Micropower DC/DC Converters with Low-Battery Detector Active in Shutdown

FEATURES

- 5V at 200mA from Two Cells
- **10μA Quiescent Current in Shutdown**
- Operates with V_{IN} as Low as 1.5V
- **Low-Battery Detector Active in Shutdown**
- Low Switch V_{CESAT}: 370mV at 1A Typical
- 120μA Quiescent Current in Active Mode
- Switching Frequency Up to 300kHz
- Programmable Peak Current with One Resistor
- 8-Lead SO Package

APPLICATIONS

- 2-, 3-, or 4-Cell to 5V or 3.3V Step-Up
- Portable Instruments
- Bar Code Scanners
- Palmtop Computers
- Diagnostic Medical Instrumentation
- Personal Data Communicators/Computers

DESCRIPTION

The LT®1304 is a micropower step-up DC/DC converter ideal for use in small, low voltage, battery-operated systems. The devices operate from a wide input supply range of 1.5V to 8V. The LT1304-3.3 and LT1304-5 generate regulated outputs of 3.3V and 5V and the adjustable LT1304 can deliver output voltages up to 25V. Quiescent current, 120μA in active mode, decreases to just 10μA in shutdown with the low-battery detector still active. Peak switch current, internally set at 1A, can be reduced by adding a single resistor from the I_{LIM} pin to ground. The high speed operation of the LT1304 allows the use of small, surface-mountable inductors and capacitors. The LT1304 is available in an 8-lead SO package.

, LTC and LT are registered trademarks of Linear Technology Corporation.

TYPICAL APPLICATION

2-Cell to 5V Step-Up Converter with Low-Battery Detect

Efficiency

ABSOLUTE MAXIMUM RATINGS

V_{IN} Voltage 8V
SW Voltage ..... –0.4V to 25V
FB Voltage (LT1304) ..... V_{IN} + 0.3V
Sense Voltage (LT1304-3.3/LT1304-5) 8V
I_{LIM} Voltage 5V
$\overline{SHDN}$ Voltage 6V
LBI Voltage ..... V_{IN}
LBO Voltage 8V
Maximum Power Dissipation 500mW
Junction Temperature ..... 125°C
Operating Temperature Range ..... 0°C to 70°C
Storage Temperature Range ..... –65°C to 150°C
Lead Temperature (Soldering, 10 sec) ..... 300°C

PACKAGE/ORDER INFORMATION

S8 PACKAGE
8-LEAD PLASTIC SO

*FIXED OUTPUT VERSION

T_{JMAX} = 125°C, θ_{JA} = 150°C/W

ORDER PART NUMBER
LT1304CS8 LT1304CS8-3.3 LT1304CS8-5
S8 PART MARKING
1304 13043 13045

Consult factory for Industrial and Military grade parts.

ELECTRICAL CHARACTERISTICS V_{IN} = 2V, $V_{\overline{SHDN}}$ = 2V unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Minimum Operating Voltage		●		1.5	1.65	V
Operating Voltage Range		●			8	V
Quiescent Current	$V_{\overline{SHDN}}$ = 2V, Not Switching	●		120	200	µA
Quiescent Current in Shutdown	$V_{\overline{SHDN}}$ = 0V, V_{IN} = 2V $V_{\overline{SHDN}}$ = 0V, V_{IN} = 5V	● ●		7 27	15 50	µA µA
Comparator Trip Point	LT1304	●	1.22	1.24	1.26	V
FB Pin Bias Current	LT1304	●		10	25	nA
Sense Pin Leakage in Shutdown	$V_{\overline{SHDN}}$ = 0V, Fixed Output Versions	●		0.002	1	µA
Output Sense Voltage	LT1304-3.3 LT1304-5	● ●	3.17 4.80	3.3 5.05	3.43 5.25	V V
Line Regulation	1.8V ≤ V_{IN} ≤ 8V	●		0.04	0.15	%/V
LBI Input Threshold	Falling Edge	●	1.10	1.17	1.25	V
LBI Bias Current		●		6	20	nA
LBI Input Hysteresis		●		35	65	mV
LBO Output Voltage Low	I_{SINK} = 500µA	●		0.2	0.4	V
LBO Output Leakage Current	LBI = 1.5V, LBO = 5V	●		0.01	0.1	µA
$\overline{SHDN}$ Input Voltage High $\overline{SHDN}$ Input Voltage Low		● ●	1.4		 0.4	V V
$\overline{SHDN}$ Pin Bias Current	$V_{\overline{SHDN}}$ = 5V $V_{\overline{SHDN}}$ = 0V	● ●	 –5	5 –2	8	µA µA
Switch OFF Time		●	1	1.5	2	µs
Switch ON Time	Current Limit Not Asserted	●	4	6	8	µs
Maximum Duty Cycle	Current Limit Not Asserted	●	76	80	88	%
Peak Switch Current	I_{LIM} Pin Open, V_{IN} = 5V 20k from I_{LIM} to GND		0.8	1 500	1.2	A mA

ELECTRICAL CHARACTERISTICS V_{IN} = 2V, $V_{\overline{SHDN}}$ = 2V unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Switch Saturation Voltage	I_{SW} = 1A I_{SW} = 700mA	 ●		0.37 0.26	 0.35	V V
Switch Leakage	Switch Off, V_{SW} = 5V	●		0.01	7	µA

The ● denotes specifications which apply over the 0°C to 70°C operating temperature range.

TYPICAL PERFORMANCE CHARACTERISTICS

Switch Saturation Voltage

Peak Switch Current Limit

On- and Off-Times

Feedback Voltage

Feedback Pin Bias Current

Supply Current

TYPICAL PERFORMANCE CHARACTERISTICS

Load Transient Response

Burst Mode™ Operation

Burst Mode is a trademark of Linear Technology Corporation.

PIN FUNCTIONS

LBI (Pin 1): Low-Battery Detector Input. When voltage on this pin is less than 1.17V, detector output is low.

LBO (Pin 2): Low-Battery Detector Output. Open collector can sink up to 500µA. Low-battery detector remains active when device is shut down.

V_{IN} (Pin 3): Input Supply. Must be bypassed close (<0.2") to the pin. See required layout in the Typical Applications.

SW (Pin 4): Collector of Power NPN. Keep copper traces on this pin short and direct to minimize RFI.

GND (Pin 5): Device Ground. Must be low impedance; solder directly to ground plane.

I_{LIM} (Pin 6): Current Limit Set Pin. Float for 1A peak switch current; a resistor to ground will lower peak current.

$\overline{SHDN}$ (Pin 7): Shutdown Input. When low, switching regulator is turned off. The low-battery detector remains active. The $\overline{SHDN}$ input should not be left floating. If $\overline{SHDN}$ is not used, tie the pin to V_{IN}.

FB/SENSE (Pin 8): On the LT1304 (adjustable) this pin goes to the comparator input. On the fixed-output versions, the pin connects to the resistor divider which sets output voltage. The divider is disconnected from the pin during shutdown.

BLOCK DIAGRAMS

Figure 1. LT1304 Block Diagram. Independent Low-Battery Detector A3 Remains Alive When Device Is in Shutdown

Figure 2. LT1304-3.3/LT1304-5 Block Diagram

OPERATION

The LT1304's operation can best be understood by examining the block diagram in Figure 1. Comparator A1 monitors the output voltage via resistor divider string R3/R4 at the FB pin. When V_{FB} is higher than the 1.24V reference, A2 and the timers are turned off. Only the reference, A1 and A3 consume current, typically 120μA. As V_{FB} drops below 1.24V plus A1's hysteresis (about 6mV), A1 enables the rest of the circuit. Power switch Q1 is then cycled on for 6μs, or until current comparator A2 turns off the ON timer, whichever comes first. Off-time is fixed at approximately 1.5μs. Q1's switching causes current to alternately build up in inductor L1 and discharge into output capacitor C2 via D1, increasing the output voltage. As V_{FB} increases enough to overcome C1's hysteresis, switching action ceases. C2 is left to supply current to the load until V_{OUT} decreases enough to force A1's output high, and the entire cycle repeats.

If switch current reaches 1A, causing A2 to trip, switch ON time is reduced. This allows continuous mode operation during bursts. A2 monitors the voltage across 7.2Ω resistor R1, which is directly related to the switch current. Q2's collector current is set by the emitter-area ratio to 0.5% of Q1's collector current. R1's voltage drop exceeds 36mV, corresponding to 1A switch current, A2's output goes high, truncating the ON time part of the switch cycle. The 1A peak current can be reduced by tying a resistor between the I_{LIM} pin and ground, causing a voltage drop to appear across R2. The drop offsets some of the 36mV reference voltage, lowering peak current. A 22k resistor limits current to approximately 550mA. A capacitor connected between I_{LIM} and ground provides soft start. Shutdown is accomplished by grounding the $\overline{SHDN}$ pin.

The low-battery detector A3 has its own 1.17V reference and is always on. The open collector output device can sink up to 500μA. Approximately 35mV of hysteresis is built into A3 to reduce "buzzing" as the battery voltage reaches the trip level.

Inductor Selection

Inductors used with the LT1304 must be capable of handling the worst-case peak switch current of 1.2A without saturating. Open flux rod or drum core units may be biased into saturation by 20% with only a small reduction in efficiency. For the majority of 2-cell or 3-cell input LT1304 applications, a 22μH or 20μH inductor such as the Sumida CD54-220 (drum) or Coiltronics CTX20-1 (toroid) will suffice. If switch current is reduced using the I_{LIM} pin, smaller inductors such as the Sumida CD43 series or Coilcraft DO1608 series can be used. Minimizing DCR is important for best efficiency. Ideally, the inductor DCR should be less than 0.05Ω, although the physical size of such an inductor makes its use prohibitive in many space conscious applications. If EMI is a concern, such as when sensitive analog circuitry is present, a toroidal inductor such as the Coiltronics CTX20-1 is suggested.

A special case exists where the V_{OUT}/V_{IN} differential is high, such as a 2V to 12V boost converter. If the required duty cycle for continuous mode operation is higher than the LT1304 can provide, the converter must be designed for discontinuous operation. This means that the inductor current decreases to zero during the switch OFF time. For a simple step-up (boost) converter, duty cycle can be calculated by the following formula:

$$DC = 1 - [(V_{IN} - V_{SAT})/(V_{OUT} + V_D)]$$

where,

V_{IN} = Minimum input voltage
V_{SAT} = Switch saturation voltage (0.3V)
V_{OUT} = Output voltage
V_D = Diode forward voltage (0.4V)

If the calculated duty cycle exceeds the minimum LT1304 duty cycle of 76%, the converter should be designed for discontinuous mode operation. The inductance must be low enough so that current in the inductor reaches the peak current in a single cycle. Inductor value can be calculated by:

$$L = (V_{IN} - V_{SAT})(t_{ON}/1A)$$

where,

t_{ON} = Minimum on-time of LT1304 (4μs)

One advantage of discontinuous mode operation is that inductor values are usually quite low so very small units can be used. Ripple current is higher than with continuous mode designs and efficiency will be somewhat less.

OPERATION

Table 1 lists inductor suppliers along with appropriate part numbers.

Table 1. Recommended Inductors

VENDOR	SERIES	PHONE NUMBER
Sumida	CD54, CD43	(708) 956-0666
Coiltronics	CTX20-1	(407) 241-7876
Dale	LPT4545	(605) 665-9301
Coilcraft	DO3316, DO1608, DO3308	(708) 639-6400

Capacitor Selection

Low ESR (Equivalent Series Resistance) capacitors should be used at the output of the LT1304 to minimize output ripple voltage. High quality input bypassing is also required. For surface mount applications AVX TPS series tantalum capacitors are recommended. These have been specifically designed for switch mode power supplies and have low ESR along with high surge current ratings. A 100µF, 10V AVX TPS surface mount capacitor typically limits output ripple voltage to 70mV when stepping up from 2V to 5V at a 200mA load. For through hole applications Sanyo OS-CON capacitors offer extremely low ESR in a small package size. Again, if peak switch current is reduced using the I_{LIM} pin, capacitor requirements can be eased and smaller, higher ESR units can be used. Suggested capacitor sources are listed in Table 2.

Table 2. Recommended Capacitors

VENDOR	SERIES	TYPE	PHONE NUMBER
AVX	TPS	Surface Mount	(803) 448-9411
Sanyo	OS-CON	Through Hole	(619) 661-6835
Sprague	595D	Surface Mount	(603) 225-1961

Diode Selection

Best performance is obtained with a Schottky rectifier such as the 1N5818. Motorola makes the MBRS130L Schottky which is slightly better than the 1N5818 and comes in a surface mount package. For lower switch currents, the MBR0530 is recommended. It comes in a very small SOD-123 package. Multiple 1N4148s in parallel can be used in a pinch, although efficiency will suffer.

I_{LIM} Function

The LT1304's current limit (I_{LIM}) pin can be used for soft start. Upon start-up, the LT1304 will draw maximum current (about 1A) from the supply to charge the output capacitor. Figure 3 shows V_{OUT} and V_{IN} waveforms as the device is turned on. The high current flow can create IR drops along supply and ground lines or cause the input supply to drop out momentarily. By adding R1 and C1 as shown in Figure 4, the switch current is initially limited to well under 1A as detailed in Figure 5. Current flowing into C1 from R1 and the I_{LIM} pin will eventually charge C1 and R1 effectively takes C1 out of the circuit. R1 also provides a discharge path for C1 when $\overline{\text{SHUTDOWN}}$ is brought low for turn-off.

Figure 3. Start-Up Response. Input Current Rises Quickly to 1A. V_{OUT} Reaches 5V in Approximately 1ms. Output Drives 20mA Load

Figure 4. 2-Cell to 5V/200mA Boost Converter Takes Four External Parts. Components with Dashed Lines Are for Soft Start (Optional)

OPERATION

If the full power capability of the LT1304 is not required, peak switch current can be limited by connecting a resistor R_{LIM} from the I_{LIM} pin to ground. With R_{LIM} = 22k, peak switch current is reduced to approximately 500mA. Smaller power components can then be used. The graph in Figure 6 shows switch current vs R_{LIM} resistor value.

Figure 5. Start-Up Response with 1μF/1MΩ Components in Figure 2 Added. Input Current Is More Controlled. V_{OUT} Reaches 5V in 6ms. Output Drives 20mA Load

Figure 6. Peak Switch Current vs R_{LIM} Value

bypass capacitor is required. If the input supply is close to the IC, a 1μF ceramic capacitor can be used instead. The LT1304 switches current in 1A pulses, so a low impedance supply must be available. If the power source (for example, a 2 AA cell battery) is within 1 or 2 inches of the IC, the battery itself provides bulk capacitance and the 1μF ceramic capacitor acts to smooth voltage spikes at switch turn-on and turn-off. If the power source is far away from the IC, inductance in the power source leads results in high impedance at high frequency. A local high capacitance bypass is then required to restore low impedance at the IC.

Figure 7. Suggested Layout for Best Performance. Input Capacitor Placement as Shown Is Highly Recommended. Switch Trace (Pin 4) Copper Area Is Minimized

Layout/Input Bypassing

The LT1304's high speed switching mandates careful attention to PC board layout. Suggested component placement is shown in Figure 7. The input supply must have low impedance at AC and the input capacitor should be placed as indicated in the figure. The value of this capacitor depends on how close the input supply is to the IC. In situations where the input supply is more than a few inches away from the IC, a 47μF to 100μF solid tantalum

Low-Battery Detector

The LT1304 contains an independent low-battery detector that remains active when the device is shut down. This detector, actually a hysteretic comparator, has an open collector output that can sink up to 500μA. The comparator also operates below the switcher's undervoltage lockout threshold, operating until V_{IN} reaches approximately 1.4V. Figure 8 illustrates the input/output characteristic of the detector. Hysteresis is clearly evident in the figure.

OPERATION

Figure 8. Low-Battery Detector Transfer Function. Pull-Up R = 22k, V_{IN} = 2V, Sweep Frequency = 10Hz

Battery Life

How may hours does it work? This is the bottom line question that must be asked of any efficiency study. AA alkaline cells are not perfect power sources. For efficient power transfer, energy must be taken from AA cells at a rate that does not induce excessive loss. AA cells internal impedance, about 0.2Ω fresh and 0.5Ω end-of-life, results in significant efficiency loss at high discharge rates. Figure 10 illustrates battery life vs load current of Figure 9's LT1304, 2-cell to 5V DC/DC converter. Note the accelerated decrease in hours at higher power levels. Figure 11 plots total watt hours vs load current. Watt hours are determined by the following formula:

$$WH = I_{LOAD}(5V)(H)$$

Figure 9. 2-Cell to 5V Converter Used in Battery Life Study

Figure 10. Battery Life vs Load Current. Dots Specify Actual Measurements

Figure 11. Output Watt Hours vs Load Current. Note Rapid Fall-Off at Higher Discharge Rates

Figure 11's graph varies significantly from electrical efficiency plot pictured on the first page of this data sheet. Why? As more current is drawn from the battery, voltage drop across the cells' internal impedance increases. This causes internal power loss (heating), reducing cell terminal voltage. Since the regulator input acts as a negative resistance, more current is drawn from the battery as the terminal voltage decreases. This positive feedback action compounds the problem.

OPERATION

Figure 12 shows overall energy conversion efficiency, assuming availability of 6.5WH of battery energy. This efficiency approximates the electrical efficiency at load current levels from 1mA to 10mA, but drops severely at load currents above 10mA (load power above 50mW). The moral of the story is this: if your system needs 5V at more than 40mA to 50mA, consider using a NiCd battery (1/10 the internal impedance) instead of a AA cell alkaline battery.

Figure 12. Overall System Efficiency Including Battery Efficiency vs Load Current. Internal Impedance of Alkaline AA Cells Accounts for Rapid Drop in Efficiency at Higher Load Current

TYPICAL APPLICATIONS

Super Burst™ Low I_Q DC/DC Converter

Super Burst Efficiency

Super Burst is a trademark of Linear Technology Corporation.

TYPICAL APPLICATIONS

2-Cell to 3.3V Boost Converter

*SUMIDA CD54-220
**AVX TPSD107M010R0100

2-Cell to 3.3V Converter Efficiency

3.3V SEPIC (Step-Up/Step-Down Converter)

*COILTRONICS CTX20-1
**TOKIN 1E105ZY5U-C103-F
† AVX TPSD476M016R0150
†† AVX TPSD107M010R0100

3.3V SEPIC Efficiency

5V SEPIC (Step-Up/Step-Down Converter)

*COILTRONICS CTX20-1
**TOKIN 1E105ZY5U-C103-F
†AVX TPSD476M016R0150
†† AVX TPSD107M010R0100

5V SEPIC Efficiency

TYPICAL APPLICATIONS

5V to 12V DC/DC Converter

*SUMIDA CD54-220
**AVX TPSD476M016R0150
† MOTOROLA MBRS130L

5V to 12V Converter Efficiency

Single Li-Ion Cell to 5V Converter with Load Disconnect at V_{IN} < 2.7V

*PRIMARY Li-Ion BATTERY PROTECTION MUST BE PROVIDED BY AN INDEPENDENT CIRCUIT
**SUMIDA CD54-220
†AVX TPSD107M010R0100

TYPICAL APPLICATIONS

Negative LCD Bias Generator

Electroluminescent Panel Driver with 200Hz Oscillator

* DALE LPE3325-A205 TRANSFORMER MEASURES 6.5mm × 8.2mm × 5.2mm (H)
(605) 665-9301

TYPICAL APPLICATIONS

2- to 4-Cell to 1kV Step-Up Converter

2- to 4-Cell to 5V Converter with Output Disconnect

TYPICAL APPLICATIONS

2-Cell to 5V Converter with Auxiliary 10V Output

2-Cell to 5V Converter with Auxiliary –5V Output

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 circuits as described herein will not infringe on existing patent rights.

PACKAGE DESCRIPTION

Dimension in inches (millimeter) unless otherwise noted.

S8 Package
8-Lead Plastic Small Outline (Narrow 0.150)
(LTC DWG # 05-08-1610)

*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

**DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LTC®1163	Triple High Side Driver for 2-Cell Inputs	1.8V Minimum Input, Drives N-Channel MOSFETs
LT1239	Backup Battery Management System	Easy-to-Use, Fail-Safe Backup Protection
LT1301	Fixed 5V/12V Step-Up Micropower DC/DC Converter	12V/200mA from 5V, 120μA I_Q, 88% Efficiency
LT1302	High Output Current Micropower DC/DC Converter	5V/600mA from 2V, 2A Internal Switch, 200μA I_Q
LT1303	Micropower DC/DC Converter	Low-Battery Detector Inactive in Shutdown
LTC1477	Protected Switch	Ultralow $R_{DS(ON)}$ Switch: 0.07Ω
LT1521	300mA, 12μA I_Q Low Dropout Regulator	500mV Dropout at Full Load

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