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ML4854

Adjustable, Low-Current, 2-Cell Boost Regulator with Shutdown and Low Battery Detect

Features

- 95% Efficiency at 200mA Load Current
- Integrated Peak Current Limit
- Variable Output Voltage Determined by External Resistors
- Variable On-time Pulse Frequency Modulation (PFM)
- Fully Internal Synchronous Rectifier (no external diodes) for High Efficiency and Low Peak Currents
- Low-Battery Detection
- Logic Controlled Shutdown with True Load Disconnect

Applications

- 2-3 alkaline/NiMH cells or 1 Li-Ion cell Operated Devices
- Cell Phones
- Medical Devices
- PDAs
- Portable Instrumentation

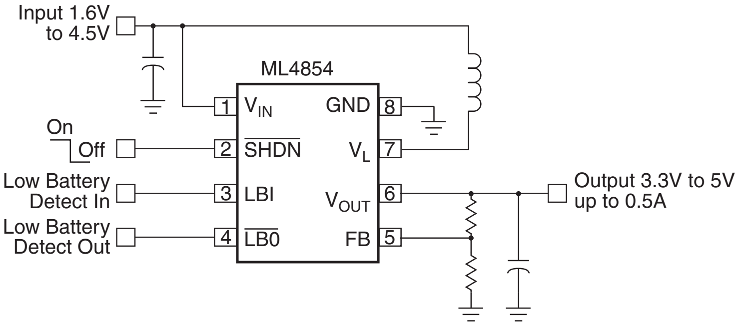
General Description

The ML4854 is a low power boost regulator designed for low voltage DC to DC conversion in two-cell battery powered systems such as cell phones and PDAs. The converter starts up at 1.3V and has an operating input voltage range from 1.6V to 4.5V. After the start it operates at an input voltage as low as 0.8V. Output voltage can be adjusted by external resistors from 3.3V to 5V with a maximum load current of 0.5A.

Quiescent current in shut down mode is less than 30µA, which maximizes the battery live time. The ON time changes with the input voltage to maintain the ripple current constant and to provide the highest efficiency over a wide load range, while maintaining low peak currents in the boost inductor. The combination of integrated synchronous rectification, variable frequency operation, and low supply current make ML4854 ideal for portable applications.

The ML4854 is available in an 8 lead TSSOP package.

Typical Application



REV. 1.0.7 5/6/03

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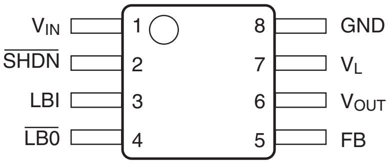
Pin Configuration

8-Lead TSSOP (T08)



TOP VIEW

Pin Description

PIN	NAME	FUNCTION
1	V_{IN}	**Battery Input Voltage**. Supplies the IC during start-up. After the output is running, the IC draws power from V_{OUT}.
2	$\overline{SHDN}$	**Shut Down**. Pulling this pin low shuts down the regulator, isolating the load from the input.
3	LBI	**Low-Battery Input**. Pulling this pin below a threshold causes the LBO pin to go low.
4	$\overline{LBO}$	**Low-Battery Output**. This pin provides an active low signal to alert the user when the LBI voltage falls below its targeted value. The open-drain output can be used to reset a microcontroller.
5	FB	**Programming Feedback Pin**. Sets the output voltage. This pin is used to adjust the output voltage via a resistive divider from V_{OUT}.
6	V_{OUT}	**Boost regulator output**. Output voltage can be set to be in the 3 to 5V range. Startup at moderate load is achievable at input voltages around 1.25V.
7	V_L	**Boost inductor connection**. An inductor is connected between this pin and V_{IN}. When servicing the output supply, this pin pulls low, charging the inductor, then shuts off dumping the energy through the synchronous rectifier to the output.
8	GND	**Ground of the IC**.

Absolute Maximum Ratings

Absolute maximum ratings are those values, beyond which the device could be permanently damaged. Absolute maximum ratings are stress ratings only and functional device operation is not implied.

Parameter	Min.	Max.	Units
V_{IN}, V_{OUT} Voltages (Relative to GND)	-0.3	7	V
Switch Voltage (V_L to GND)	-0.3	V_{OUT}+0.3	V
Voltage on any other Pin	-0.3	V_{OUT}+0.3	V
Peak Switch Current (Ipeak)	— Internally Limited —		
Output Current (I_{OUT})		500	mA
Continuous Power Dissipation		320	mW
Thermal Resistance (θ_{JA})		124	°C/W
Junction Temperature		150	°C
Storage Temperature Range	-65	+165	°C
Lead Temperature (soldering, 10s)		300	°C

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Recommended Operating Conditions

Parameter	Min.	Max.	Units
Temperature Range	-40	+85	°C
V_{IN} Operating Range	1.6	0.9 V_{OUT}	V
V_{OUT} Operating Range	3.0	5.0	V

Electrical Characteristics

Unless otherwise specified, V_{IN}=1.6V to 3V, I_{LOAD}=1mA, T_A=-40°C to +85°C. Test Circuit Fig.1. Typical values are at T_A= +25°C

Parameter	Conditions	Min.	Typ.	Max.	Units
Start Up Voltage	I_{LOAD}<1mA		1.25	1.5	V
Operating Voltage	After start I_{LOAD} =10mA, V_{OUT}=3.3V/5V	0.8			V
Output Voltage	V_{OUT}(nom.)=3.3V V_{OUT}(nom.)=5V	3.15 4.775	3.3 5	3.45 5.225	V V
Output Voltage Adjust Range		3		5	V
Steady State Output Current (see diagram)	V_{OUT}=3.3V, V_{IN}=2.5V		500		mA
	V_{OUT}=5V, V_{IN}=2.5V		330		mA
Pulse Width	V_{IN} = 3V	0.8	1.32	1.9	µs
	V_{IN} = 2.4V	1.2	1.64	2.3	µs
	V_{IN} = 1.8V	1.8	2.15	3.1	µs
	V_{IN} = 1.5V	2.2	2.57	4.0	µs
Minimum Off-Time			0.5		µs
Line Regulation	V_{IN}=1.6V to 3V, I_{OUT}=2mA, V_{OUT}=3.3V		0.5		%
	V_{OUT}=5V		0.5		%
Load Regulation	0 to 250mA V_{IN}=2.4V ,V_{OUT}=3.3V		1.0		%
	0 to 150mA V_{IN}=2.4V ,V_{OUT}=5V		1.0		%
Feedback Voltage (VFB)			1.230		V
LBI Threshold Voltage			0.390		V
LBI Hysteresys			25		mV
Internal NFET, PFET ON Resist.	I_{LOAD} = 100mA		275		mΩ
Efficiency	(I_{LOAD}=200mA) V_{IN}=3V, V_{OUT} = 3.3V		95		%
Quiescent Current – SHDN	SHDN=0V, R1 excluded,V_{IN}=3V		26	100	µA
	SHDN=3V, R1 excluded,V_{IN}=3V		85	200	µA
LBO Output Voltage	V_{LBI}= 0, I_{SINK}=1mA		0.2		V
SHDN Input Voltage @V_{IN}=3V	V_{OUT}=3.3V/5V		1.6		V
SHDN Input Voltage @V_{IN}=1.6V	V_{OUT}=3.3V/5V		0.8		V

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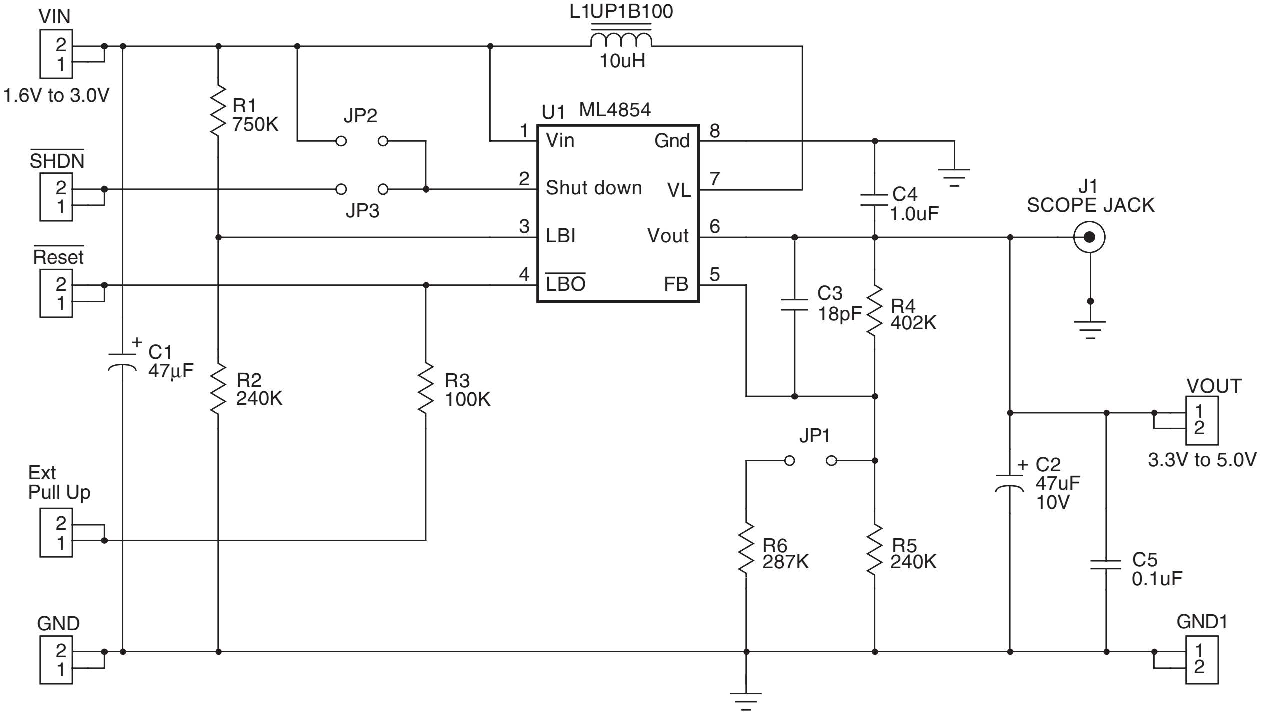

Figure 1. Test Circuit

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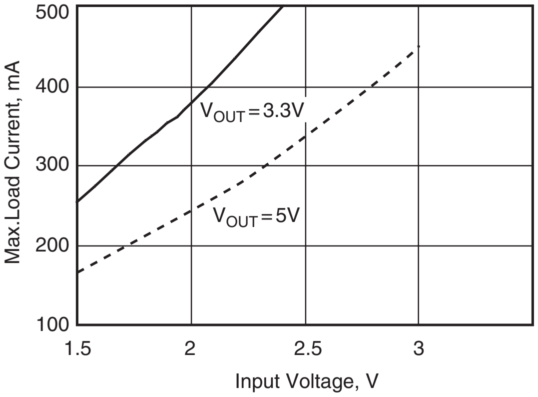
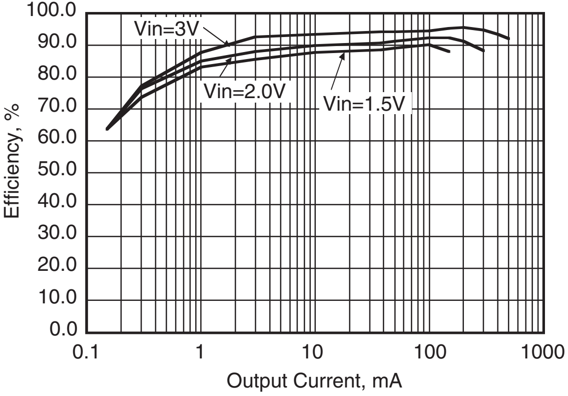
Typical Operating Characteristics (L=10µH, C_{IN}=47µF, C_{OUT}=47µF//1.0µF T=25°C)

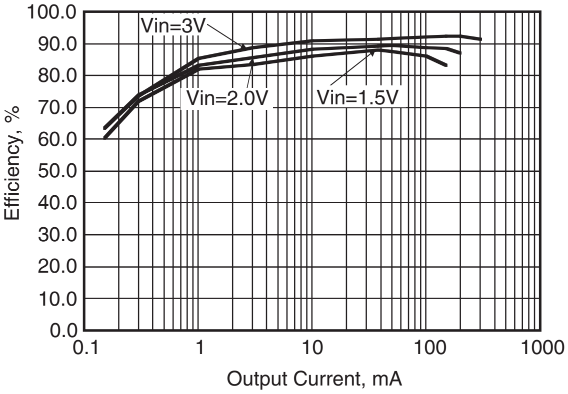
Maximum Steady State Load Current vs. Input Voltage



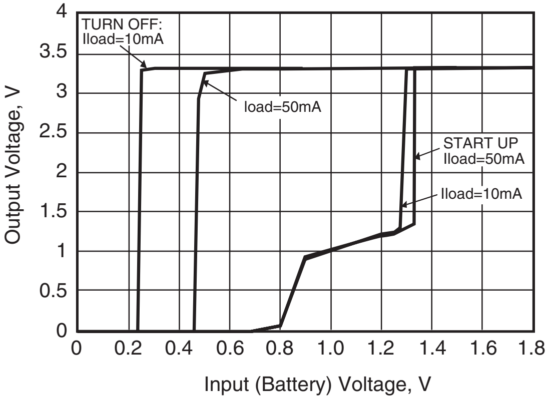
Efficiency vs. Load Current Vout = 3.3V



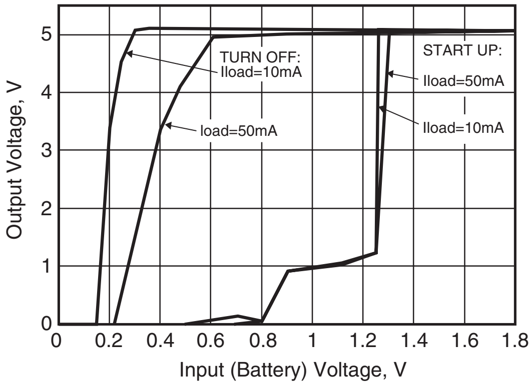
Efficiency vs. Load Current Vout = 5V



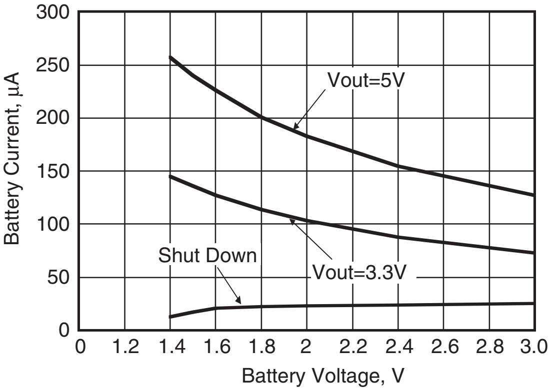
Starting Up and Turning Off VOUT=3.3V Iload=10mA/50mA



Starting Up and turning Off VOUT=5V Iload=10mA/50mA



No-Load Battery Current vs. Input Battery Voltage



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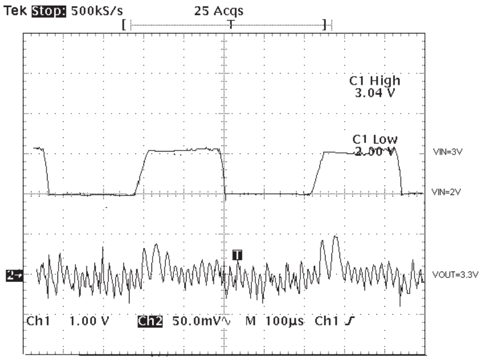
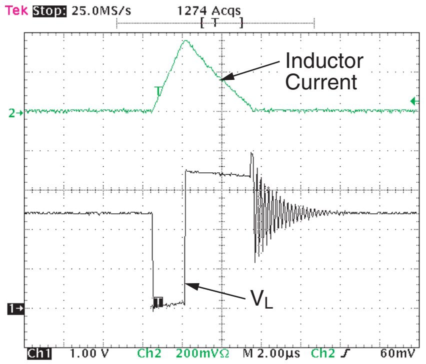
Typical Operating Characteristics (Continued)

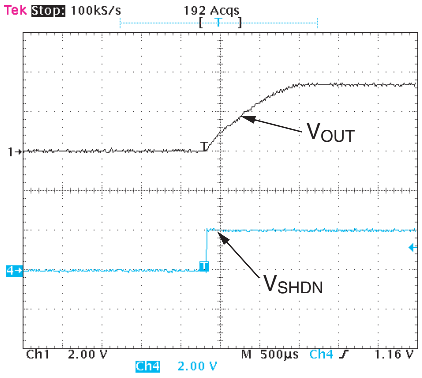
Line Transient Response @100mA Load



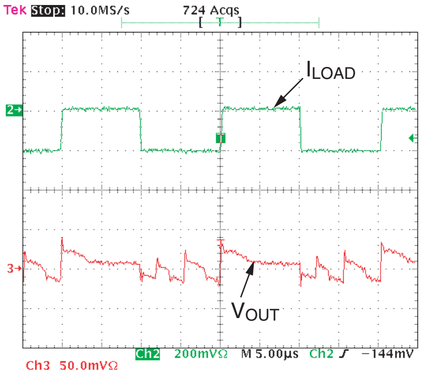
Inductor Current and Switching Node Voltage



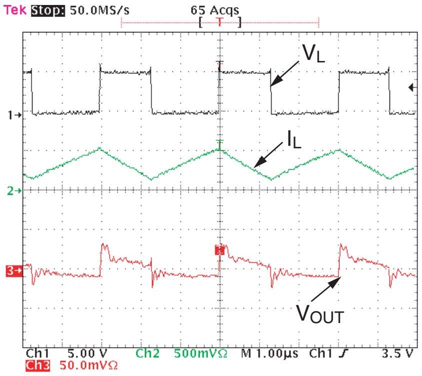
Exiting Shutdown



Load Transient Response



Heavy-Load Switching Waveforms



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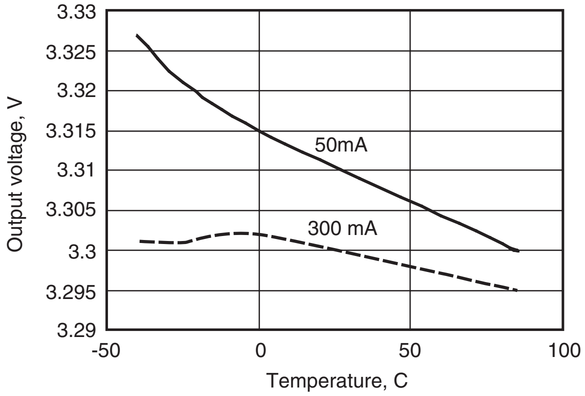
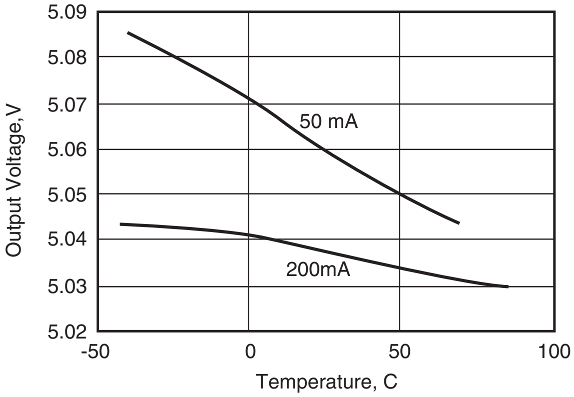
Typical Operating Characteristics (Continued)

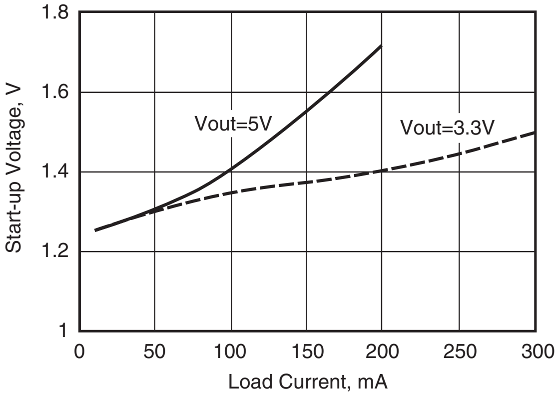
Output Voltage vs. Temperature



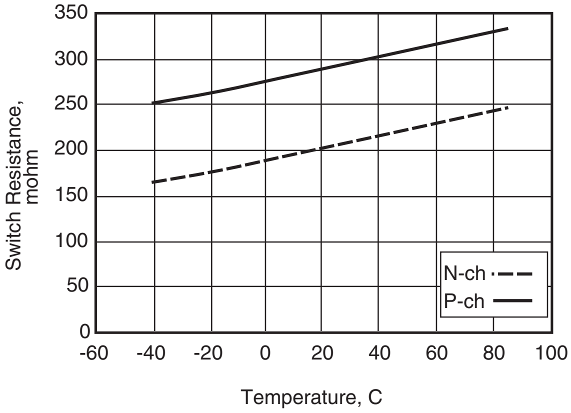
Output Voltage vs. Temperature



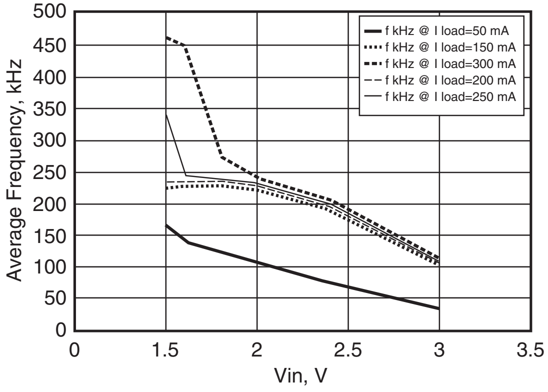
Start-up Voltage vs. Load Current



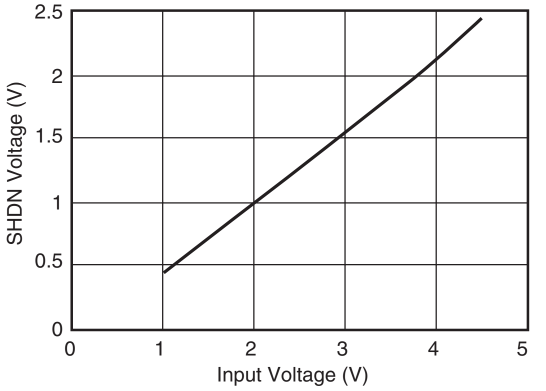
Switch ON Resistance vs. Temperature



Operating Frequency, Vout=3.3V



$\overline{\text{SHDN}}$ Threshold Voltage vs. Input Voltage



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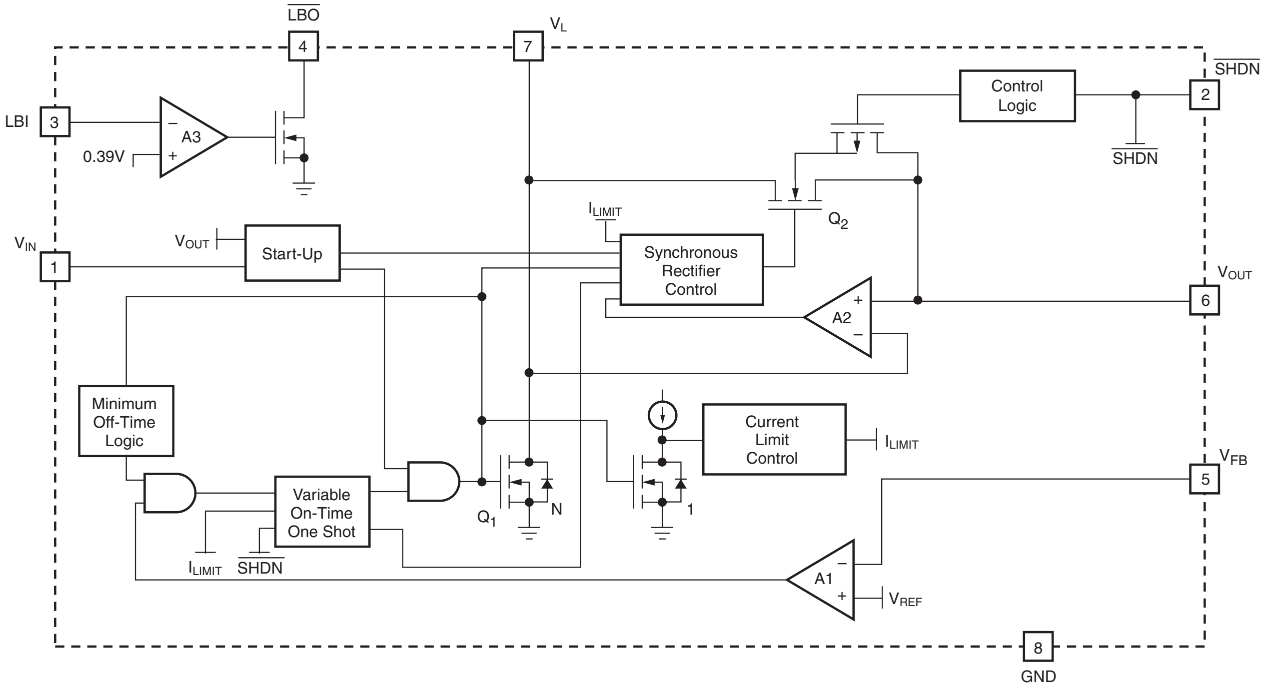
Block Diagram



Functional Description

Boost regulator

ML4854 is an adjustable boost regulator that combines variable ON and minimum OFF architecture with synchronous rectification. Unique control circuitry provides high-efficiency power conversion for both light and heavy loads by transitioning between discontinuous and continuous conduction based on load conditions. There is no oscillator; a constant-peak-current limit of 1.5A in the switch allows the inductor current to vary between this peak limit and some lesser value. The switching frequency depends upon the load and the input voltage, and can range up to 650kHz.

The input voltage (V_{IN}) comes to V_{IN} pin and through the external Inductor to the V_L pin of the device. The loop from V_{OUT} closes through the external resistive voltage divider to the feedback pin V_{FB}. The transfer ratio of this divider determines the output voltage. When V_{FB} voltage drops below V_{REF} =1.23V, the error amplifier A1 signals to the regulator to deliver a charge to the output by triggering the Variable On-Time One Shot. This generates a pulse at the gate of the Power NMOS transistor Q1. This transistor will charge the Inductor L1 for the time interval (T_{ON}) resulting in a peak current given by:

$$I_{L(PEAK)} = \frac{T_{ON} \times V_{IN}}{L_1}$$

When the one shot times out, the Q1 transistor releases the V_L pin, allowing the inductor to fly-back and momentary charge the output through the body diode of the transistor Q2. But, as the voltage across the Q2 changes polarity, its gate will be driven low by the Synchronous Rectifier Control Circuit (SRC), causing Q2 to short out its body diode. The inductor then delivers the charge to the load by discharging into it through Q2.

Under lightly loaded conditions, the amount of energy delivered in this single pulse satisfies the voltage-control loop, and the converter does not command any more energy pulses until the output again drops below the lower-voltage threshold. Under medium and heavy loads, a single energy pulse is not sufficient to force the output voltage above its upper threshold before the minimum off time has expired and a second charge cycle is commanded. Since the inductor current has not reached zero in this case, the peak current is greater than the previous value at the end of the second cycle. The result is a ratcheting of inductor current until either the output voltage is satisfied, or the converter reaches its set current limit.

After a period of time $T_{OFF} > 0.5\mu S$, determined by Minimum Off–Time Logic and if V_{OUT} is low ($V_{FB} < V_{REF}$), the Variable On-Time One Shot will be turned ON again and the process repeats.

The output capacitor of the converter (see Test circuit) filters the variable component, limiting the output voltage ripple to a value determined by its capacitance and its ESR.

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The synchronous rectifier significantly improves efficiency without the addition of an external component, so that conversion efficiency can be as high as 94% over a large load range, as shown in the "Typical Operating Characteristics." Even at light loads, the efficiency stays high because the switching losses of the converter are minimized by reducing the switching frequency.

Error Detection Comparator (LBI – LBO)

An additional comparator A3 is provided to detect low V_{IN} or any other error conditions that is important to the user. The non-inverting input of the comparator is internally connected to a reference threshold voltage V_{th} while the inverting input is connected to the LBI pin. The output of the low battery comparator is a simple open-drain output that goes active low if the battery voltage drops below the programmed threshold voltage on LBI. The output requires a pull-up resistor, with a recommended value of 100 kΩ, be connected only to V_{OUT}.

The low-battery detector circuit is typically used to supervise the battery voltage and to generate an error flag or a RESET command when the battery voltage drops below a user-set threshold voltage. The function is active only when the device is enabled. When the device is disabled, the LBO-pin is high impedance.

Shutdown

The device enters shutdown when $V_{\overline{SHDN}}$ is low (approximately less than $0.5V_{IN}$). During shutdown the regulator stops switching, all internal control circuitry including the low-battery comparator is switched off and the load is disconnected from the input. The output voltage may drop below the input voltage during shutdown. The typical dependence shutdown voltage versus input voltage and the timing process of the exiting shutdown are shown in the "Typical Operating Characteristics." For normal operation $V_{\overline{SHDN}}$ should be driven up $0.8V_{IN}$ or connected to the V_{IN}.

Application Information

Selecting the Output Voltage

The output voltage V_{OUT} can be adjusted from 3V to 5V, choosing resistors R4 and R5 of the divider in the feedback circuit (see Test Circuit). The value of the R5 is recommended to be less than 270k. R4 can be calculated using the following equation:

$R4 = R5[(V_{OUT}/V_{REF}) - 1]$
where $V_{REF} = 1.23V$

A compensation capacitor C3=18pF parallel with R4 provides better pulse grouping.

Setting the LBI Threshold of Low-Battery Detector Circuit

The LBO-pin goes active low when the voltage on the LBI-pin decreases below the set threshold typical voltage of 390 mV, which is set by the internal reference voltage. The battery voltage, at which the detection circuit switches, can be programmed with a resistive divider connected to the LBI-pin. The resistive divider scales down the battery voltage to a voltage level of tenths of volt, which is then compared to the LBI threshold voltage. The LBI-pin has a built-in hysteresis of 25 mV. The resistor values R1 and R2 can be calculated using the following equation:

$V_{IN\_MIN} = 0.39 \times (R1+R2)/R2$

The value of R2 should be 270k or less to minimize bias current errors. R1 is then found by rearranging the equation:

$R1 = R2 \times (V_{IN\_MIN}/0.39 - 1)$

If the low-battery detection circuit is not used, the LBI-pin should be connected to GND (or to V_{IN}) and the LBO-pin can be left unconnected or tied to GND. Do not let the LBI-pin float.

Component selection

Output capacitor selection

The major parameter necessary to define the output capacitor is the maximum allowed output voltage ripple of the converter. This ripple is determined by two parameters of the capacitor, the capacitance and the ESR.

The contribution due to the capacitance can be determined by looking at the change in capacitor voltage required to store the energy delivered by the inductor in a single charge –discharge cycle, as determined by the formula:

$$\Delta V_{OUT} = \frac{T_{ON}^2 \times V_{IN}^2}{2 \times L \times C(V_{OUT} - V_{IN})}$$

For example, if V_{IN}=3V, V_{OUT}=5V, L=10µH, T_{ON} =1.2µs, C=47µF, the calculation by this formula gives an expected output ripple due to only the capacitor value of 6.5mV.

In continuous inductor mode operation, this additional component of the ripple, due to capacitor ESR, can be calculated using equation:

$$\Delta V_{ESR} = (ESR) \times \left(\frac{I_{OUT}}{1-D} + \frac{V_{IN} \times t_{ON}}{2L}\right)$$

Where D is the duty cycle.

An additional ripple of 28 mV, at 100mA load current, is the result of using a ceramic capacitor with an ESR of 70mΩ. The total ripple is the sum of the ripple caused by the capacitance and the ripple caused by the ESR of the capacitor. In this example, the total ripple is 34.5mV. It is possible to

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improve the design by enlarging the capacitor or using smaller capacitors in parallel to reduce the ESR or by using better capacitors with lower ESR.

Tradeoffs have to be made between performance and costs of the external parts of the converter circuit. For common, general purpose applications, a ceramic output capacitor with a capacitance of 47µF and ESR less than 0.1Ω could be a good choice. If a tantalum capacitor is used, a 100nF ceramic capacitor in parallel, placed close to the IC, is recommended.

Input Capacitor Selection

Since the ML4854 does not require a large decoupling capacitor at the input to operate properly, a 47µF capacitor is sufficient for most applications requiring a good transient response of the regulator. Optimum efficiency occurs when the capacitor value is large enough to decouple the source impedance. This usually occurs for capacitor values in excess of 47µF.

Table 1. Recommended capacitors

Vendor	Description
MuRata	X5R Ceramic
AVX	TAJ,TPS series tantalum
Sprague	595D series tantalum
Kemet	T494 series tantalum

Inductor Selection

To select the boost inductor, it is necessary to keep the possible peak inductor current below the absolute peak current limit of the power switch of the device. The highest peak current through the inductor and the switch depends on the load current (I_{LOAD}), the input voltage(V_{IN}) and the output voltage (V_{OUT}).

The maximum load current depends upon the inductance L, according to the equation:

$$I_{LOADmax} = \frac{V_{IN}\left[I_{LIM} - t_{OFFmin}\frac{V_{OUT} - V_{IN}}{2L}\right]}{V_{OUT}} \times \eta$$

where, by design, $t_{OFFmin} = 0.5\mu S$, $I_{LIM} = 0.8A$ and the efficiency η is usually 0.9. For $V_{IN}=3V$, $V_{OUT}=5V$ the resulting $I_{LOADmax}$ will be around 0.4A.

The second parameter for choosing the inductor is the desired current ripple in the inductor. Normally, it is advisable to work with a ripple of less than 20% of the average inductor current. A larger inductor value provides a smaller ripple which reduces the magnetic hysteresis losses in the inductor, as well as output voltage ripple and EMI. But in the same way, regulation time at load changes will rise. Due to the nature of the “go/no go” control, larger inductor values typically result in larger overall voltage ripple, because once the output voltage level is satisfied, the converter goes discontinuous, resulting in the residual energy of the inductor, causing overshoot. The losses in the inductor caused by magnetic hysteresis losses and copper losses are a major parameter for total circuit efficiency. For better efficiency the ESR of the inductor should be kept as low as possible. Lower value inductors typically offer lower ESR and smaller physical size.

An inductor value of 10 µH works well in most applications, but values between 5 µH to 22 µH are also acceptable. A MuRata LQ66C100M4, 10µH surface-mount inductor is suitable, having a current rating of 1.6A and a max. ESR of 36 mΩ. Other choices for surface-mount inductors are shown in Table 2.

Table 2. Recommended Inductors

Supplier	Manufacturer Part Number
MuRata	LQ66C100M4
Coilcraft	DT1608C-103
Coiltronics	UP1B100
Sumida	CDR63B-100

Thermal considerations

Implementation of integrated circuits in low-profile surface-mount packages typically requires special attention to power dissipation. Many system-dependent issues such as thermal coupling, airflow, added heat sinks and convection surfaces, and the presence of other heat-generating components affect the power-dissipation limits of a given component.

Three basic approaches for enhancing thermal performance are:

- Improving the power dissipation capability of the PCB design
- Improving the thermal coupling of the component to the PCB
- Introducing airflow in the system

The maximum junction temperature, $T_{J\,(MAX)}$ of the ML4854 devices is 150°C. The thermal resistance of the 8-pin TSSOP package (T08) is $\theta_{JA} = 124°C/W$. Specified regulator operation is assured to a maximum ambient temperature $T_{A(MAX)}$ of 85°C. Therefore, the maximum power dissipation is about 320 mW. More power can be dissipated if the maximum ambient temperature of the application is lower, according to the relation:

$$P_{D(MAX)} = [T_{J(MAX)} - T_{A(MAX)}] / \theta_{JA}$$

Layout and Grounding Considerations

Careful design of printed circuit board is recommended since high frequency switching and high peak currents are present in DC/DC converters applications. A general rule is to place the converter circuitry well away from any sensitive analog

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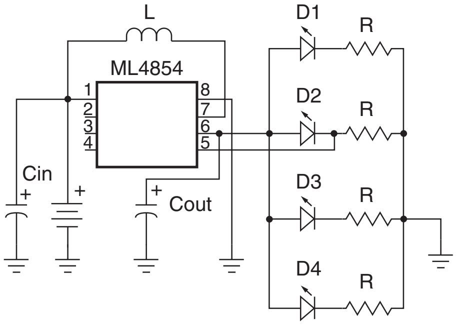
components. The PCB layout should be based on some simple rules to minimize EMI and to ensure good regulation performances:

1. Place the IC, inductor, input and output capacitor as close together as possible.
2. Keep the output capacitor as close to the ML4854 as possible with very short traces to V_{OUT} and GND pins. Typically it should be within 0.25 inches or 6 mm.
3. Keep the traces for the power components wide, typically > 50 mils or 1.25 mm.
4. Place the external networks for LBI and FB close to ML4854, but as far away as possible from the power components to prevent voltage transient from coupling into sensitive nodes.
5. On multilayer boards, use component side copper for grounding around the IC and connect back to a quiet ground plane using vias. The ground planes act as electrostatic shields for some of the RF energy radiated.
6. The connection of the GND pin of the IC (pin 8) to the overall grounding system should be directly to the bottom of the output filter capacitor. A star grounding system radiating from where the power enters the PCB, is a recommended practice.

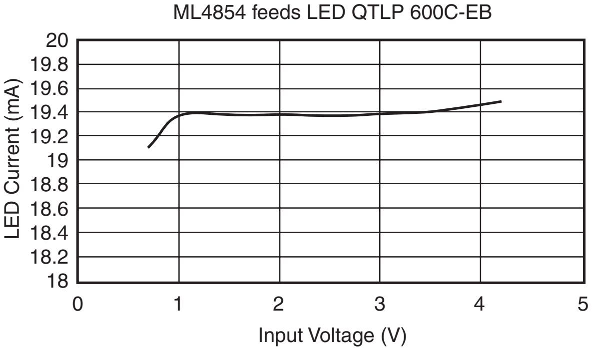
Application Example:

Using ML4854 as a constant current source to drive four LEDs:



L = 10µH
Cin = Cout = 10µF
R = 62 ohm
D1...D4 = QTLP 600C-EB (blue)

The current through the LEDs is maintained constant within a large input voltage range as shown in the diagram below:


ML4854 feeds LED QTLP 600C-EB

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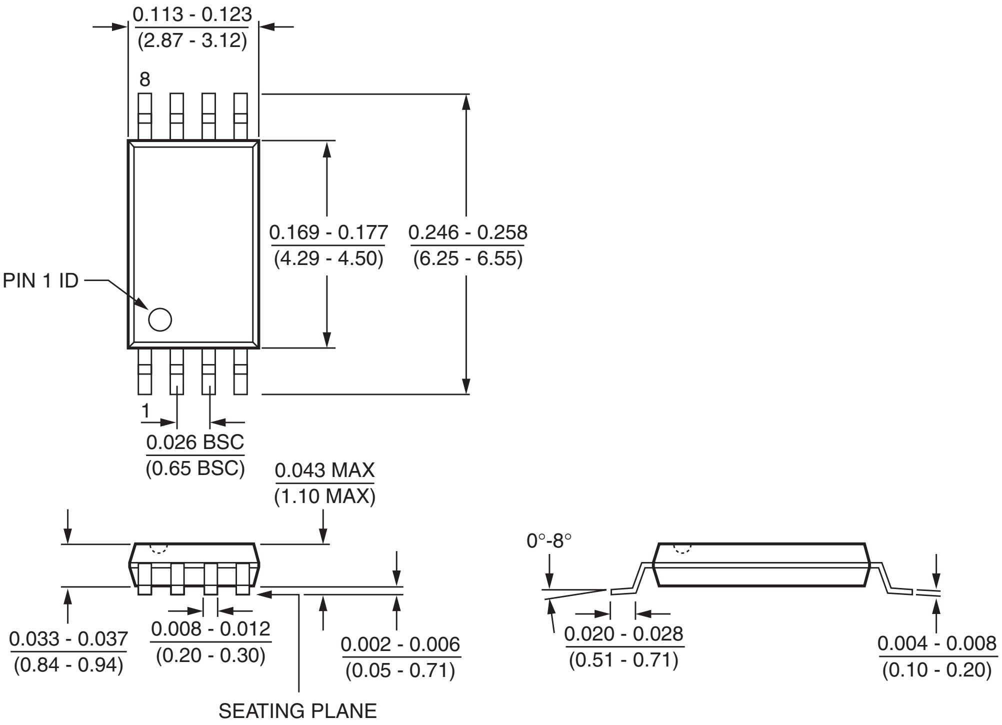
Mechanical Dimensions

Package: T08
8-Lead TSSOP



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Ordering Information

Part Number	Temperature Range	Package
ML4854IT	–40°C to 85°C	8 Pin TSSOP (T08)

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