# 600mA, 500kHz Step-Down Switching Regulator in SOT-23 and DFN Packages

## FEATURES

- **Wide Input Range: 3.6V to 36V**
- 5V at 600mA from 16V to 36V Input
- 3.3V at 600mA from 12V to 36V Input
- 5V at 500mA from 6.3V to 36V Input
- 3.3V at 500mA from 4.5V to 36V Input
- Fixed Frequency 500kHz Operation
- Uses Tiny Capacitors and Inductors
- Soft-Start
- Internally Compensated
- Low Shutdown Current: <2μA
- Output Adjustable Down to 1.25V
- Low Profile (1mm) SOT-23 (ThinSOT™) and (2mm × 3mm × 0.75mm) 6-Pin DFN Packages

## APPLICATIONS

- Automotive Battery Regulation
- Industrial Control Supplies
- Wall Transformer Regulation
- Distributed Supply Regulation
- Battery-Powered Equipment

## DESCRIPTION

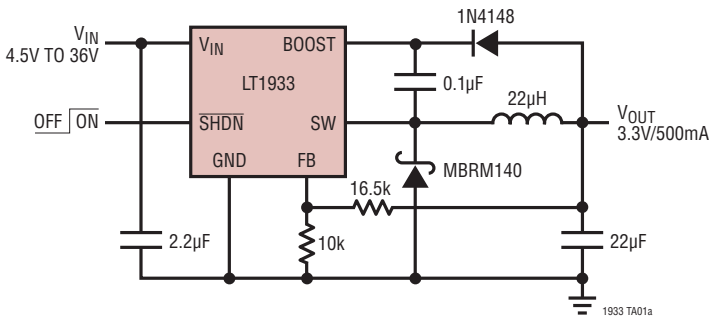
The LT®1933 is a current mode PWM step-down DC/DC converter with an internal 0.75A power switch, packaged in a tiny 6-lead SOT-23. The wide input range of 3.6V to 36V makes the LT1933 suitable for regulating power from a wide variety of sources, including unregulated wall transformers, 24V industrial supplies and automotive batteries. Its high operating frequency allows the use of tiny, low cost inductors and ceramic capacitors, resulting in low, predictable output ripple.

Cycle-by-cycle current limit provides protection against shorted outputs, and soft-start eliminates input current surge during start up. The low current (<2μA) shutdown provides output disconnect, enabling easy power management in battery-powered systems.

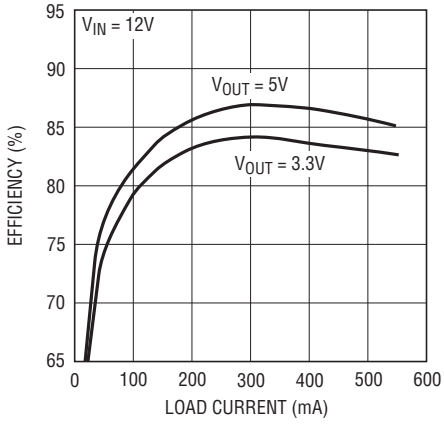
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## TYPICAL APPLICATION

**3.3V Step-Down Converter**




**Efficiency**

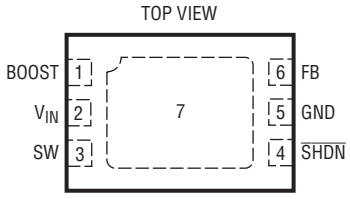


## ABSOLUTE MAXIMUM RATINGS

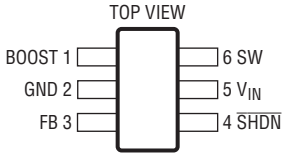
**(Note 1)**

Input Voltage ($V_{IN}$) ..... –0.4V to 36V
BOOST Pin Voltage ..... 43V
BOOST Pin Above SW Pin ..... 20V
$\overline{SHDN}$ Pin ..... –0.4V to 36V
FB Voltage ..... –0.4V to 6V
Operating Temperature Range (Note 2)
LT1933E ..... –40°C to 85°C
LT1933I ..... –40°C to 125°C
LT1933H ..... –40°C to 150°C
Maximum Junction Temperature
LT1933E, LT1933I ..... 125°C
LT1933H ..... 150°C
Storage Temperature Range ..... –65°C to 150°C
Lead Temperature, S6 Package
(Soldering, 10 sec) ..... 300°C

## PIN CONFIGURATION




DCB PACKAGE
6-LEAD (2mm × 3mm) PLASTIC DFN
$\theta_{JA}$ = 73.5°C/W, $\theta_{JC}$ = 12°C/W
EXPOSED PAD (PIN 7) IS GND, MUST BE SOLDERED TO PCB




S6 PACKAGE
6-LEAD PLASTIC TSOT-23
$\theta_{JA}$ = 165°C/W, $\theta_{JC}$ = 102°C/W

## ORDER INFORMATION

| LEAD FREE FINISH | TAPE AND REEL | PART MARKING | PACKAGE DESCRIPTION | TEMPERATURE RANGE |
|---|---|---|---|---|
| LT1933IDCB#PBF | LT1933IDCB#TRPBF | LCGM | 6-Lead (2mm × 3mm) Plastic DFN | –40°C to 125°C |
| LT1933HDCB#PBF | LT1933HDCB#TRPBF | LCGN | 6-Lead (2mm × 3mm) Plastic DFN | –40°C to 150°C |
| LT1933ES6#PBF | LT1933ES6#TRPBF | LTAGN | 6-Lead Plastic TSOT-23 | –40°C to 85°C |
| LT1933IS6#PBF | LT1933IS6#TRPBF | LTAGP | 6-Lead Plastic TSOT-23 | –40°C to 125°C |
| LT1933HS6#PBF | LT1933HS6#TRPBF | LTDDQ | 6-Lead Plastic TSOT-23 | –40°C to 150°C |
| **LEAD BASED FINISH** | **TAPE AND REEL** | **PART MARKING** | **PACKAGE DESCRIPTION** | **TEMPERATURE RANGE** |
| LT1933IDCB | LT1933IDCB#TR | LCGM | 6-Lead (2mm × 3mm) Plastic DFN | –40°C to 125°C |
| LT1933HDCB | LT1933HDCB#TR | LCGN | 6-Lead (2mm × 3mm) Plastic DFN | –40°C to 150°C |
| LT1933ES6 | LT1933ES6#TR | LTAGN | 6-Lead Plastic TSOT-23 | –40°C to 85°C |
| LT1933IS6 | LT1933IS6#TR | LTAGP | 6-Lead Plastic TSOT-23 | –40°C to 125°C |
| LT1933HS6 | LT1933HS6#TR | LTDDQ | 6-Lead Plastic TSOT-23 | –40°C to 150°C |

Consult LTC Marketing for parts specified with wider operating temperature ranges.

For more information on lead free part marking, go to: http://www.linear.com/leadfree/
For more information on tape and reel specifications, go to: http://www.linear.com/tapeandreel/

## ELECTRICAL CHARACTERISTICS

**The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A$ = 25°C. $V_{IN}$ = 12V, $V_{BOOST}$ = 17V, unless otherwise noted. (Note 2)**

| PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Undervoltage Lockout | | | | 3.35 | 3.6 | V |
| Feedback Voltage | | ● | 1.225 | 1.245 | 1.265 | V |
| FB Pin Bias Current | $V_{FB}$ = Measured $V_{REF}$ + 10mV (Note 4) | ● | | 40 | 120 | nA |
| Quiescent Current | Not Switching | | | 1.6 | 2.5 | mA |
| Quiescent Current in Shutdown | $V_{\overline{SHDN}}$ = 0V | | | 0.01 | 2 | µA |
| Reference Line Regulation | $V_{IN}$ = 5V to 36V | | | 0.01 | | %/V |
| Switching Frequency | $V_{FB}$ = 1.1V | | 400 | 500 | 600 | kHz |
| | $V_{FB}$ = 0V | | | 55 | | kHz |
| Maximum Duty Cycle | | ● | 88 | 94 | | % |
| Switch Current Limit | (Note 3) | | 0.75 | 1.05 | | A |
| Switch $V_{CESAT}$ | $I_{SW}$ = 400mA, S6 Package<br>$I_{SW}$ = 400mA, DCB6 Package | | | 370<br>370 | 500 | mV<br>mV |
| Switch Leakage Current | | | | | 2 | µA |
| Minimum Boost Voltage Above Switch | $I_{SW}$ = 400mA | | | 1.9 | 2.3 | V |
| BOOST Pin Current | $I_{SW}$ = 400mA | | | 18 | 25 | mA |
| $\overline{SHDN}$ Input Voltage High | | | 2.3 | | | V |
| $\overline{SHDN}$ Input Voltage Low | | | | | 0.3 | V |
| $\overline{SHDN}$ Bias Current | $V_{\overline{SHDN}}$ = 2.3V (Note 5)<br>$V_{\overline{SHDN}}$ = 0V | | | 34<br>0.01 | 50<br>0.1 | µA<br>µA |

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** The LT1933E is guaranteed to meet performance specifications from 0°C to 70°C. Specifications over the –40°C to 85°C operating temperature range are assured by design, characterization and correlation with statistical process controls. The LT1933I specifications are guaranteed over the –40°C to 125°C temperature range. The LT1933H specifications are guaranteed over the –40°C to 150°C temperature range.

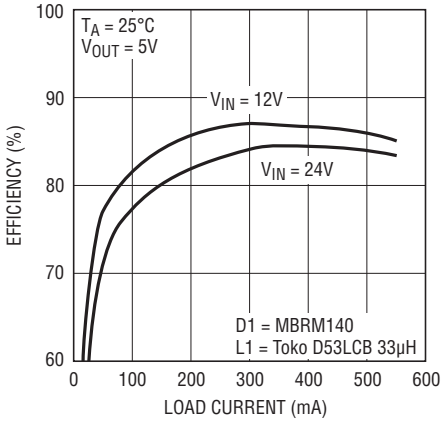
**Note 3:** Current limit guaranteed by design and/or correlation to static test. Slope compensation reduces current limit at higher duty cycle.

**Note 4:** Current flows out of pin.

**Note 5:** Current flows into pin.

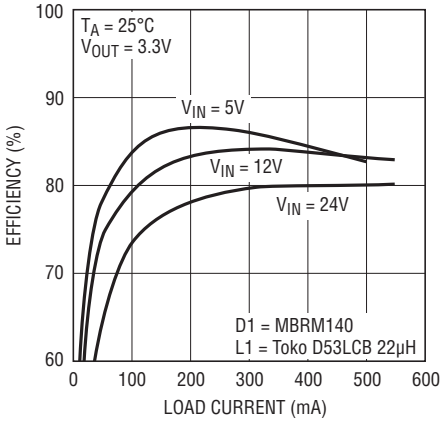
# TYPICAL PERFORMANCE CHARACTERISTICS

### Efficiency, $V_{OUT}$ = 5V



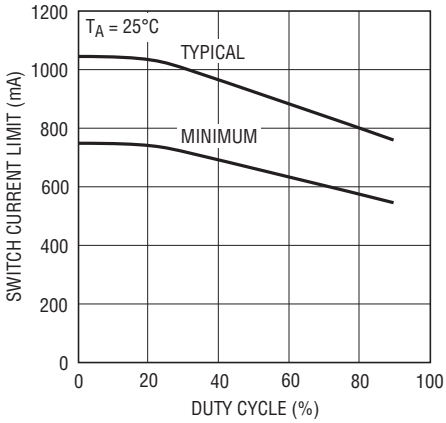

1933 G01

### Efficiency, $V_{OUT}$ = 3.3V



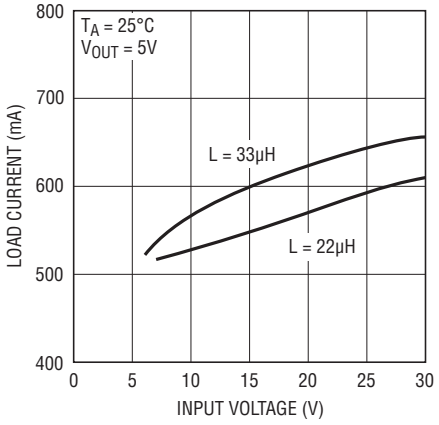

1933 G02

### Switch Current Limit



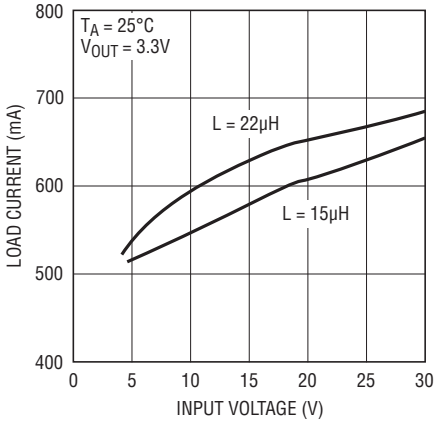

1933 G03

### Maximum Load Current



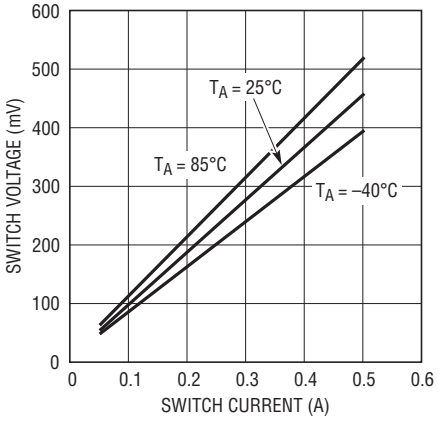

1933 G04

### Maximum Load Current



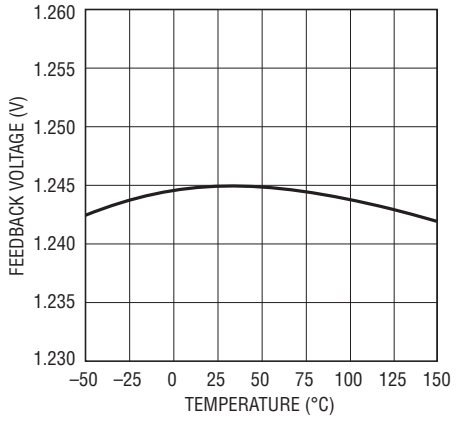

1933 G05

### Switch Voltage Drop



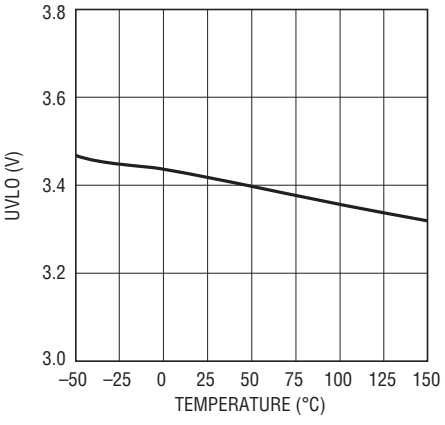

1933 G06

### Feedback Voltage



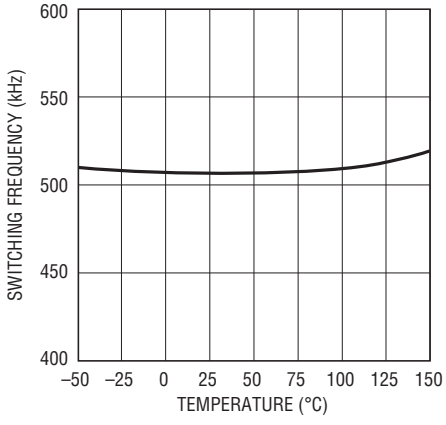

1933 G07

### Undervoltage Lockout




1933 G08

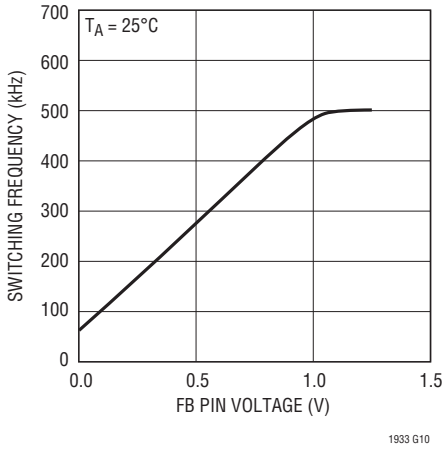
### Switching Frequency



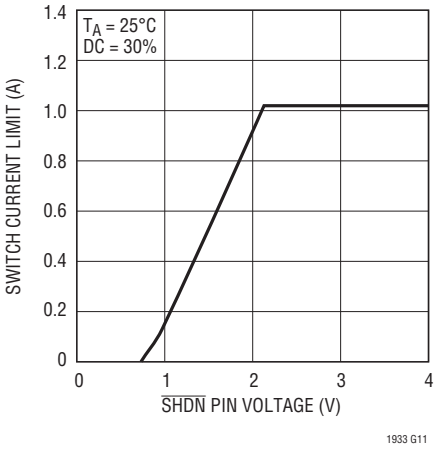

1933 G09

# TYPICAL PERFORMANCE CHARACTERISTICS

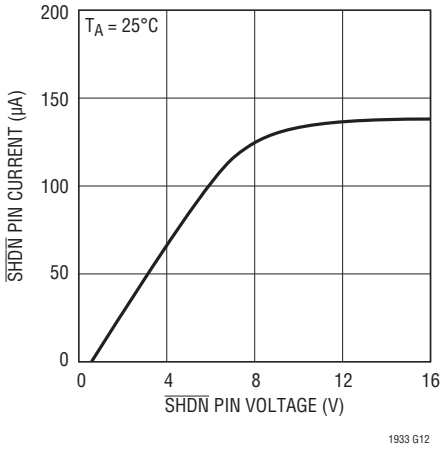
### Frequency Foldback



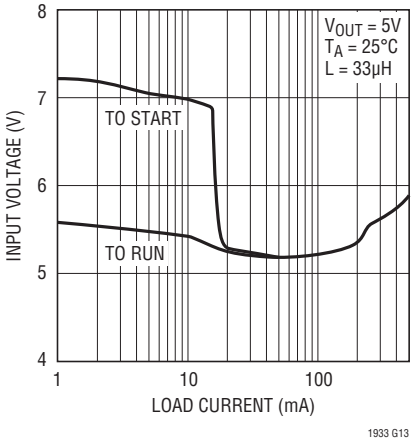

### Soft-Start



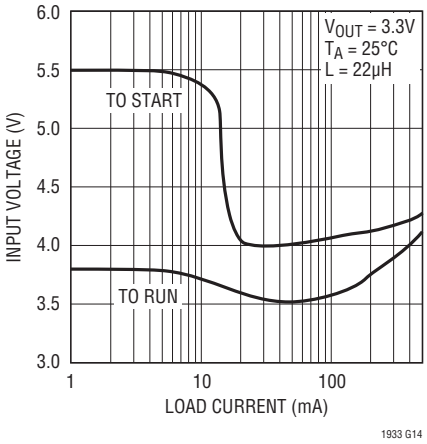

### SHDN Pin Current



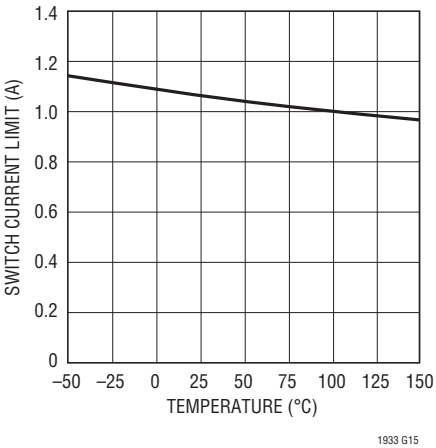

### Typical Minimum Input Voltage



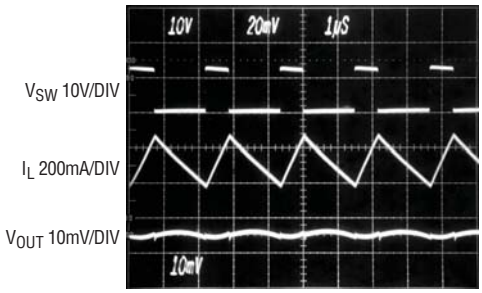

### Typical Minimum Input Voltage




### Switch Current Limit

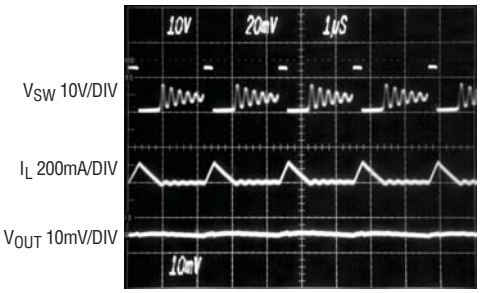



### Operating Waveforms




$V_{IN}$ = 12V, $V_{OUT}$ = 3.3V, $I_{OUT}$ = 400mA,
L = 22µH, $C_{OUT}$ = 22µF

### Operating Waveforms, Discontinuous Mode




$V_{IN}$ = 12V, $V_{OUT}$ = 3.3V, $I_{OUT}$ = 20mA,
L = 22µH, $C_{OUT}$ = 22µF

## PIN FUNCTIONS (SOT-23/DFN)

**BOOST (Pin 1):** The BOOST pin is used to provide a drive voltage, higher than the input voltage, to the internal bipolar NPN power switch.

**GND (Pin 2/Pin 5 and Exposed Pad, Pin 7):** Tie the GND pin to a local ground plane below the LT1933 and the circuit components. Return the feedback divider to this pin.

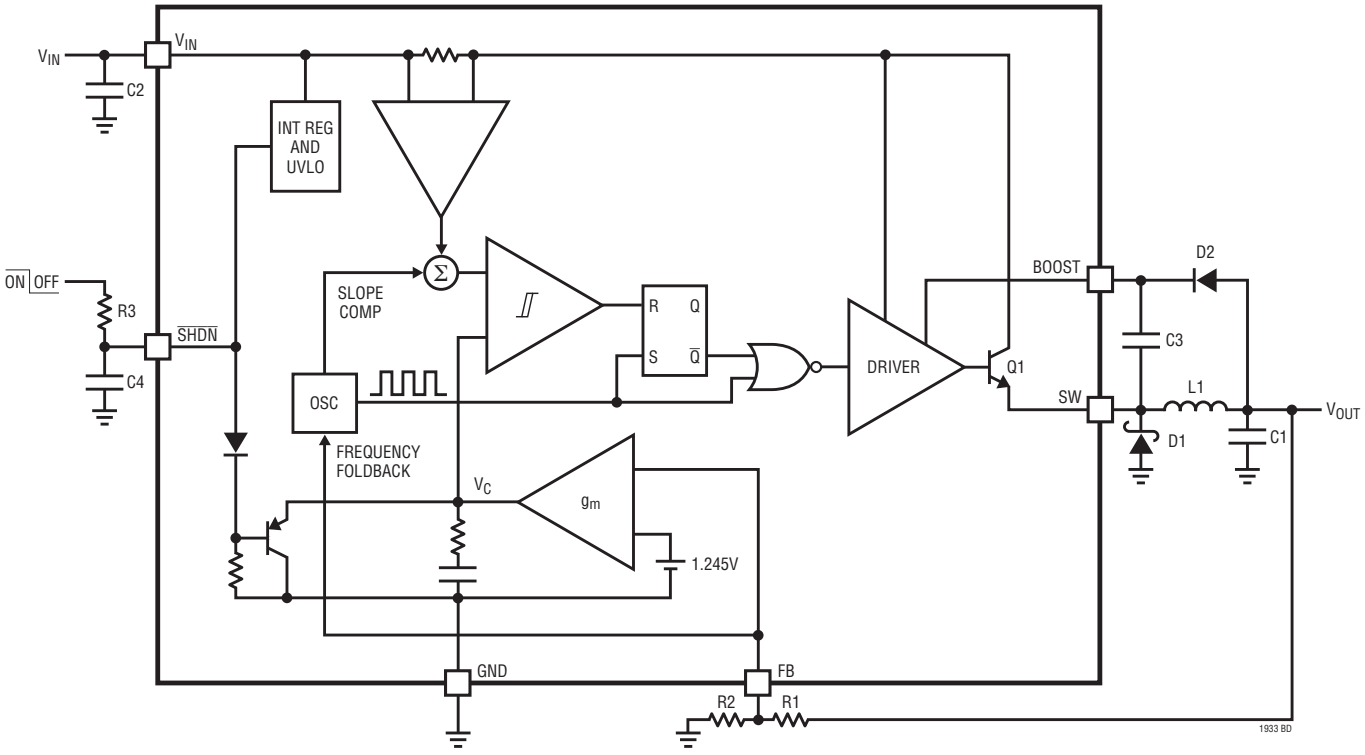
**FB (Pin 3/Pin 6):** The LT1933 regulates its feedback pin to 1.245V. Connect the feedback resistor divider tap to this pin. Set the output voltage according to $V_{OUT}$ = 1.245V (1 + R1/R2). A good value for R2 is 10k.

**$\overline{SHDN}$ (Pin 4):** The $\overline{SHDN}$ pin is used to put the LT1933 in shutdown mode. Tie to ground to shut down the LT1933. Tie to 2.3V or more for normal operation. If the shutdown feature is not used, tie this pin to the $V_{IN}$ pin. $\overline{SHDN}$ also provides a soft-start function; see the Applications Information section.

**$V_{IN}$ (Pin 5/Pin 2):** The $V_{IN}$ pin supplies current to the LT1933's internal regulator and to the internal power switch. This pin must be locally bypassed.

**SW (Pin 6):** The SW pin is the output of the internal power switch. Connect this pin to the inductor, catch diode and boost capacitor.

## BLOCK DIAGRAM



## OPERATION (Refer to Block Diagram)

The LT1933 is a constant frequency, current mode step down regulator. A 500kHz oscillator enables an RS flip-flop, turning on the internal 750mA power switch Q1. An amplifier and comparator monitor the current flowing between the $V_{IN}$ and SW pins, turning the switch off when this current reaches a level determined by the voltage at $V_C$. An error amplifier measures the output voltage through an external resistor divider tied to the FB pin and servos the $V_C$ node. If the error amplifier's output increases, more current is delivered to the output; if it decreases, less current is delivered. An active clamp (not shown) on the $V_C$ node provides current limit. The $V_C$ node is also clamped to the voltage on the $\overline{SHDN}$ pin; soft-start is implemented by generating a voltage ramp at the $\overline{SHDN}$ pin using an external resistor and capacitor.

An internal regulator provides power to the control circuitry. This regulator includes an undervoltage lockout to prevent switching when $V_{IN}$ is less than ~3.35V. The $\overline{SHDN}$ pin is used to place the LT1933 in shutdown, disconnecting the output and reducing the input current to less than 2µA.

The switch driver operates from either the input or from the BOOST pin. An external capacitor and diode are used to generate a voltage at the BOOST pin that is higher than the input supply. This allows the driver to fully saturate the internal bipolar NPN power switch for efficient operation.

The oscillator reduces the LT1933's operating frequency when the voltage at the FB pin is low. This frequency foldback helps to control the output current during startup and overload.

## APPLICATIONS INFORMATION

### FB Resistor Network

The output voltage is programmed with a resistor divider between the output and the FB pin. Choose the 1% resistors according to:

$$R1 = R2(V_{OUT}/1.245 - 1)$$

R2 should be 20k or less to avoid bias current errors. Reference designators refer to the Block Diagram.

### Input Voltage Range

The input voltage range for LT1933 applications depends on the output voltage and on the absolute maximum ratings of the $V_{IN}$ and BOOST pins.

The minimum input voltage is determined by either the LT1933's minimum operating voltage of ~3.35V, or by its maximum duty cycle. The duty cycle is the fraction of time that the internal switch is on and is determined by the input and output voltages:

$$DC = (V_{OUT} + V_D)/(V_{IN} - V_{SW} + V_D)$$

where $V_D$ is the forward voltage drop of the catch diode (~0.4V) and $V_{SW}$ is the voltage drop of the internal switch (~0.4V at maximum load). This leads to a minimum input voltage of:

$$V_{IN(MIN)} = (V_{OUT} + V_D)/DC_{MAX} - V_D + V_{SW}$$

with $DC_{MAX} = 0.88$

The maximum input voltage is determined by the absolute maximum ratings of the $V_{IN}$ and BOOST pins and by the minimum duty cycle $DC_{MIN} = 0.08$ (corresponding to a minimum on time of 130ns):

$$V_{IN(MAX)} = (V_{OUT} + V_D)/DC_{MIN} - V_D + V_{SW}$$

Note that this is a restriction on the operating input voltage; the circuit will tolerate transient inputs up to the absolute maximum ratings of the $V_{IN}$ and BOOST pins.

### Inductor Selection and Maximum Output Current

A good first choice for the inductor value is:

$$L = 5\ (V_{OUT} + V_D)$$

where $V_D$ is the voltage drop of the catch diode (~0.4V) and L is in µH. With this value the maximum load current will be above 500mA. The inductor's RMS current rating must be greater than your maximum load current and its

## APPLICATIONS INFORMATION

saturation current should be about 30% higher. For robust operation in fault conditions the saturation current should be ~1A. To keep efficiency high, the series resistance (DCR) should be less than 0.2Ω. Table 1 lists several vendors and types that are suitable.

Of course, such a simple design guide will not always result in the optimum inductor for your application. A larger value provides a slightly higher maximum load current, and will reduce the output voltage ripple. If your load is lower than 500mA, then you can decrease the value of the inductor and operate with higher ripple current. This allows you to use a physically smaller inductor, or one with a lower DCR resulting in higher efficiency. There are several graphs in the Typical Performance Characteristics section of this data sheet that show the maximum load current as a function of input voltage and inductor value for several popular output voltages. Low inductance may result in discontinuous mode operation, which is OK, but further reduces maximum load current. For details of maximum output current and discontinuous mode operation, see Linear Technology Application Note 44. Finally, for duty cycles greater than 50% ($V_{OUT}/V_{IN} > 0.5$), there is a minimum inductance required to avoid subharmonic oscillations. Choosing L greater than $3(V_{OUT} + V_D)$ µH prevents subharmonic oscillations at all duty cycles.

### Catch Diode

A 0.5A or 1A Schottky diode is recommended for the catch diode, D1. The diode must have a reverse voltage rating equal to or greater than the maximum input voltage. The ON Semiconductor MBR0540 is a good choice; it is rated for 0.5A forward current and a maximum reverse voltage of 40V. The MBRM140 provides better efficiency, and will handle extended overload conditions.

### Input Capacitor

Bypass the input of the LT1933 circuit with a 2.2µF or higher value ceramic capacitor of X7R or X5R type. Y5V types have poor performance over temperature and applied voltage, and should not be used. A 2.2µF ceramic is adequate to bypass the LT1933 and will easily handle the ripple current. However, if the input power source has high impedance, or there is significant inductance due to long wires or cables, additional bulk capacitance may be necessary. This can be provided with a low performance electrolytic capacitor.

Step-down regulators draw current from the input supply in pulses with very fast rise and fall times. The input capacitor is required to reduce the resulting voltage ripple at the LT1933 and to force this very high frequency

**Table 1. Inductor Vendors**

| Vendor | URL | Part Series | Inductance Range (µH) | Size (mm) |
|---|---|---|---|---|
| Coilcraft | www.coilcraft.com | D01608C | 10 to 22 | 2.9 × 4.5 × 6.6 |
| | | MSS5131 | 10 to 22 | 3.1 × 5.1 × 5.1 |
| | | MSS6122 | 10 to 33 | 2.2 × 6.1 × 6.1 |
| Sumida | www.sumida.com | CR43 | 10 to 22 | 3.5 × 4.3 × 4.8 |
| | | CDRH4D28 | 10 to 33 | 3.0 × 5.0 × 5.0 |
| | | CDRH5D28 | 22 to 47 | 3.0 × 5.7 × 5.7 |
| Toko | www.toko.com | D52LC | 10 to 22 | 2.0 × 5.0 × 5.0 |
| | | D53LC | 22 to 47 | 3.0 × 5.0 × 5.0 |
| Würth Elektronik | www.we-online.com | WE-TPC MH | 10 to 22 | 2.8 × 4.8 × 4.8 |
| | | WE-PD4 S | 10 to 22 | 2.9 × 4.5 × 6.6 |
| | | WE-PD2 S | 10 to 47 | 3.2 × 4.0 × 4.5 |

## APPLICATIONS INFORMATION

switching current into a tight local loop, minimizing EMI. A 2.2µF capacitor is capable of this task, but only if it is placed close to the LT1933 and the catch diode; see the PCB Layout section. A second precaution regarding the ceramic input capacitor concerns the maximum input voltage rating of the LT1933. A ceramic input capacitor combined with trace or cable inductance forms a high quality (under damped) tank circuit. If the LT1933 circuit is plugged into a live supply, the input voltage can ring to twice its nominal value, possibly exceeding the LT1933's voltage rating. This situation is easily avoided; see the Hot Plugging Safely section.

### Output Capacitor

The output capacitor has two essential functions. Along with the inductor, it filters the square wave generated by the LT1933 to produce the DC output. In this role it determines the output ripple, and low impedance at the switching frequency is important. The second function is to store energy in order to satisfy transient loads and stabilize the LT1933's control loop.

Ceramic capacitors have very low equivalent series resistance (ESR) and provide the best ripple performance. A good value is

$$C_{OUT} = 60/V_{OUT}$$

where $C_{OUT}$ is in µF. Use X5R or X7R types, and keep in mind that a ceramic capacitor biased with $V_{OUT}$ will have less than its nominal capacitance. This choice will provide low output ripple and good transient response. Transient performance can be improved with a high value capacitor, but a phase lead capacitor across the feedback resistor R1 may be required to get the full benefit (see the Compensation section).

High performance electrolytic capacitors can be used for the output capacitor. Low ESR is important, so choose one that is intended for use in switching regulators. The ESR should be specified by the supplier, and should be 0.1Ω or less. Such a capacitor will be larger than a ceramic capacitor and will have a larger capacitance, because the capacitor must be large to achieve low ESR. Table 2 lists several capacitor vendors.

**Table 2. Inductor Vendors**

| Vendor | Phone | URL | Part Series | Comments |
|---|---|---|---|---|
| Panasonic | (714) 373-7366 | www.panasonic.com | Ceramic, Polymer, Tantalum | EEF Series |
| Kemet | (864) 963-6300 | www.kemet.com | Ceramic, Tantalum | T494, T495 |
| Sanyo | (408) 749-9714 | www.sanyovideo.com | Ceramic, Polymer, Tantalum | POSCAP |
| Murata | (404)436-1300 | www.murata.com | Ceramic | |
| AVX | | www.avxcorp.com | Ceramic, Tantalum | TPS Series |
| Taiyo Yuden | (864)963-6300 | www.taiyo-yuden.com | Ceramic | |

## APPLICATIONS INFORMATION

Figure 1 shows the transient response of the LT1933 with several output capacitor choices. The output is 3.3V. The load current is stepped from 100mA to 400mA and back to 100mA, and the oscilloscope traces show the output voltage. The upper photo shows the recommended value. The second photo shows the improved response (less voltage drop) resulting from a larger output capacitor and a phase lead capacitor. The last photo shows the response to a high performance electrolytic capacitor. Transient performance is improved due to the large output capacitance, but output ripple (as shown by the broad trace) has increased because of the higher ESR of this capacitor.

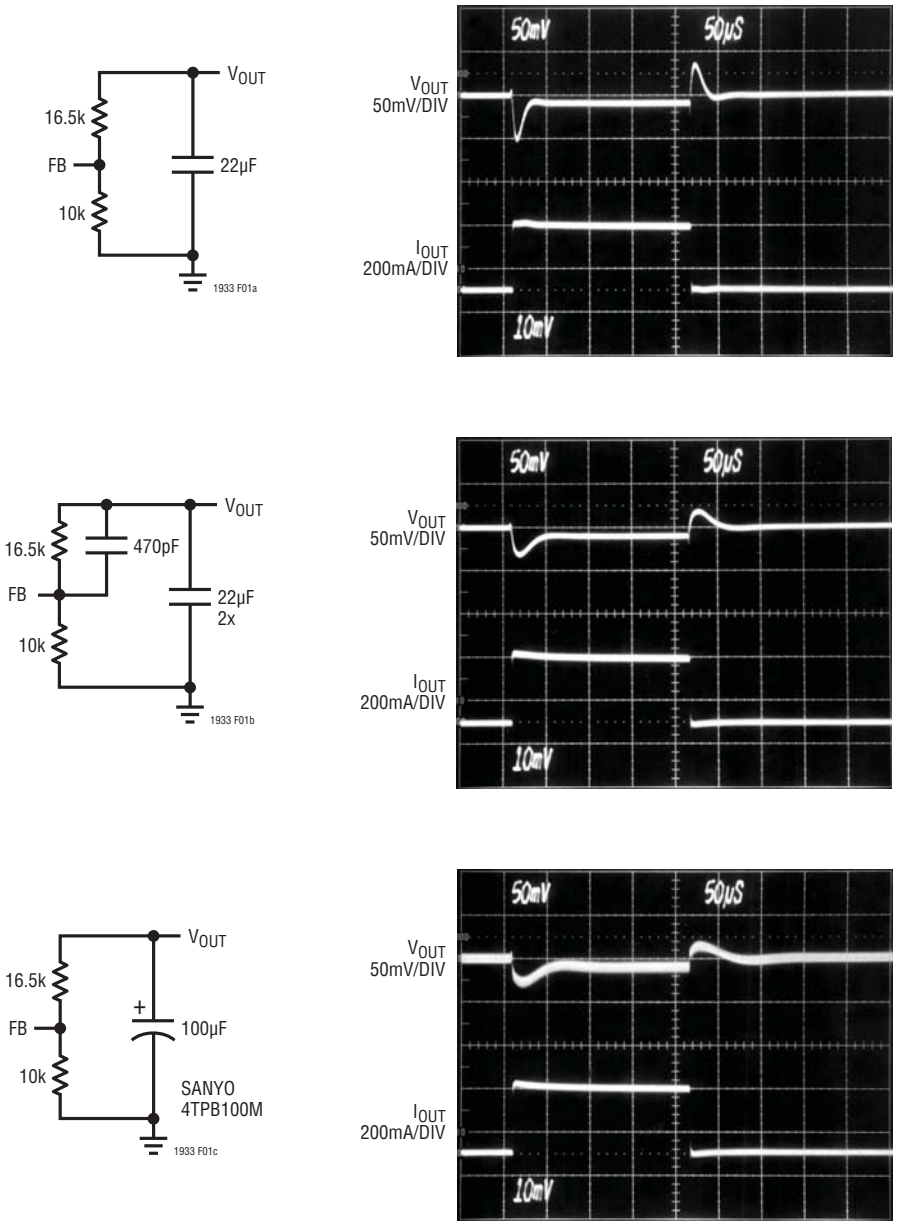



**Figure 1. Transient Load Response of the LT1933 with Different Output Capacitors as the Load Current is Stepped from 100mA to 400mA. $V_{IN}$ = 12V, $V_{OUT}$ = 3.3V, L = 22µH.**

## APPLICATIONS INFORMATION

### BOOST Pin Considerations

Capacitor C3 and diode D2 are used to generate a boost voltage that is higher than the input voltage. In most cases a 0.1µF capacitor and fast switching diode (such as the 1N4148 or 1N914) will work well. Figure 2 shows two ways to arrange the boost circuit. The BOOST pin must be at least 2.3V above the SW pin for best efficiency. For outputs of 3V and above, the standard circuit (Figure 2a) is best. For outputs between 2.5V and 3V, use a 0.47µF capacitor and a small Schottky diode (such as the BAT-54). For lower output voltages the boost diode can be tied to the input (Figure 2b). The circuit in Figure 2a is more efficient because the BOOST pin current comes from a lower voltage source. You must also be sure that the maximum voltage rating of the BOOST pin is not exceeded.

The minimum operating voltage of an LT1933 application is limited by the undervoltage lockout (~3.35V) and by the maximum duty cycle as outlined above. For proper startup, the minimum input voltage is also limited by the boost circuit. If the input voltage is ramped slowly, or the LT1933 is turned on with its $\overline{SHDN}$ pin when the output is already in regulation, then the boost capacitor may not be fully charged. Because the boost capacitor is charged with the energy stored in the inductor, the circuit will rely on some minimum load current to get the boost circuit running properly. This minimum load will depend on input and output voltages, and on the arrangement of the boost circuit. The minimum load generally goes to zero once the circuit has started. Figure 3 shows a plot of minimum load to start and to run as a function of input voltage. In many

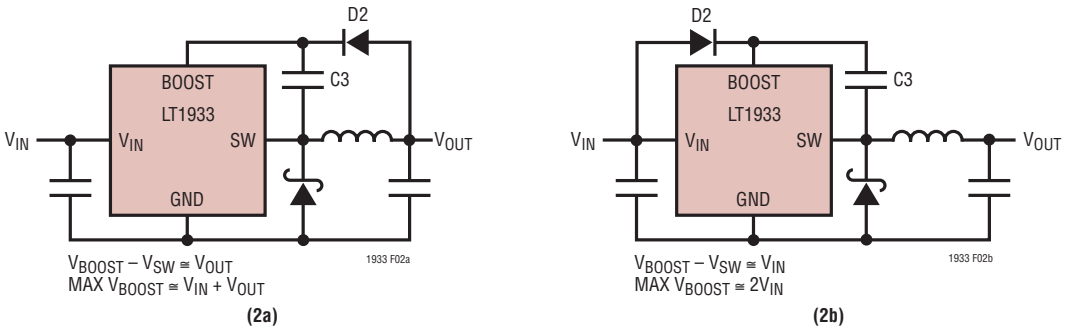



**Figure 2. Two Circuits for Generating the Boost Voltage**

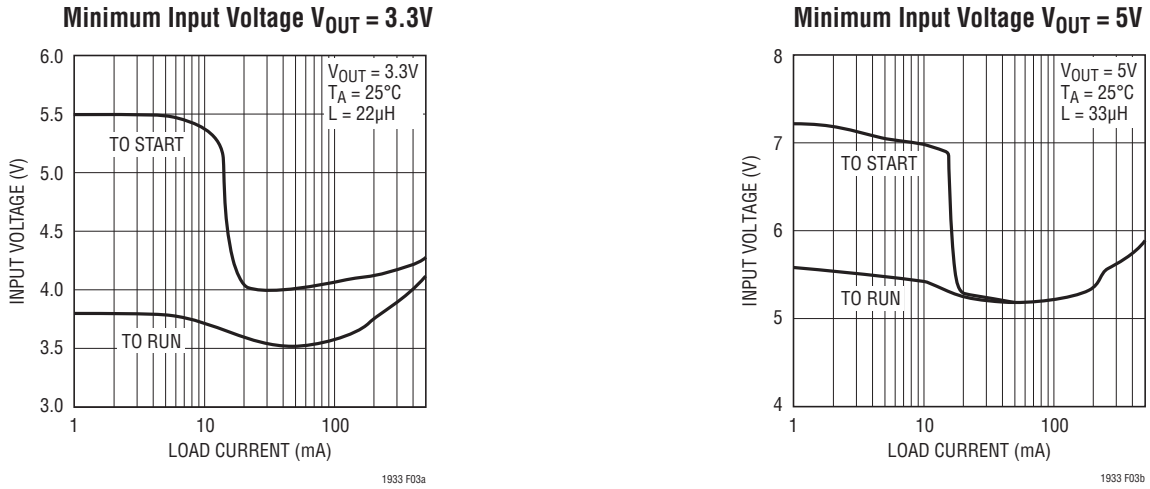



**Figure 3. The Minimum Input Voltage Depends on Output Voltage, Load Current and Boost Circuit**

## APPLICATIONS INFORMATION

cases the discharged output capacitor will present a load to the switcher which will allow it to start. The plots show the worst-case situation where $V_{IN}$ is ramping very slowly. For lower start-up voltage, the boost diode can be tied to $V_{IN}$; however, this restricts the input range to one-half of the absolute maximum rating of the BOOST pin.

At light loads, the inductor current becomes discontinuous and the effective duty cycle can be very high. This reduces the minimum input voltage to approximately 300mV above $V_{OUT}$. At higher load currents, the inductor current is continuous and the duty cycle is limited by the maximum duty cycle of the LT1933, requiring a higher input voltage to maintain regulation.

### Soft-Start

The $\overline{SHDN}$ pin can be used to soft-start the LT1933, reducing the maximum input current during start up. The $\overline{SHDN}$ pin is driven through an external RC filter to create a voltage ramp at this pin. Figure 4 shows the start up waveforms with and without the soft-start circuit. By choosing a large RC time constant, the peak start up current can be reduced to the current that is required to regulate the output, with no overshoot. Choose the value of the resistor so that it can supply 60µA when the $\overline{SHDN}$ pin reaches 2.3V.

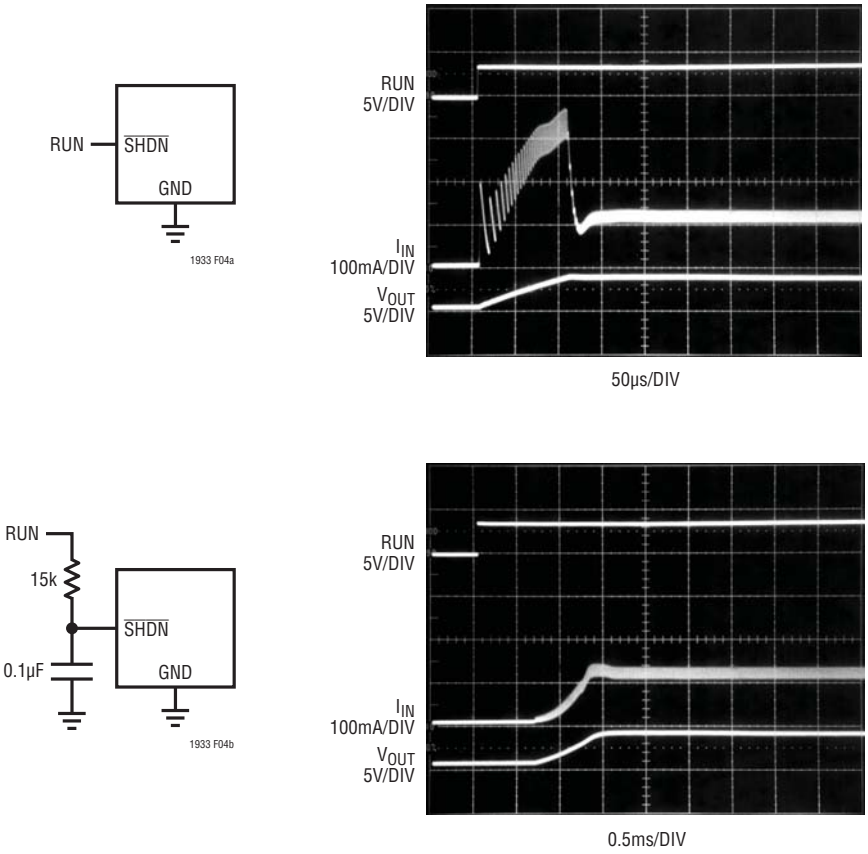



**Figure 4. To Soft-Start the LT1933, Add a Resistor and Capacitor to the $\overline{SHDN}$ Pin. $V_{INI}$ = 12V, $V_{OUT}$ = 3.3V, $C_{OUT}$ = 22µF, $R_{LOAD}$ = 10Ω**

## APPLICATIONS INFORMATION

### Shorted and Reversed Input Protection

If the inductor is chosen so that it won't saturate excessively, an LT1933 buck regulator will tolerate a shorted output. There is another situation to consider in systems where the output will be held high when the input to the LT1933 is absent. This may occur in battery charging applications or in battery backup systems where a battery or some other supply is diode OR-ed with the LT1933's output. If the $V_{IN}$ pin is allowed to float and the $\overline{SHDN}$ pin is held high (either by a logic signal or because it is tied to $V_{IN}$), then the LT1933's internal circuitry will pull its quiescent current through its SW pin. This is fine if your system can tolerate a few mA in this state. If you ground the $\overline{SHDN}$ pin, the SW pin current will drop to essentially zero. However, if the $V_{IN}$ pin is grounded while the output is held high, then parasitic diodes inside the LT1933 can pull large currents from the output through the SW pin and the $V_{IN}$ pin. Figure 5 shows a circuit that will run only when the input voltage is present and that protects against a shorted or reversed input.

### Hot Plugging Safely

The small size, robustness and low impedance of ceramic capacitors make them an attractive option for the input bypass capacitor of LT1933 circuits. However, these capacitors can cause problems if the LT1933 is plugged into a live supply (see Linear Technology Application Note 88 for a complete discussion). The low loss ceramic capacitor combined with stray inductance in series with the power source forms an under damped tank circuit, and the voltage at the $V_{IN}$ pin of the LT1933 can ring to twice the nominal input voltage, possibly exceeding the LT1933's rating and damaging the part. If the input supply is poorly controlled or the user will be plugging the LT1933 into an energized supply, the input network should be designed to prevent this overshoot.

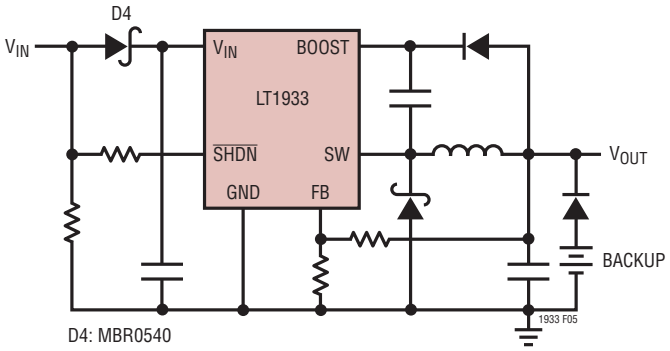
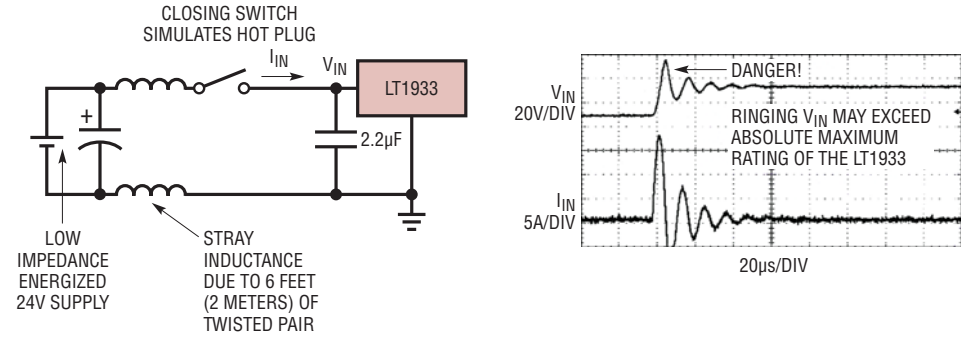
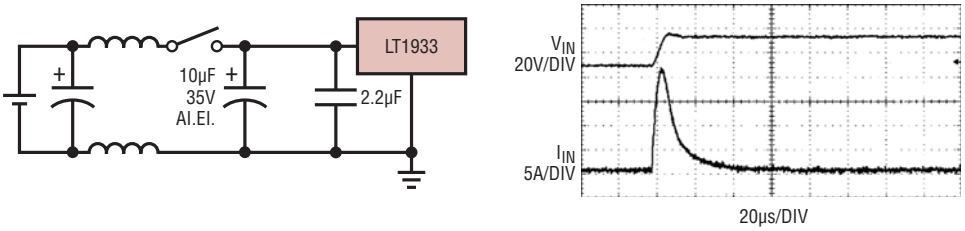



**Figure 5. Diode D4 Prevents a Shorted Input from Discharging a Backup Battery Tied to the Output; It Also Protects the Circuit from a Reversed Input. The LT1933 Rns Only When the Input is Present**

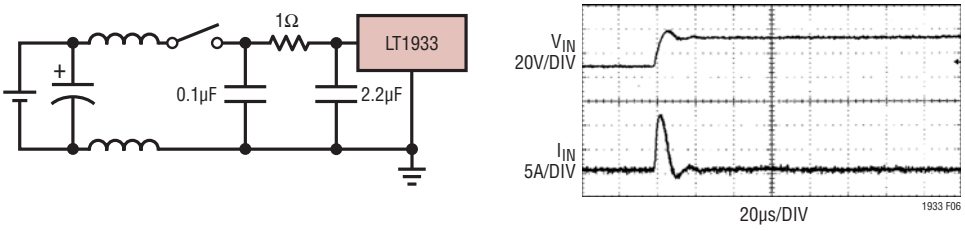
## APPLICATIONS INFORMATION




**(6a)**




**(6b)**




**(6c)**

**Figure 6. A Well Chosen Input Network Prevents Input Voltage Overshoot and Ensures Reliable Operation When the LT1933 is Connected to a Live Supply**

## APPLICATIONS INFORMATION

Figure 6 shows the waveforms that result when an LT1933 circuit is connected to a 24V supply through six feet of 24-gauge twisted pair. The first plot is the response with a 2.2µF ceramic capacitor at the input. The input voltage rings as high as 35V and the input current peaks at 20A. One method of damping the tank circuit is to add another capacitor with a series resistor to the circuit. In Figure 6b an aluminum electrolytic capacitor has been added. This capacitor's high equivalent series resistance damps the circuit and eliminates the voltage overshoot. The extra capacitor improves low frequency ripple filtering and can slightly improve the efficiency of the circuit, though it is likely to be the largest component in the circuit. An alternative solution is shown in Figure 6c. A 1Ω resistor is added in series with the input to eliminate the voltage overshoot (it also reduces the peak input current). A 0.1µF capacitor improves high frequency filtering. This solution is smaller and less expensive than the electrolytic capacitor. For high input voltages its impact on efficiency is minor, reducing efficiency less than one half percent for a 5V output at full load operating from 24V.

### Frequency Compensation

The LT1933 uses current mode control to regulate the output. This simplifies loop compensation. In particular, the LT1933 does not require the ESR of the output capacitor for stability allowing the use of ceramic capacitors to achieve low output ripple and small circuit size.

Figure 7 shows an equivalent circuit for the LT1933 control loop. The error amp is a transconductance amplifier with finite output impedance. The power section, consisting of the modulator, power switch and inductor, is modeled as a transconductance amplifier generating an output current proportional to the voltage at the $V_C$ node. Note that the output capacitor integrates this current, and that the capacitor on the $V_C$ node ($C_C$) integrates the error amplifier output current, resulting in two poles in the loop. $R_C$ provides a zero. With the recommended output capacitor, the loop crossover occurs above the $R_CC_C$ zero. This simple model works well as long as the value of the inductor is not too high and the loop crossover frequency is much lower than the switching frequency. With a larger ceramic capacitor (very low ESR), crossover may be lower and a phase lead capacitor ($C_{PL}$) across the feedback divider may improve the phase margin and transient response. Large electrolytic capacitors may have an ESR large enough to create an additional zero, and the phase lead may not be necessary.

If the output capacitor is different than the recommended capacitor, stability should be checked across all operating conditions, including load current, input voltage and temperature. The LT1375 data sheet contains a more thorough discussion of loop compensation and describes how to test the stability using a transient load.

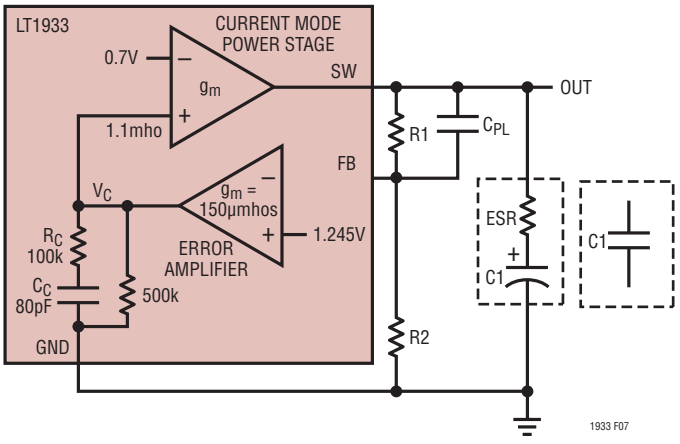


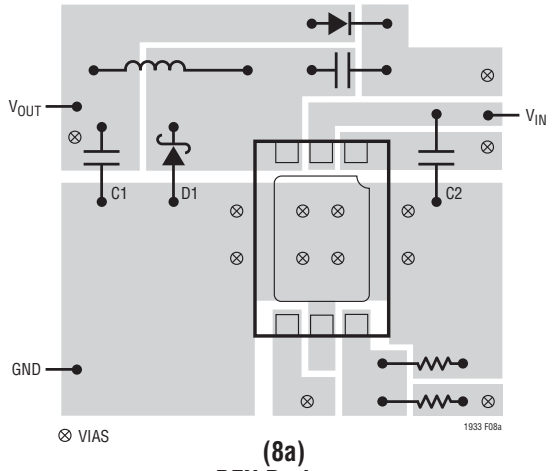

**Figure 7. Model for Loop Response**

## APPLICATIONS INFORMATION

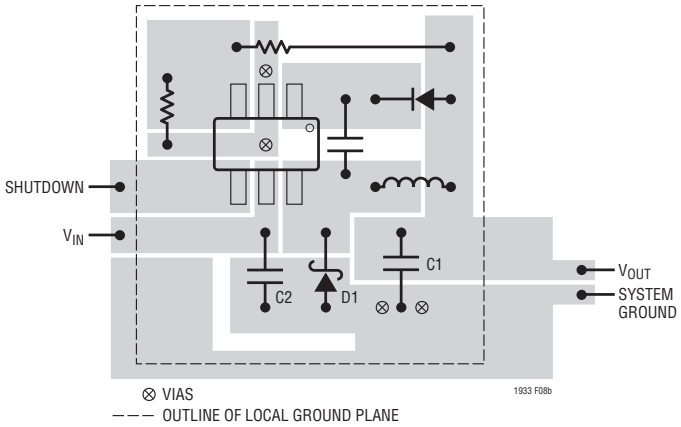
### PCB Layout

For proper operation and minimum EMI, care must be taken during printed circuit board layout. Figure 8 shows the recommended component placement with trace, ground plane and via locations. Note that large, switched currents flow in the LT1933's $V_{IN}$ and SW pins, the catch diode (D1) and the input capacitor (C2). The loop formed by these components should be as small as possible and tied to system ground in only one place. These components, along with the inductor and output capacitor, should be placed on the same side of the circuit board, and their connections should be made on that layer. Place a local, unbroken ground plane below these components, and tie this ground plane to system ground at one location, ideally at the ground terminal of the output capacitor C1. The SW and BOOST nodes should be as small as possible. Finally, keep the FB node small so that the ground pin and ground traces will shield it from the SW and BOOST nodes. Include two vias near the GND pin of the LT1933 to help remove heat from the LT1933 to the ground plane.

Figure 8a shows the layout for the DFN package. Vias near and under the exposed die attach paddle minimize the thermal resistance of the LT1933.




**(8a)**
**DFN Package**

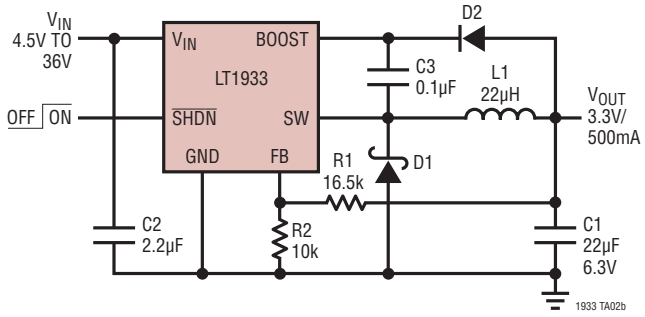



**(8b)**
**SOT-23 Package**

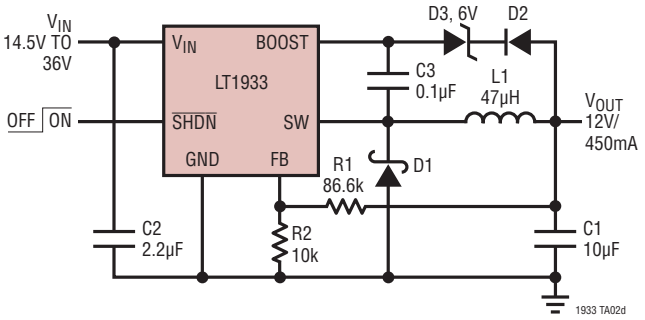
**Figure 8. A Good PCB Layout Ensures Proper, Low EMI Operation**

## TYPICAL APPLICATIONS

**3.3V Step-Down Converter**

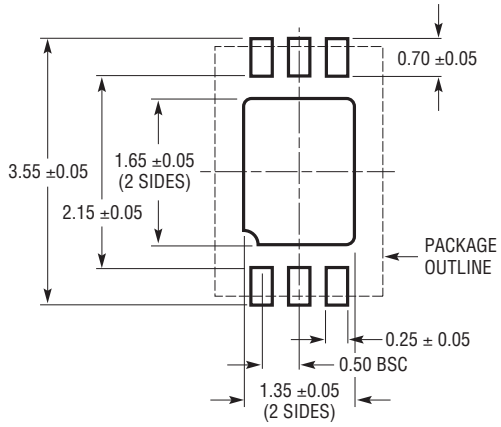



**12V Step-Down Converter**

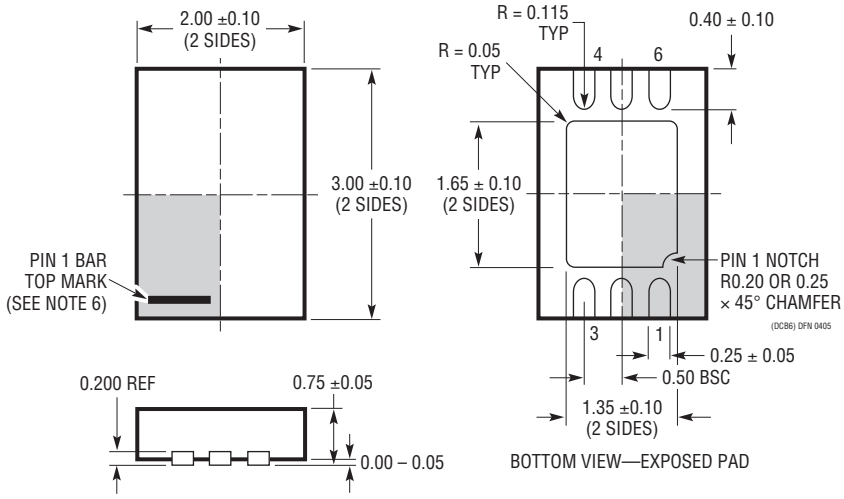


# PACKAGE DESCRIPTION

**DCB Package**
**6-Lead Plastic DFN (2mm × 3mm)**
(Reference LTC DWG # 05-08-1715)




RECOMMENDED SOLDER PAD PITCH AND DIMENSIONS

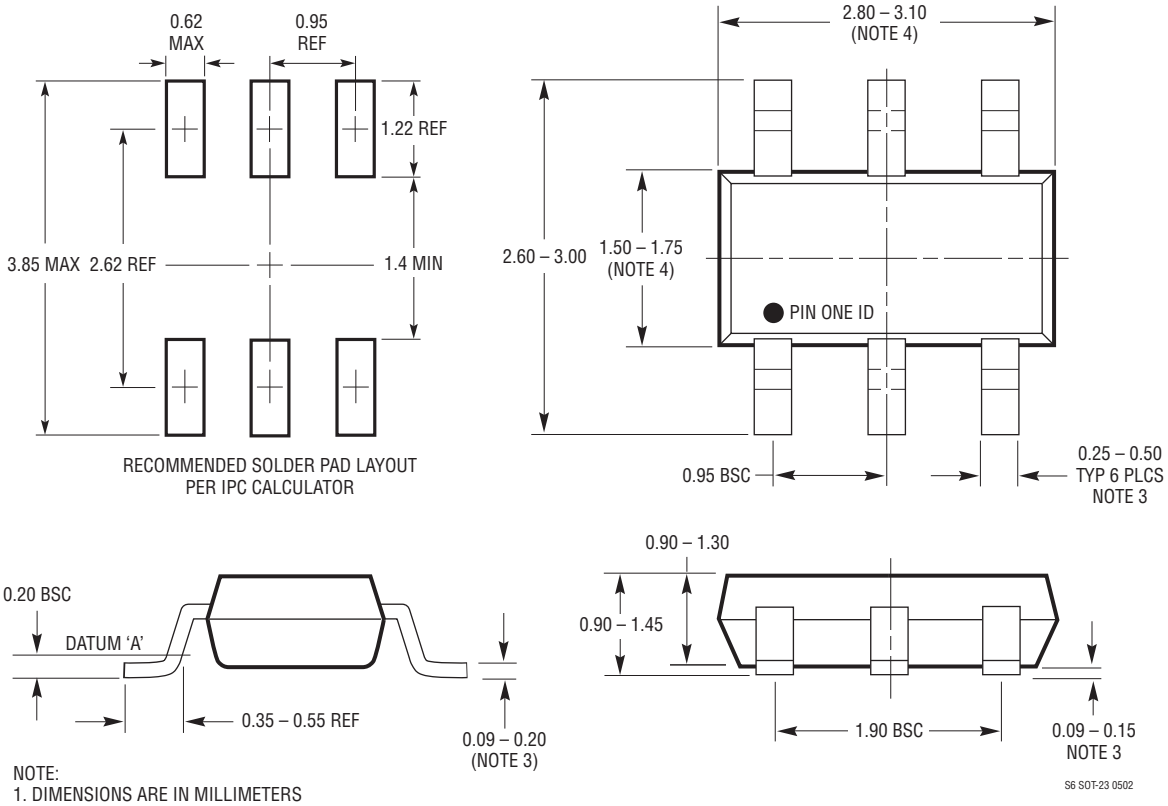



BOTTOM VIEW—EXPOSED PAD

NOTE:
1. DRAWING TO BE MADE A JEDEC PACKAGE OUTLINE M0-229 VARIATION OF (TBD)
2. DRAWING NOT TO SCALE
3. ALL DIMENSIONS ARE IN MILLIMETERS
4. DIMENSIONS OF EXPOSED PAD ON BOTTOM OF PACKAGE DO NOT INCLUDE MOLD FLASH. MOLD FLASH, IF PRESENT, SHALL NOT EXCEED 0.15mm ON ANY SIDE
5. EXPOSED PAD SHALL BE SOLDER PLATED
6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION ON THE TOP AND BOTTOM OF PACKAGE

# PACKAGE DESCRIPTION

**S6 Package**
**6-Lead Plastic SOT-23**
(Reference LTC DWG # 05-08-1634)




NOTE:
1. DIMENSIONS ARE IN MILLIMETERS
2. DRAWING NOT TO SCALE
3. DIMENSIONS ARE INCLUSIVE OF PLATING
4. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
5. MOLD FLASH SHALL NOT EXCEED 0.254mm
6. PACKAGE EIAJ REFERENCE IS SC-74A (EIAJ)

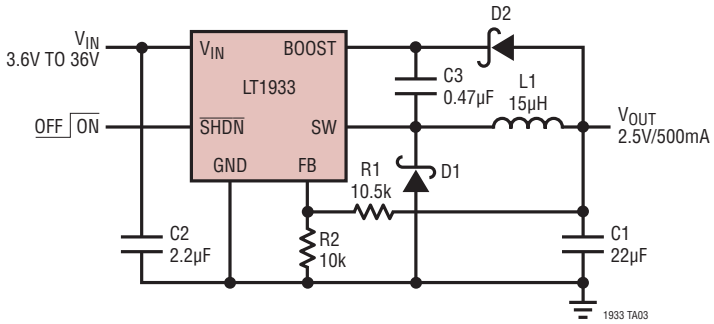
**ATTENTION: ORIGINAL SOT23-6L PACKAGE.**
MOST SOT23-6L PRODUCTS CONVERTED TO THIN SOT23 PACKAGE, DRAWING # 05-08-1636 AFTER APPROXIMATELY APRIL 2001 SHIP DATE



Information furnished by Linear Technology Corporation is believed to be accurate and reliable. However, no responsibility is assumed for its use. Linear Technology Corporation makes no representation that the interconnection of its circuits as described herein will not infringe on existing patent rights.

## TYPICAL APPLICATION

**2.5V Step-Down Converter**




## RELATED PARTS

| PART NUMBER | DESCRIPTION | COMMENTS |
|---|---|---|
| LT1074/LT1074HV | 4.4A $I_{OUT}$, 100kHz, High Efficiency Step-Down DC/DC Converter | $V_{IN}$: 7.3V to 45V/64V, $V_{OUT(MIN)}$ = 2.21V, $I_Q$ = 8.5mA, $I_{SD}$ = 10µA, DD-5/DD-7, TO220-5/TO220-7 Packages |
| LT1076/LT1076HV | 1.6A $I_{OUT}$, 100kHz, High Efficiency Step-Down DC/DC Converter | $V_{IN}$: 7.3V to 45V/64V, $V_{OUT(MIN)}$ = 2.21V, $I_Q$ = 8.5mA, $I_{SD}$ = 10µA, DD-5/DD-7, TO220-5/TO220-7 Packages |
| LT1676 | 60V, 440mA $I_{OUT}$, 100kHz, High Efficiency Step-Down DC/DC Converter | $V_{IN}$: 7.4V to 60V, $V_{OUT(MIN)}$ = 1.24V, $I_Q$ = 3.2mA, $I_{SD}$ = 2.5µA, S8 Package |
| LT1765 | 25V, 2.75mA $I_{OUT}$, 1.25MHz, High Efficiency Step-Down DC/DC Converter | $V_{IN}$: 3V to 25V, $V_{OUT(MIN)}$ = 1.2V, $I_Q$ = 1mA, $I_{SD}$ = 15µA, S8, TSSOP16E Packages |
| LT1766 | 60V, 1.2A $I_{OUT}$, 200kHz, High Efficiency Step-Down DC/DC Converter | $V_{IN}$: 5.5V to 60V, $V_{OUT(MIN)}$ = 1.2V, $I_Q$ = 2.5mA, $I_{SD}$ = 25µA, S8, TSSOP16/TSSOP16E Packages |
| LT1767 | 25V, 1.2A $I_{OUT}$, 1.25MHz, High Efficiency Step-Down DC/DC Converter | $V_{IN}$: 3V to 25V, $V_{OUT(MIN)}$ = 1.2V, $I_Q$ = 1mA, $I_{SD}$ = 6µA, S8, MS8/MS8E Packages |
| LT1776 | 40V, 550mA $I_{OUT}$, 200kHz, High Efficiency Step-Down DC/DC Converter | $V_{IN}$: 7.4V to 40V, $V_{OUT(MIN)}$ = 1.24V, $I_Q$ = 3.2mA, $I_{SD}$ = 30µA, S8, N8, S8 Packages |
| LT1940 | 25V, Dual 1.4A $I_{OUT}$, 1.1MHz, High Efficiency Step-Down DC/DC Converter | $V_{IN}$: 3.6V to 25V, $V_{OUT(MIN)}$ = 1.25V, $I_Q$ = 3.8mA, $I_{SD}$ < 30µA, TSSOP16E Package |
| LT1956 | 60V, Dual 1.2A $I_{OUT}$, 500kHz, High Efficiency Step-Down DC/DC Converter | $V_{IN}$: 5.5V to 60V, $V_{OUT(MIN)}$ = 1.2V, $I_Q$ = 2.5mA, $I_{SD}$ = 25µA, TSSOP16/TSSOP16E Packages |
| LT1976 | 60V, Dual 1.2A $I_{OUT}$, 200kHz, High Efficiency Step-Down DC/DC Converter with Burst Mode® | $V_{IN}$: 3.3V to 60V, $V_{OUT(MIN)}$ = 1.2V, $I_Q$ = 100µA, $I_{SD}$ < 1µA, TSSOP16E Package |
| LT3010 | 80V, 50mA, Low Noise Linear Regulator | $V_{IN}$: 1.5V to 80V, $V_{OUT(MIN)}$ = 1.28V, $I_Q$ = 30µA, $I_{SD}$ < 1µA, MS8E Package |
| LT3407 | Dual 600mA $I_{OUT}$, 1.5MHz, Synchronous Step-Down DC/DC Converter | $V_{IN}$: 2.5V to 5.5V, $V_{OUT(MIN)}$ = 0.6V, $I_Q$ = 40µA, $I_{SD}$ < 1µA, MS10E Package |
| LT3412 | 2.5A $I_{OUT}$, 4MHz, Synchronous Step-Down DC/DC Converter | $V_{IN}$: 2.5V to 5.5V, $V_{OUT(MIN)}$ = 0.8V, $I_Q$ = 60µA, $I_{SD}$ < 1µA, TSSOP16E Package |
| LTC3414 | 4A $I_{OUT}$, 4MHz, Synchronous Step-Down DC/DC Converter | $V_{IN}$: 2.3V to 5.5V, $V_{OUT(MIN)}$ = 0.8V, $I_Q$ = 64µA, $I_{SD}$ < 1µA, TSSOP20E Package |
| LT3430/LT3431 | 60V, 2.75A $I_{OUT}$, 200kHz/500kHz, Synchronous Step-Down DC/DC Converter | $V_{IN}$: 5.5V to 60V, $V_{OUT(MIN)}$ = 1.2V, $I_Q$ = 2.5mA, $I_{SD}$ = 30µA, TSSOP16E Package |

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Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408) 432-1900 • FAX: (408) 434-0507 • www.linear.com
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