieve high duty cycle operation and thus avoid output dropout when $V_{IN}$ is only slightly above the required $V_{OUT}$. The low minimum off-time also factors into fast transient performance. If the switching converter's control loop is designed for high bandwidth and high speed, the minimum off-time of the LTC3833 does not limit performance. That is, in a load step condition, the time between consecutive on-time pulses can be as low as 90ns for a high bandwidth design.

Figure 2 shows a low voltage, high current application typical of a microprocessor power supply where the LTC3833 responds quickly to a 20A load step and release.

## WIDE FREQUENCY RANGE FOR A MULTITUDE OF APPLICATIONS

The LTC3833 is capable of a full decade of switching frequency, from 200kHz to 2MHz (programmed with an external resistor on the RT pin). This wide range allows the LTC3833 to meet the requirements of a wide variety of applications, from low frequency applications that require high efficiency, to higher frequency

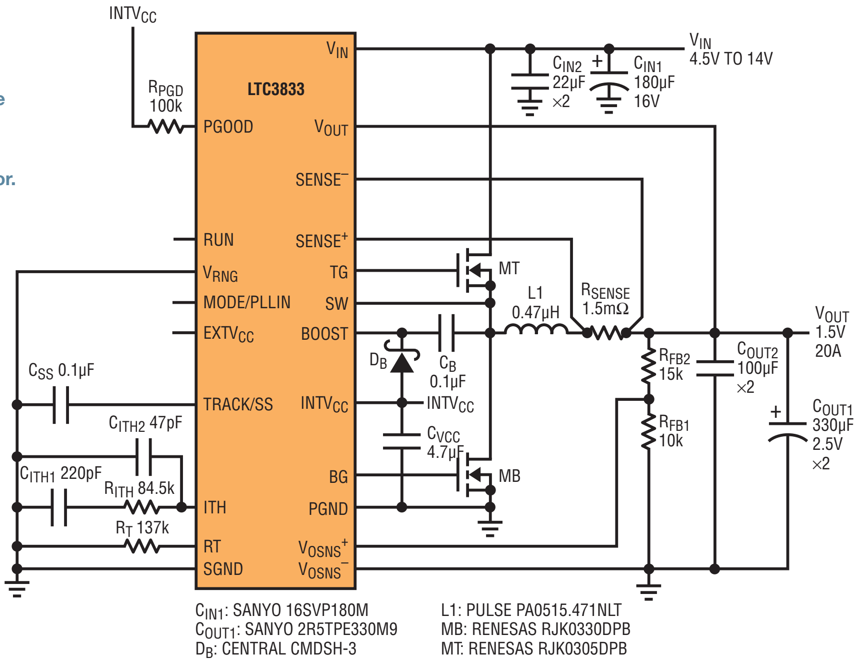



**Figure 2a. 14V input, 1.5V output, 20A, 300kHz step-down converter. The LTC3833 excels in low voltage, high current applications such as these, which are typical of a microprocessor power supply. It can respond quickly to sudden, high slew current requirements of the microprocessor.**

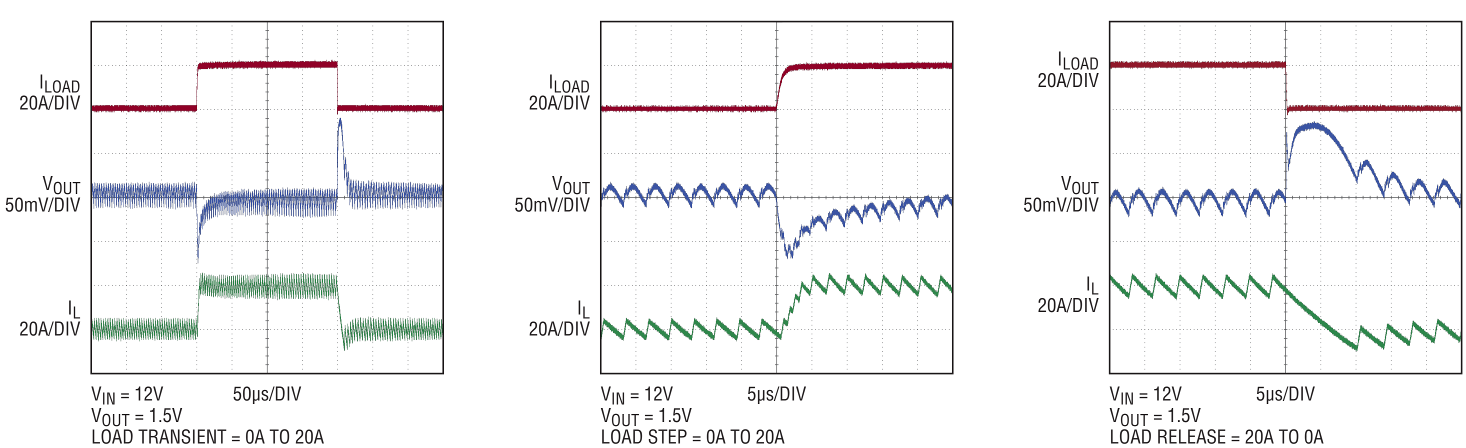
applications that require smaller solution size, to 2MHz applications that stay above the AM radio band while being able to downconvert from a high input rail and deliver high output current.

The choice of operating frequency is a tradeoff between efficiency and component size. Lower frequencies are more efficient due to a reduction of switching-related losses in the converter. On the other hand, lower frequencies require larger inductors and capacitors to achieve a given output ripple. At higher frequencies, smaller components can be used to achieve the same output ripple, but at the cost of efficiency. Table 1 illustrates the trade-offs between efficiency and inductor size required to maintain output ripple when the LTC3833 is used to generate a 1.8V output at several frequencies and input voltages. As seen from the table, switching losses are exacerbated at higher frequencies and higher $V_{IN}$, mainly due to the higher $V_{DS}$ across the high side MOSFET.

The LTC3833's wide frequency range also helps minimize EMI interference from the switching regulator. The switching frequency can be chosen, and held over line and load, such that the operating frequency and harmonics of the regulator fall outside of the frequency band of the end application. This allows the end application to easily filter out switching noise of the DC/DC converter. Figure 3 shows an example of a 5.5V application that operates above the AM radio band ($f_{SW}$ > 1800kHz) that could be used to power electronics in an automotive infotainment system.

The LTC3833 provides an additional safeguard against EMI and noise interference by allowing it to be synchronized to an external clock applied to the MODE/PLLIN pin. This way, the end application has control over the DC/DC converter's switching cycles and timing so it does not interfere during critical time periods in the application where sensitive signal processing might occur.

**Figure 2b. The LTC3833 can respond quickly to sudden, high slew current requirements.**



High $V_{IN}$, high frequency applications are susceptible to minimum on-time limitations. Consider converting 28V down to 2.5V at 1.2MHz: this requires an on-time of about 74ns, which the LTC3833 easily achieves.

## HIGH STEP-DOWN RATIOS AT HIGH FREQUENCY

The LTC3833 supports high side MOSFET on-times down to 20ns. This is important as lower minimum on-times translate to higher possible step-down ratios ($V_{IN}$ to $V_{OUT}$) at a given switching frequency. Higher switching frequencies require lower on-times to achieve the same step-down ratio. Although the LTC3833's minimum on-time is a function of $V_{IN}$, $V_{OUT}$ and switching frequency (see the data sheet at www.linear.com/3833 for details), it scales in the correct direction—the lowest minimum on-time is at high $V_{IN}$ to low $V_{OUT}$ at high frequency.

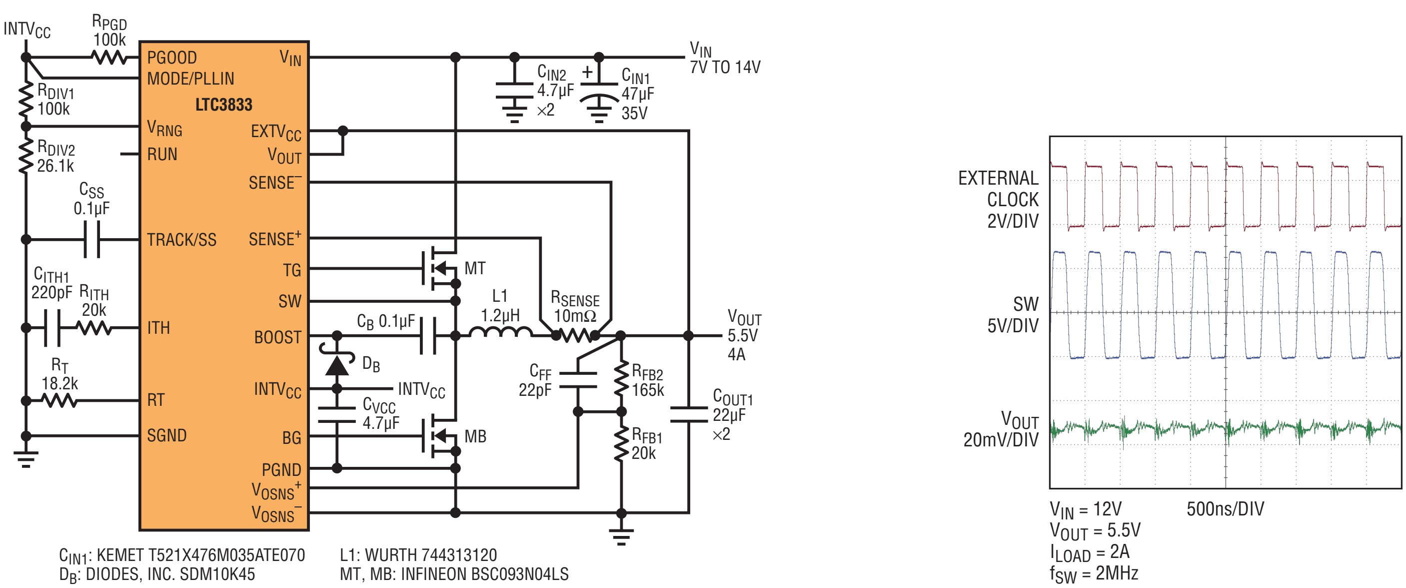
Of course, high $V_{IN}$, high frequency applications are susceptible to minimum on-time limitations. Consider the application in Figure 1 that requires converting 28V down to 2.5V at 1.2MHz. This requires an on-time of about 74ns, which the LTC3833 easily achieves. In contrast, most conventional current mode controllers cannot achieve 74ns of on-time. To run at high frequency, a conventional current mode controller would require two stages of DC/DC conversion, with stage one converting down to an intermediate voltage rail (e.g. 12V), and stage two converting to the final required voltage. This effectively doubles the solution size and degrades overall efficiency.

At very low on-times (20ns–60ns), the power MOSFETs' own switching delays can limit the minimum achievable on-time. Appropriate care must be given to choose power MOSFETs that have low turn-on and turn-off delays, and more importantly, little or no imbalance between their turn-on and turn-off delays. For example, most power MOSFETs' turn-off delay is about 30ns greater than their turn-on delay. This difference directly adds to the LTC3833's 20ns minimum on-time for an effective minimum on-time of about 50ns. Figure 4 shows a high step down ratio application operating at 2MHz where the high side power MOSFET has about a 12ns imbalance between turn-on and turn-off delays.

## HIGH ACCURACY WITH MINIMAL EFFORT

The LTC3833 features true remote differential output sensing. This enables accurate regulation of the output even in high power distributed systems with heavy load currents and shared ground planes. Remote differential sensing is critical for low output voltages, where small offsets caused by parasitic IR drops in

**Figure 3. 14V input, 5.5V output, 4A, 2MHz step-down converter. The LTC3833 can operate at switching frequencies above the AM radio band (f > 1.8MHz) allowing the AM radio to sufficiently filter switching noise and EMI emanating from the step-down converter.**



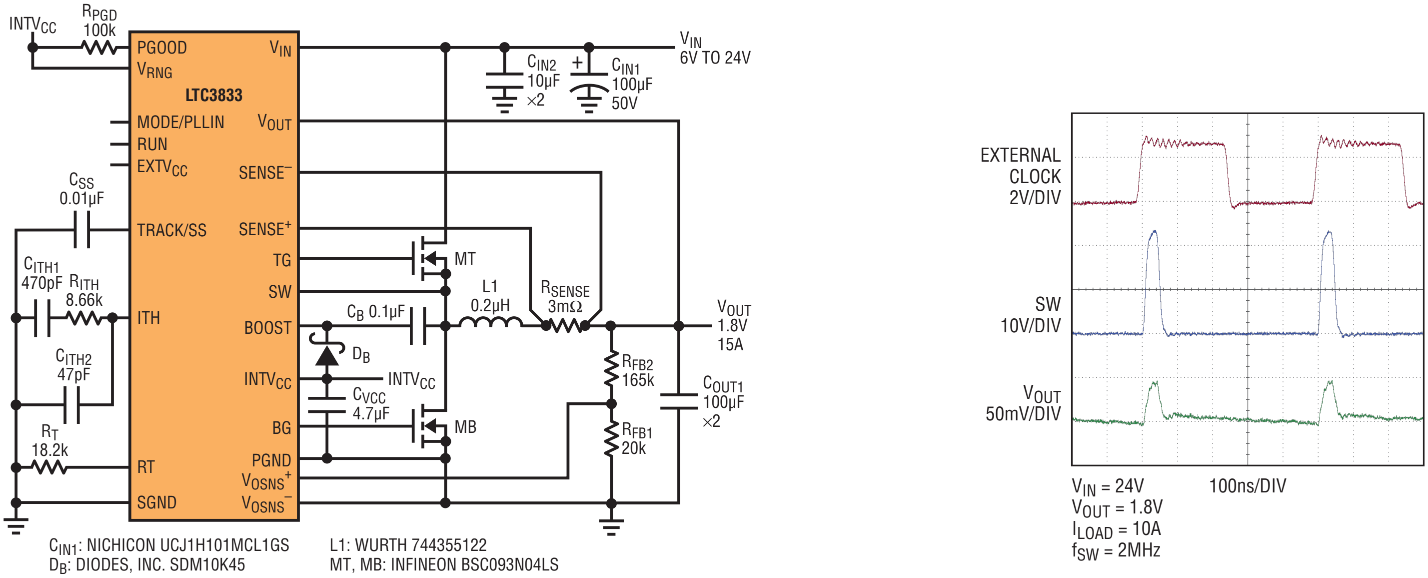



**Figure 4. 24V input, 1.8V output, 15A, 2MHz step-down converter. The LTC3833 can achieve very low on-times, which allows for a single-stage converter design. Using a traditional controller with longer minimum on-times would require two or more stages, which would mean a costlier, bigger and less efficient design.**

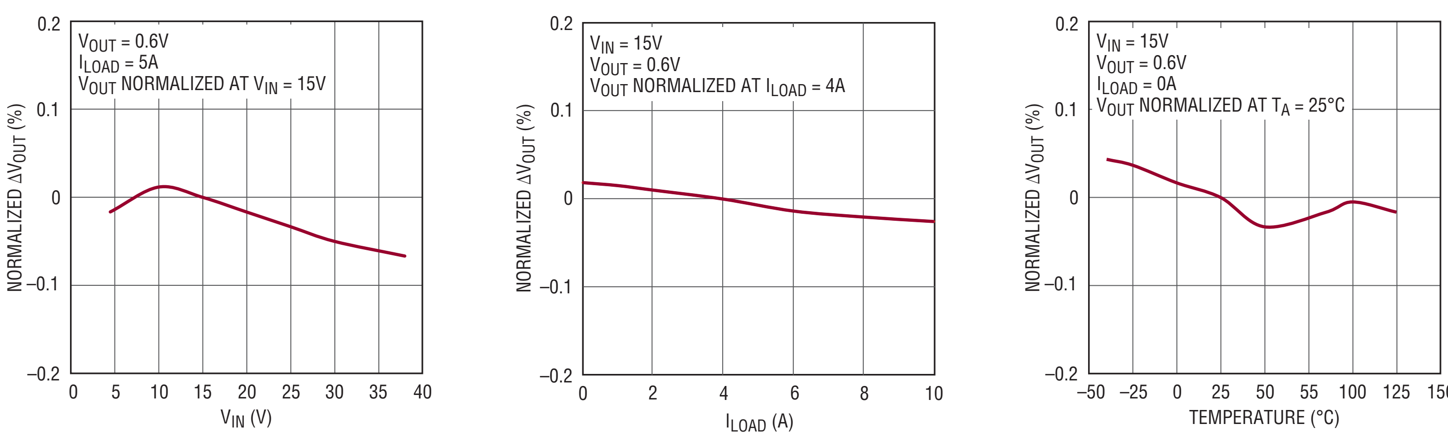
board traces can cost several percentage points in regulation accuracy.

Remote differential output sensing and an accurate internal reference combine to give the LTC3833 excellent output regulation accuracy over line, load and temperature, even when there are offsets caused by trace losses on the PC board. The LTC3833 is able to achieve output accuracy figures of ±0.25% at 25°C, ±0.67% from 0°C to 85°C and ±1% from –40°C to 125°C. Total accuracy that accounts for line, load and remote ground variations are ±1% from 0°C to 85°C and ±1.5% from –40°C to 125°C. Figure 5 illustrates typical regulation accuracy that could be expected from the LTC3833 over line, load and temperature.

Conventional schemes for remote differential output sensing involves a unity gain differential amplifier that senses the remote output and remote ground terminals directly (Figure 6). The output of this amplifier is then scaled down through an external resistor divider (which also programs the output voltage) and fed back into the core controller. In addition to greater design effort involved with this scheme, input and/or output common mode range limitations of the unity gain amplifier can reduce the range of output voltages where remote differential sensing can be used.

Remote differential output sensing is seamless in the LTC3833. It is simple to use, requires minimal, if any, design effort, and requires less area than other remote sensing schemes. As in traditional feedback sensing, the output is sensed through a

**Figure 5. Typical regulation accuracy of the LTC3833 over line, load and temperature**



The LTC3833 features true remote differential output sensing. This allows for accurate regulation of the output even in high power distributed systems with heavy load currents and shared ground planes. Remote differential sensing is critical for low output voltages, where small offsets caused by parasitic IR drops in board traces can cost several percentage points in regulation accuracy.

resistor divider network that is used to program the output voltage. The LTC3833 takes this one step further by sensing the output's remote ground terminal where the other end of the resistor divider network is terminated. Therefore, output voltage programming is similar to other feedback-sensing controllers, but with the advantage that the LTC3833 is able to correct for board losses and offsets. The LTC3833 is invaluable when regulation accuracy is required in high power, high current distributed applications where multiple systems share power and ground planes.

The LTC3833 is designed to handle remote ground offsets as large as ±500mV with respect to local ground. This includes the ability to soft-start smoothly from an initial condition state where the output of the regulator is sitting 500mV below local ground.

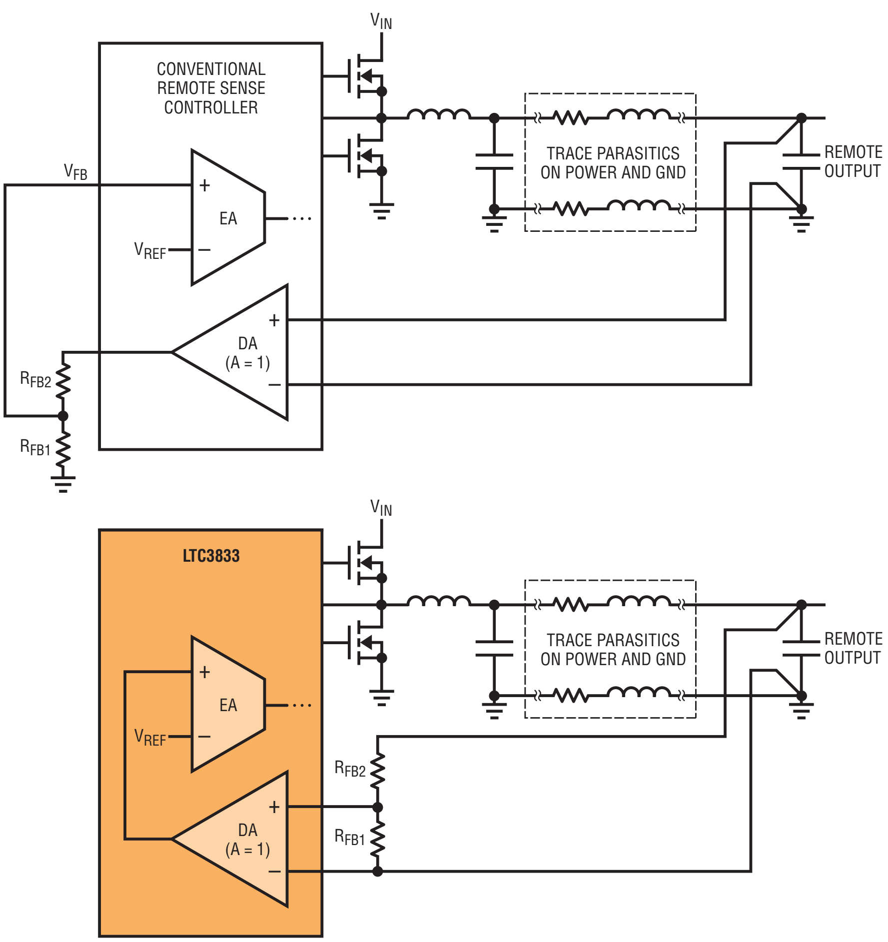



Figure 6. Conventional remote differential sensing involves more design effort and board space than remote sensing with the LTC3833.

## OTHER FEATURES

### Programmable Current Limit

As a valley current mode controller, the LTC3833 senses and controls the valley point of the inductor current in order to maintain output regulation. The inductor current is sensed with a sense resistor in series with the inductor or by sensing the inductor's DCR voltage drop through a RC network across the inductor. Either way, the inductor current is continuously sensed in all switching cycles, which allows accurate and fast control of the output current including output current limit.

The LTC3833 allows programming the output current limit through the voltage on VRNG pin, providing an extra degree of freedom when choosing inductors and sense resistors for a given application. The maximum current sense voltage across the sense resistor or inductor's DCR can be programmed continually from 30mV to 100mV. Figure 7 shows the maximum current sense voltage as a function of the VRNG voltage.

### $EXTV_{CC}$ and $INTV_{CC}$

The LTC3833 has an internal 5.3V low dropout regulator that powers internal control circuitry including the strong high and low side gate drivers, and is available to the outside world through the $INTV_{CC}$ pin. The $INTV_{CC}$ regulator can source a maximum of 50mA while maintaining good regulation, so it can be used in moderation as a supply to power external circuitry or as a bias voltage source. An external supply source (≥4.8V) can be connected to $EXTV_{CC}$ pin to bypass the internal regulator. This is especially

**The LTC3833 also features a continuously programmable current limit, $EXTV_{CC}$, selectable pulse-skipping or forced continuous modes, run enable, supply tracking and soft-start.**

useful for high $V_{IN}$ applications where the internal linear regulator becomes less efficient. If the LTC3833 switching regulator is generating a 5V output, it can be connected back to $EXTV_{CC}$ (shown in Figures 3 and 8). This scheme can increase overall efficiency by 2%–3% versus using the internal 5.3V regulator.

### Pulse-Skipping or Forced Continuous Mode at Light Loads

The LTC3833 offers two modes of operation at light loads to best meet the requirements of a given application. For applications that require high efficiency at light loads, the LTC3833 can be programmed for pulse-skipping mode (by tying MODE/PLLIN pin to GND), which allows the switching regulator to transition into discontinuous conduction mode, thus increasing efficiency by lowering the number of switching cycles. The downsides of pulse-skipping mode are the variable switching frequency (dependent on load current) and a slightly higher output voltage ripple.

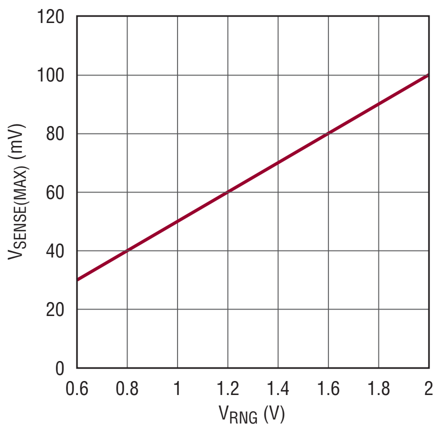
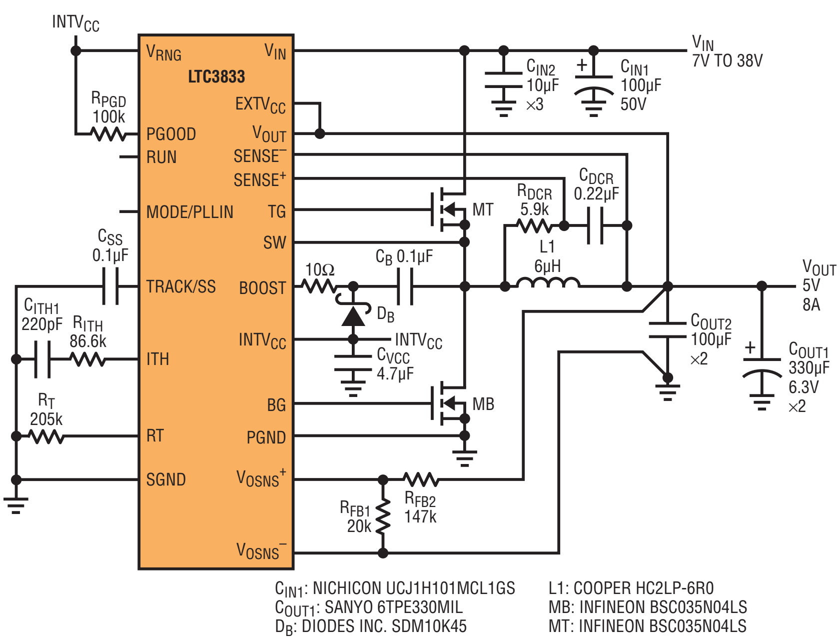



Figure 7. The LTC3833 provides a programmable current limit.

On the other hand, for applications that require predictable EMI performance and value constant switching frequency or require very accurate regulation at light loads, the LTC3833 can be programmed for forced continuous mode (by tying MODE/PLLIN pin to $INTV_{CC}$). In forced continuous mode, the LTC3833 maintains the programmed switching frequency even at no load, but sacrifices light load efficiency in the process. Figure 8 shows an example of the differences in efficiency between the two modes.

### Soft-Start and Tracking

The LTC3833 provides soft-start—either from zero or prebiased output voltage condition (Figure 9)—and external tracking capability through the TRACK/SS pin. The soft-start time and ramp rate can be programmed by a capacitor from TRACK/SS pin to GND. This capacitance and the 1μA current source out of the TRACK/SS pin determine the soft-start time



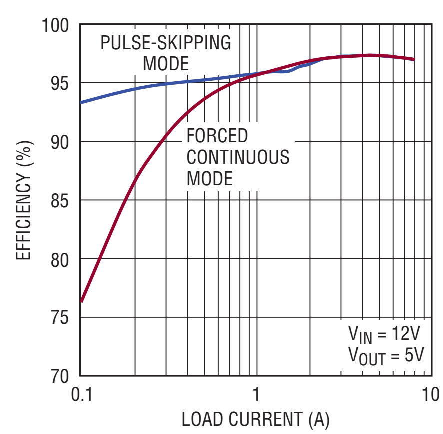




Figure 8. 38V input, 5V output, 8A, 200kHz step-down converter. The LTC3833 offers two modes of operation at light loads: pulse-skipping mode for higher efficiency or forced continuous mode for constant switching frequency.

**The LTC3833 acts quickly and effectively to protect the output and external components of the switching regulator if the output encounters overvoltage, overcurrent and short-circuit conditions.**

and ramp rate. The output reaches its final programmed value when TRACK/SS voltage reaches 0.6V, the internal reference voltage for the LTC3833. Alternatively, an external ramp can drive the TRACK/SS pin in order to track the output of the switching regulator to the external ramp, providing better control of power-up and power-down conditions of the switching regulator.

### Run Enable

The LTC3833 provides a dedicated enable/disable function through the RUN pin. The LTC3833 self-enables when the RUN pin is left floating. It is disabled or shut down by forcing RUN to GND. The quiescent current of the LTC3833 in shutdown is 15µA. The LTC3833 is enabled when RUN is pulled greater than 1.2V, which is an accurate, well-controlled threshold. This allows the RUN pin to be programmed as an input undervoltage lockout if desired by programming a resistor divider from $V_{IN}$ to RUN to GND. The RUN pin can also sink about 35µA of current, allowing it to be pulled directly up to $V_{IN}$ through a sufficiently large pull-up resistor.

### Power Good and Fault Protection

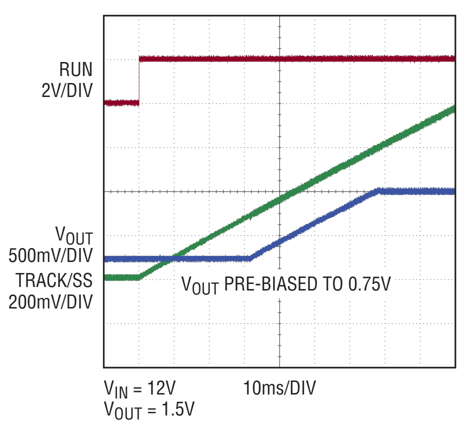
The LTC3833 acts quickly and effectively to protect the output and external components of the switching regulator if the output encounters overvoltage, overcurrent and short-circuit conditions.

The programmed current limit prevents overcurrent conditions and allows the output to droop down when the output current exceeds current limit. During short-circuit conditions, the LTC3833 forces foldback current limiting, where the current limit is progressively lowered to about a quarter of the programmed current limit for a hard short at the output (Figure 10).

Overvoltage conditions are handled by forcing the low side power MOSFET to turn on to discharge the overvoltage at the output.

The LTC3833 provides a power good function through the PGOOD pin, which is an open drain output that is resistively pulled up to a logic level voltage (or $INTV_{CC}$) externally. If the output is within ±7.5% of the programmed value, then PGOOD is high, indicating power is good.

Figure 9. The LTC3833 can smoothly start up into a prebiased output.




## CONCLUSION

The LTC3833 is a synchronous step-down DC/DC controller that can meet the demands of high current, low voltage applications while remaining versatile enough to fit a wide range of step-down DC/DC applications.

It provides the usual set of features such as soft-start, power good and fault protection commonly available with step-down controllers. It also adds some invaluable extras, including remote output sensing, programmable current limit, external clock synchronization and $EXTV_{CC}$. It also features high performance specs, including 0.67% output accuracy, switching frequency (up to 2MHz) above the AM radio band, high step-down ratios through a 20ns minimum on-time, and quick response time to transient conditions in the line and load. ■

Figure 10. During a short circuit at the output, the LTC3833 reduces the output current to 1/4 of programmed current limit.