![UNITRODE logo]

Single Cell Lithium-Ion to +3.3V Converter

FEATURES

- Converts Lithium-Ion Cell to +3.3V at 700mA Load Current

- Load Disconnect in Shutdown

- High Efficiency Flyback Operation

- Internal 0.15Ω Switch

- Low Battery LED Driver

- Internal 2A Current Limit

- Internal 200kHz Oscillator

- 8 Pin D, N, 14 Pin PW Packages

DESCRIPTION

The UCC3954, along with a few external components, develops a regulated +3.3V from a single lithium-ion battery whose terminal voltage can vary between 2.5V and 4.2V. The UCC3954 employs a simple flyback (Buck-Boost) technique to convert the battery energy to +3.3V. This is accomplished by referencing the lithium-ion cell's positive terminal to system ground. The negative terminal of the battery is the return point for the UCC3954. This approach enables the converter to maintain constant frequency operation whether the cell voltage is above or below the output voltage. An additional benefit of this technique is its inherent ability to disconnect the battery from the load in shutdown mode.

The UCC3954 operates as a fixed 200kHz switching frequency voltage mode flyback converter. The oscillator time base and ramp are internally generated by the UCC3954 and require no external components. A 2A current limit for the internal 0.15Ω power switch provides protection in the case of an output short circuit. When left open, an internal 100kΩ resistor pulls the $\overline{SD}$ pin to BAT−, which puts the UCC3954 in shutdown mode, and thereby reduces power consumption to sub-µA levels. A low battery detect function will drive the LOWBAT pin low (minimum of 5mA sink current) when the battery has been discharged to within 200mV of the predefined lockout voltage. The LOWBAT pin is intended for use with an external LED to provide visual warning that the battery is nearly exhausted. The lockout mode is activated when the battery is discharged to 2.55V. In lockout mode, the part consumes 15µA. Once the UCC3954 has entered lockout mode, the user must insert a fresh battery whose open circuit voltage is greater than 3.1V. This prevents a system-level oscillation of the lockout function due to the lithium-ion battery's large equivalent series resistance.

Additional features of the UCC3954 include a trimmed −1.1V reference and internal feedback scaling resistors, a precision error amplifier, low quiescent current drain in shutdown mode, and a softstart function. The UCC3954 is offered in the 8 pin D, 14 pin PW (surface mount), and N (through hole) packages.
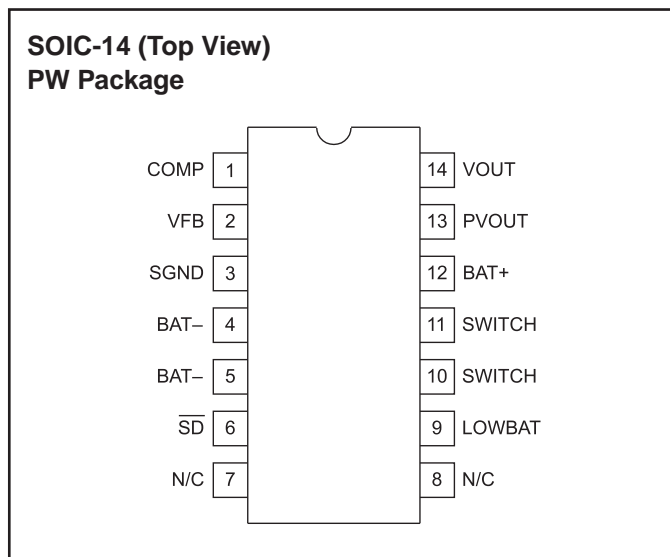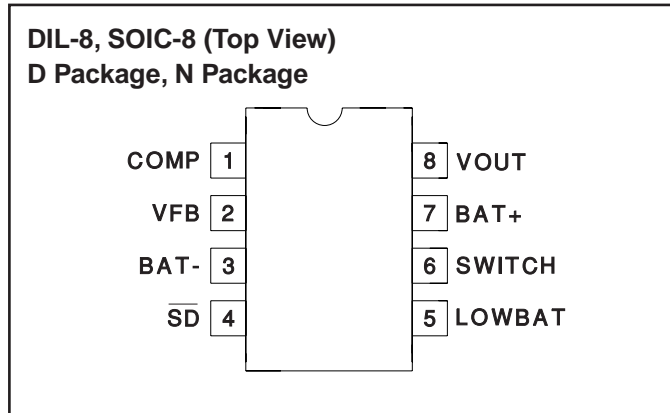
BLOCK DIAGRAM
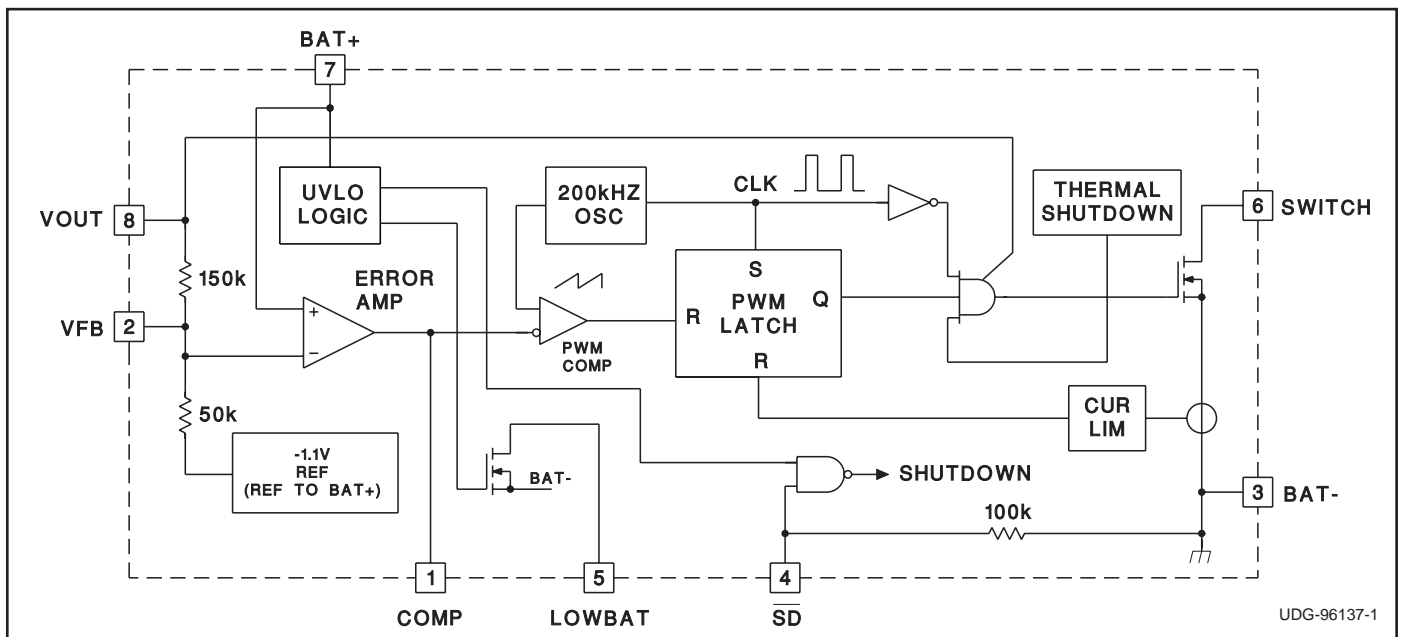
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ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage (BAT+ to BAT–) 4.5V
VOUT
   Maximum Forced Voltage (ref. to BAT+) 5.5V
SWITCH
   Maximum Forced Voltage (ref. to BAT–) 10.2V
   Maximum Forced Current . . . . Internally Limited
$\overline{SD}$
   Maximum Forced Voltage (ref. to BAT+) 5.5V
   Maximum Forced Current 10mA
COMP
   Maximum Forced Voltage (ref. to BAT–) 4.5V
   Maximum Forced Current . . . . Self Limiting
Storage Temperature . . . . –65°C to +150°C
Junction Temperature . . . . –55°C to +150°C
Lead Temperature (Soldering, 10 sec.) . . . . +300°C

Unless otherwise indicated, voltages are reference to BAT– and currents are positive into, negative out of the specified terminal. Pulsed is defined as a less than 10% duty cycle with a maximum duration of 500μs. Consult Packaging Section of Databook for thermal limitations and considerations of packages.

CONNECTION DIAGRAMS

DIL-8, SOIC-8 (Top View)
D Package, N Package

Pin	Name		Pin	Name
1	COMP		8	VOUT
2	VFB		7	BAT+
3	BAT-		6	SWITCH
4	$\overline{SD}$		5	LOWBAT

SOIC-14 (Top View)
PW Package

Pin	Name		Pin	Name
1	COMP		14	VOUT
2	VFB		13	PVOUT
3	SGND		12	BAT+
4	BAT–		11	SWITCH
5	BAT–		10	SWITCH
6	$\overline{SD}$		9	LOWBAT
7	N/C		8	N/C

ELECTRICAL CHARACTERISTICS: Unless otherwise specified, T_A = –20°C to 70°C for the UCC3954, $\overline{SD}$ = V_{BAT+} = 3.5V (ref. to V_{BAT-}), VOUT = 3.3 (ref. to V_{BAT+}). $T_A = T_J$

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Input Supply					
Supply Current (total) – active	I_{BAT+} + I_{VOUT}		1	2	mA
Supply Current (BAT+)– Shutdown	V_{SDB} = 0V (reference to BAT–)		0.2	5	μA
Supply Current (BAT+) –UVLO			30	40	μA
BAT+ Turn On Threshold	With Respect to BAT+ Turnoff	250	300	375	mV
BAT+ Turn Off Threshold		2.35	2.55	2.75	V
Low BAT+ Indicate Threshold	With Respect to BAT+ Turnoff	50	100	325	mV
Error Amplifier					
Output Voltage High	Maximum Duty Cycle, I_{OH} = 1ma	2.0	2.4		V
Output Voltage Low	Minimum Duty Cycle, I_{OL} = 1ma	0	0.14	0.5	V
VOUT Regulation Voltage	T_A = 25°C	3.22	3.3	3.38	V
		3.20	3.3	3.39	V

ELECTRICAL CHARACTERISTICS: Unless otherwise specified, T_A = –20°C to 70°C for the UCC3954, $\overline{SD}$ = V_{BAT+} = 3.5V (ref. to V_{BAT-}), VOUT = 3.3 (ref. to V_{BAT+}). T_A = T_J

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Oscillator/PWM					
Intital Accurancy	T_A = 25°C	180	200	220	kHz
		175	200	225	kHz
PWM Modulator Gain	V_{COMP} = 1.6V to 2V	40	50	60	%/V
PWM Maximum Duty Cycle		65	75	85	%
PWM Minimum Duty Cycle			3	5	%
Shutdown					
Disable Threshold	Reference to BAT–	0.8	1.5	2.5	V
Lowbat					
On Resistance	V_{LOWBAT} = 1V	40	100	220	Ω
Soft Start					
Rise TIme	Note 2, R_{LOAD} = 33Ω, C_{COMP} = 39nF, C_{LOAD} = 330µF		10		msec
Output Switch					
Saturation Voltage	I_{SWITCH} = 200mA		30	70	mV
Overcurrent Threshold	Note 2	2.0	3.0	3.5	Amps

Note 1: V_{BAT+} <2V to reset.

Note 2: Guaranteed by design. Not 100% tested in production.

PIN DESCRIPTIONS

BAT+: Logic supply voltage for the UCC3954. Connect to the positive terminal of the lithium-ion battery and system ground. Bypass with a low ESR, ESL capacitor if located more than 1 inch from the battery positive terminal. This is also the return for the +3.3V load

BAT–: Return for the UCC3954. Switch current flows through this pin to the negative terminal of the battery. Proper board layout precautions should be taken to minimize trace length in this path.

COMP: Output of the voltage error amplifier. Loop compensation component C_{COMP} is connected between COMP and VFB.

LOWBAT: An open drain output that will pull low and sink 10mA (typ) to drive an external LED if the battery voltage falls below the low BAT+ warning threshold. Note that this output pulls low to BAT–.

PVOUT: (PW Package only) This is the bootstrap input for the internal FET drive. It should be tied to the 3.3V output along with V_{OUT} .

SD: Shutdown input for the UCC3954. An internal 100kΩ resistor pulls $\overline{SD}$ to BAT– when the circuit is left open. Pulling $\overline{SD}$ up to system ground (BAT+) or to V_{OUT}, starts the UCC3954. The UCC3954 enters a lockout mode when a dead battery is detected (<2.55V). Until a fresh battery is inserted (>3.1V), the part will remain in the low current lockout state.

SGND: (PW Package only) This is a separate signal ground pin which should be externally tied to BAT–.

SWITCH: Drain terminal of the internal 0.15Ω power switch. The current into this pin is internally limited.

VFB: This is the virtual ground of the error amplifier. Nominally at the same voltage as BAT+, the pin is provided for external compensation by means of a single capacitor to form a simple dominant pole.

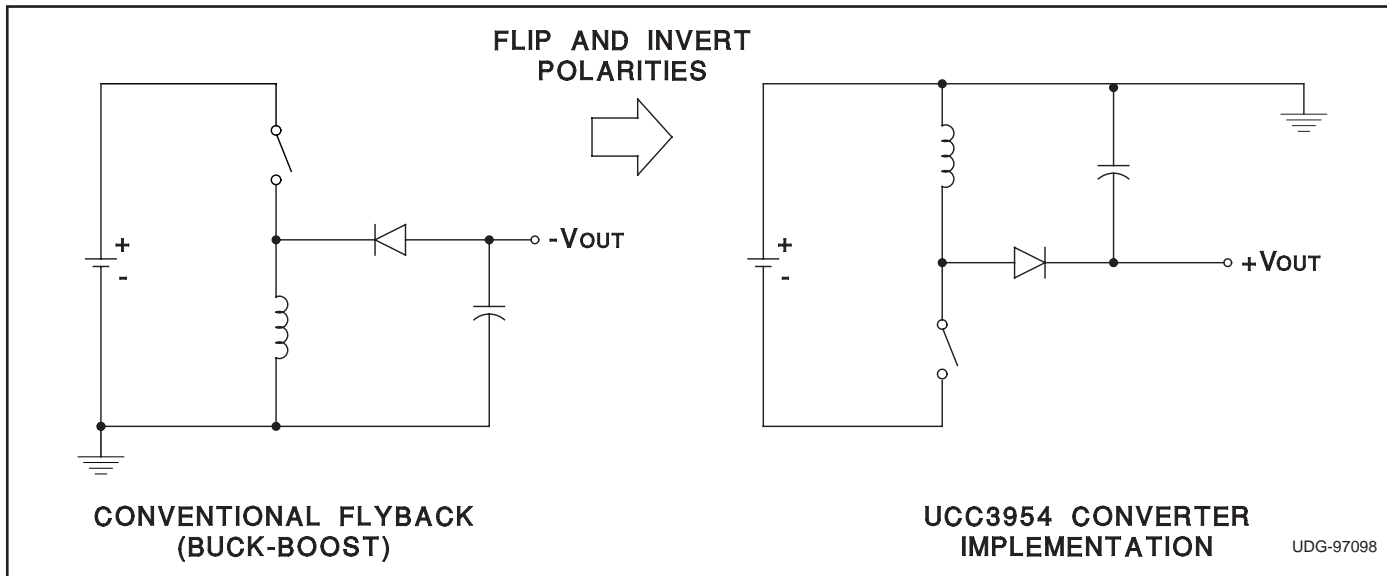**VOUT:** Regulated 3.3V supply feedback to the UCC3954.

Figure 1. Simplified Circuit Diagram

APPLICATION INFORMATION

Circuit Topology

The UCC3954 uses a fixed frequency (200KHz), voltage mode PWM flyback topology. It can operate from a battery input voltage that is above or below the output voltage by referencing the battery's (+) terminal to the output (system) ground and the battery's (–) terminal to the IC's "ground" pin. It is typically operated in the continuous conduction mode (CCM), except at light loads to reduce losses due to high peak inductor current. The simplified diagram in Figure 1 helps to visualize the circuit topology. Figure 2 illustrates the current waveforms in the major circuit elements.

Only a few external components are required to develop a regulated 3.3V output from a single Lithium-Ion cell. A low ESR (Equivalent Series Resistance) and ESL (Equivalent Series Inductance) decoupling capacitor should be placed as close as possible to BAT+ and BAT–. This is especially important when operating at low battery voltages, where the peak current could cause excessive input ripple, causing the input voltage to drop below the UCC3954's shutdown threshold. The other parts required are a compensation capacitor, inductor, Schottky diode and output filter capacitor. The output filter capacitor should also be a good low ESR/ESL capacitor.

Choosing an Inductor

The inductor value selected, for a given input voltage and load current, will determine if the converter is operating in the continuous or the discontinuous conduction mode. In general, the efficiency will be higher in the continuous mode (larger inductor value), due to the lower peak currents. This also reduces the demands on the output filter

capacitor and lowers output ripple voltage. However, a larger inductor value will also be physically larger for the same current rating, and reduces loop bandwidth, making it more difficult to compensate. For the input voltage range and fixed operating frequency of the UCC3954, an inductor value of around 33μH is a good compromise. See Table 1 for values and part numbers of inductors for specific ranges of load current.

Remember that the inductor must be able to maintain most of its inductance at the peak switching current.

Output Capacitor Selection

To minimize output voltage ripple, a good high frequency capacitor(s) must be used. Low ESR tantalums or Sanyo
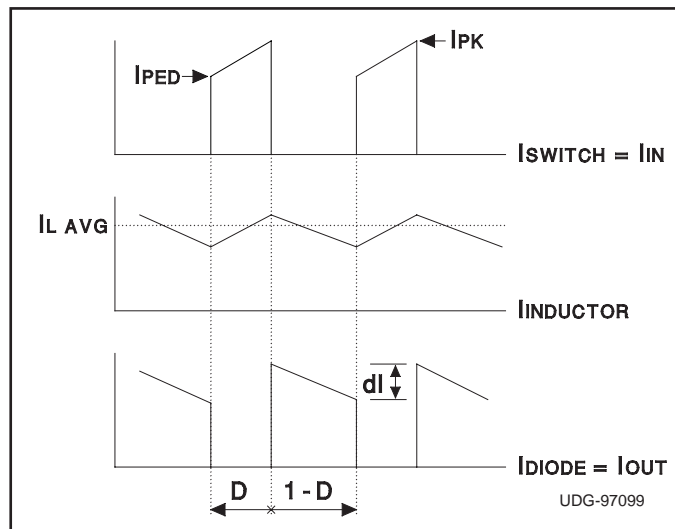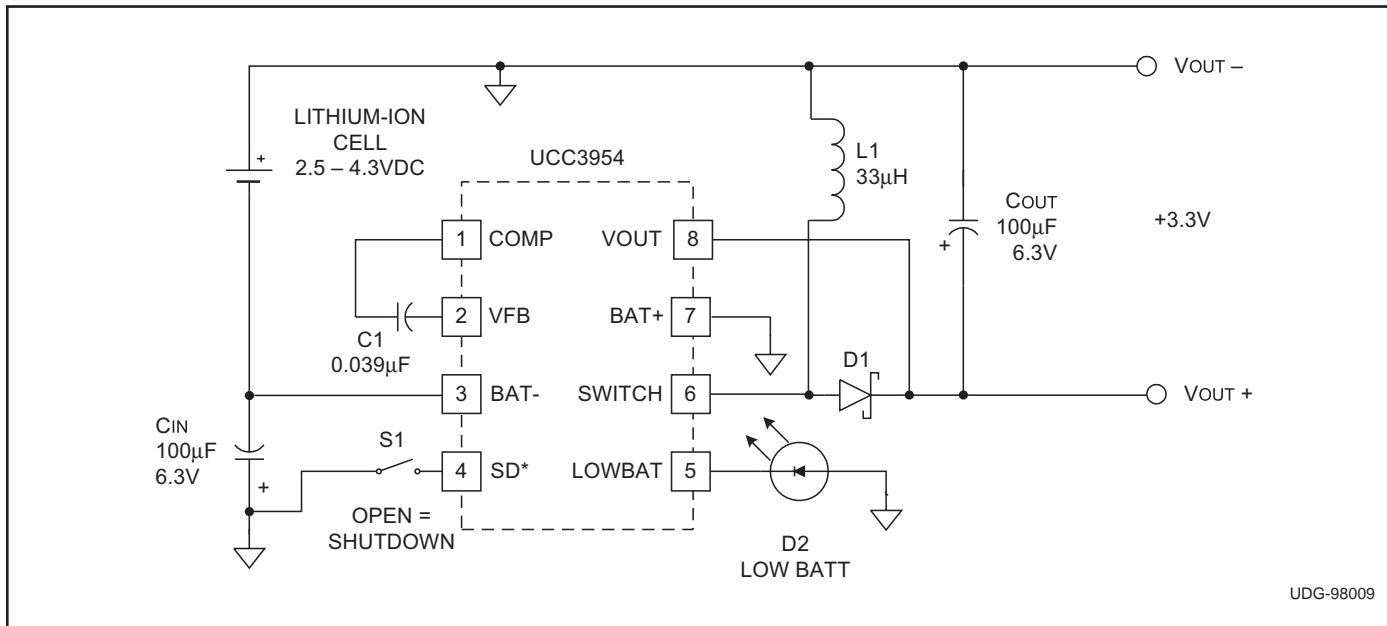

Figure 2. Current Waveforms

Figure 3. Application Circuit Using Dominant Pole Compensation. Typical Values are Shown.

APPLICATION INFORMATION (cont.)

OSCON's are recommended. Surface mounting will eliminate the lead inductance. Suggested values and part numbers for C_{OUT} at different load currents are given in Table 1.

Compensation Capacitor

For applications where the load is fairly constant, the loop may be compensated with a single capacitor between COMP and VFB. The value shown in the Application Circuit of Figure 3 provides good stability margin over a wide range of load, using the values shown for L1 and C_{OUT}.

Lead-Lag Compensation for Dynamic Loads

When large dynamic load transients are expected, the simple dominant pole compensation method may not provide adequate dynamic load regulation. In this case, lead-lag compensation is recommended, as shown in the application circuit of Figure 4. The addition of R1 and C1

in the error amp feedback loop provides significantly wider loop bandwidth, resulting in improved transient response. The optimum values of these compensation components will depend on a number of factors; including input voltage, load current, inductor value and output capacitance, as well as the ESR of the inductor and output capacitor. The compensation values shown in Figure 4 will provide good loop stability and good transient response over the full range of input voltage and output load. They were chosen assuming a nominal inductor value of 33µH.

Power Stage Component Selection

Recommended values and part numbers are given in Table 1 for C_{IN}, C_{OUT}, L1 and D1 for two ranges of load current. The ranges were selected based on the current ratings for two common surface mount inductor sizes.

| Load Current	C_{IN}	C_{OUT}	L1	D1
$I_{OUT} < 200mA$	47µF, 6.3V AVX TPSC476M006R0350	100µF, 6.3V AVX TPSC107M06R0150	33µH Coilcraft DO1608C-333	0.5A, 20V Schottky Motorola MBR0520LT1
$I_{OUT} > 200mA$	100µF, 10V AVX TPSD107M010R0100	330µF, 6.3V AVX TPSE337M006R0100	33µH Coilcraft DO3316P-333 Coiltronics CTX33-4	1A, 30V Schottky Motorola MBRS130LT3

Table 1. Power Stage Component Selection Guide
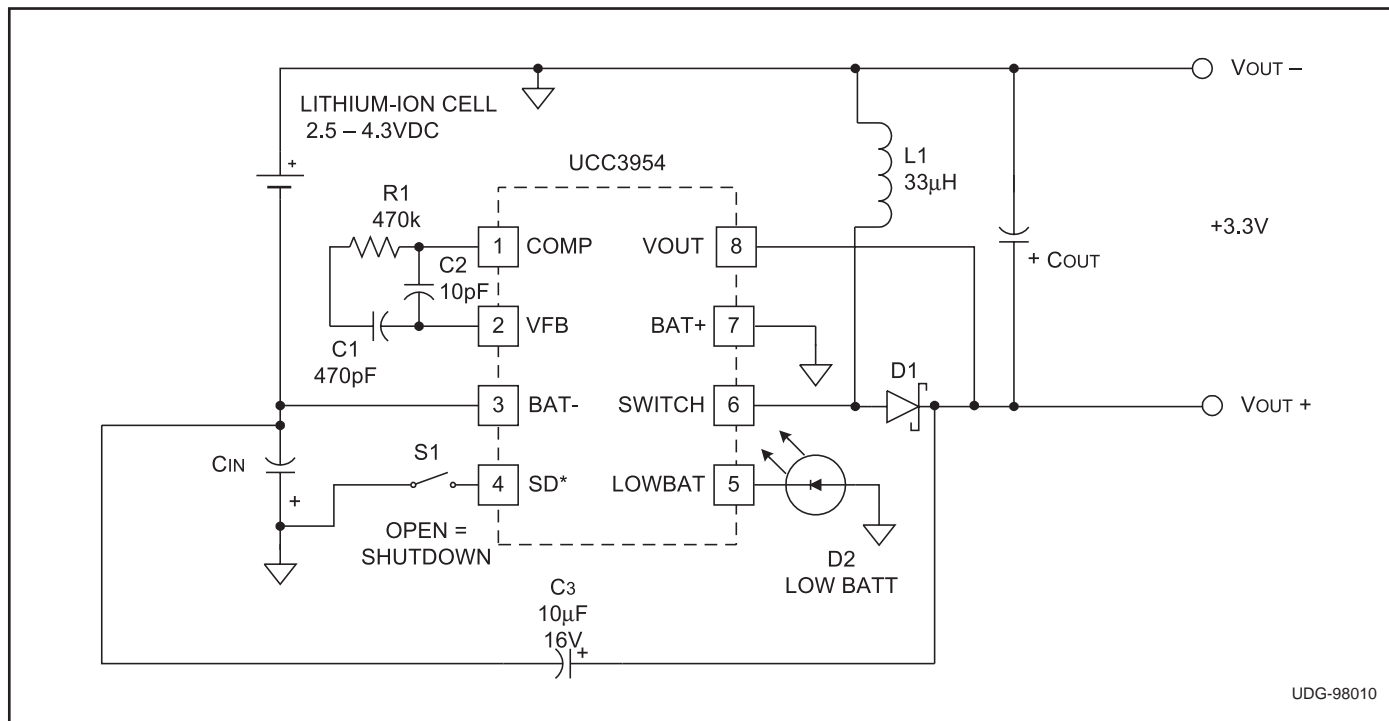
Figure 4. Application Circuit Showing Lead-Lag Compensation and Additional Cap to Reduce Output Ripple Using Cancellation Technique.

See Table 1 for Suggested Component Values and Part Numbers

Reducing Output Ripple for Noise Sensitive Applications

In some applications it may be necessary to have very low output voltage ripple. There are a number of ways to achieve this goal. Since the ripple is dominated by the ESR of the output filter capacitor, one way to reduce the ripple is to put multiple low ESR capacitors in parallel. However, this brute force method can be expensive and take up excessive board real estate.

A more effective method of ripple reduction is shown in Figure 4. By adding a small tantalum capacitor (C3) between the 3.3V output and the negative battery input (BAT–), both input and output voltage ripple are reduced. This technique is a kind of ripple current cancellation scheme, since the ripple voltage on these two nodes is 180° out of phase. Using this method, output ripple can be reduced by up to 50%. As with the other filter capacitors, it is imperative that stray inductance and resistance in series with the capacitor be minimized for maximum effectiveness. Note that this capacitor sees the sum of the input and output voltages; therefore an absolute minimum voltage rating of 10V is required.

For applications where extremely low output ripple is required, a small LC filter is recommended. This is shown in Figure 5. The addition of a small inductor and filter capacitor will reduce the ripple well below what could be achieved with capacitors alone. It is also very effective in eliminating any high frequency noise spikes resulting from the main output capacitor's ESL and the Schottky diode's parasitic capacitance. The LC values shown will provide significant ripple reduction while having a negligible effect on output regulation. Note that the corner frequency of 41kHz was chosen to be well below the 200kHz switching frequency, but high enough to avoid the loop crossover frequency, which is typically below 10kHz. This avoids loop stability issues in case the feedback is taken from the output of the LC filter. By leaving the feedback (VOUT) connection point before the LC filter, the filter cap value can be increased to achieve even higher ripple attenuation without affecting stability margin.
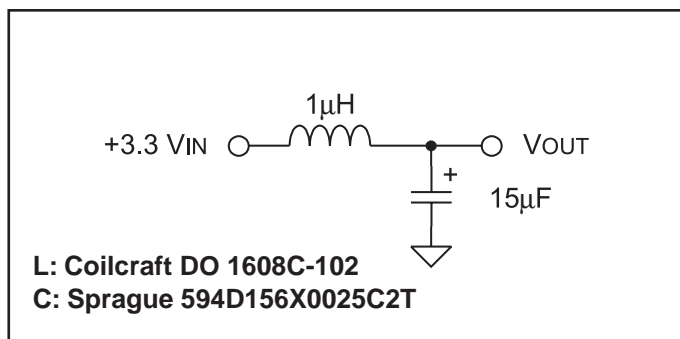

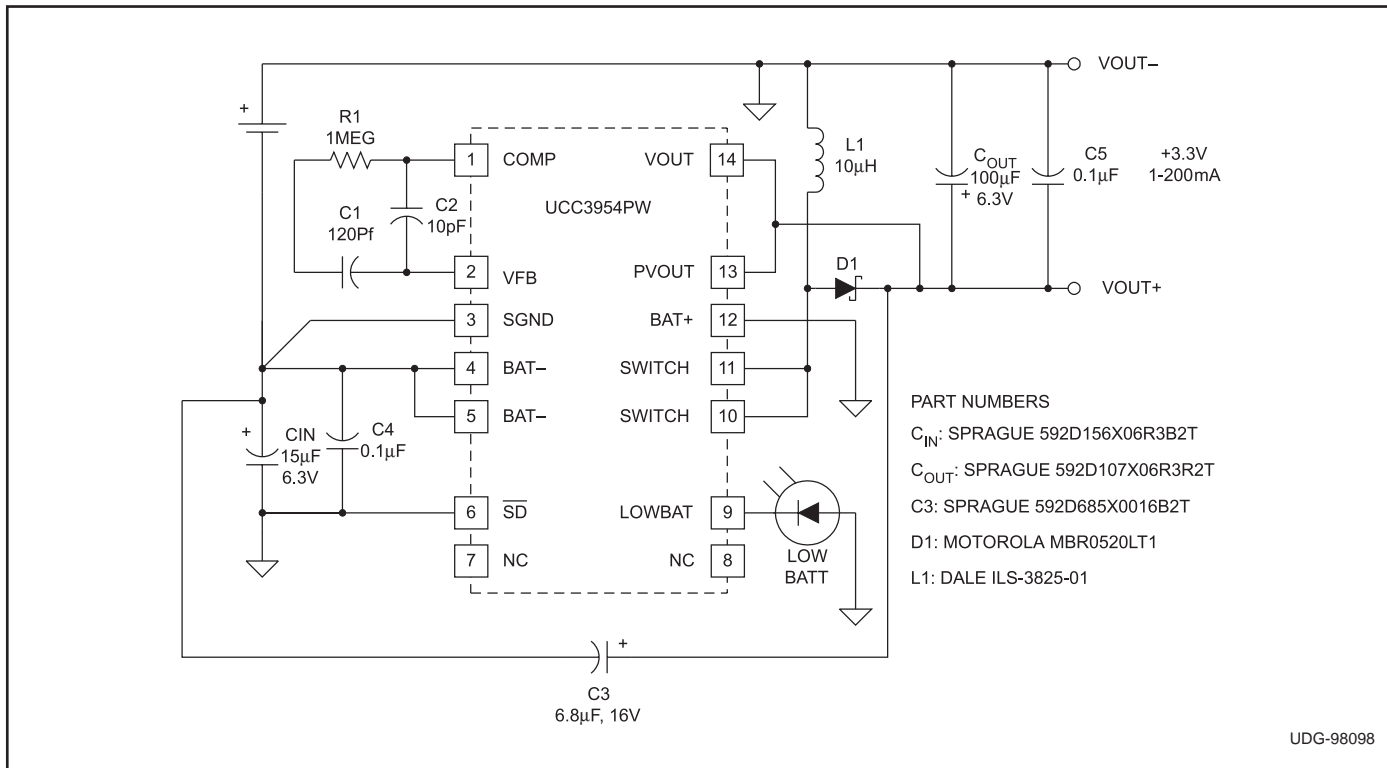**Figure 5. LC Filter for Very Low Noise Applications**

Figure 6. Application Circuit Using the 14 Pin TSSOP Package and Other Low Profile Components to Achieve 1.2mm Overall Maximum Height.*

The maximum height on D1 is 1.35mm.

Very Low Profile Applications

The UCC3954 is available in a low profile (1.2mm) 14 pin TSSOP package. The application circuit shown in Figure 6 is an example of a complete 200mA, 3.3V converter which will fit within a 1.2mm max height envelope*. Note that the low inductor value for L1 (10µH) requires a minimum load of at least 1mA to guarantee output regulation.

Minimum Load

Note that the pulse width modulator within the UCC3954 cannot go to zero percent duty cycle. Therefore, it stores a finite amount of energy in L1 every switching cycle. Normally, this would prevent regulation under no-load conditions. However, for inductor values greater than 15µH, no minimum load is required to maintain output regulation. This is because the current drawn by the VOUT pin, used for feedback and to bootstrap the internal MOSFET's gate drive, satisfies the minimum load requirement. However, the higher peak current resulting from inductor values below 15µH requires a small minimum load to maintain output regulation. These lower value inductors are not optimal, and will not be as efficient due to the higher peak currents, but may be necessary to reduce size in some applications, such as that of Figure 6.

Low Battery Warn Output

The UCC3954 includes an open drain Low Battery Warn output that turns on and pulls the LOWBAT pin down to BAT– when the battery input voltage drops to the Low Bat threshold. This indicates that the battery voltage is very low and approaching the UCC3954 turn off threshold.

The LOWBAT output switch is designed to have a high on-resistance, so an LED can be driven directly if desired, with no current limiting resistor. The anode of the LED can be connected to system ground (BAT+) or to the +3.3V output (this will result in a higher LED current).

For systems where it is desired to read the LOWBAT output as a digital signal referenced to the +3.3V ground, a level shifter is needed. The circuit shown in Figure 7 is a simple resistive level shifter, consisting of R1 and R2, which provides a +3.3V compatible output. The output will normally be pulled up to +3.3V until a low battery condition exists, at which point it will be about 0.3V above the 3.3V ground. Figure 8 shows the typical converter efficiency for different loads as a function of input voltage.
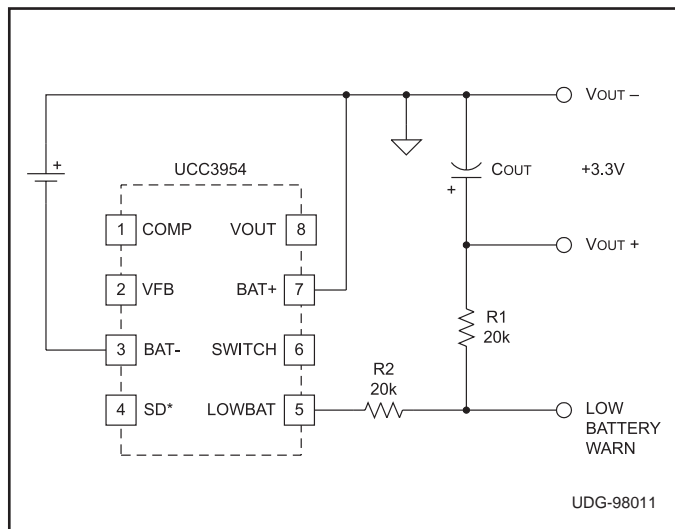
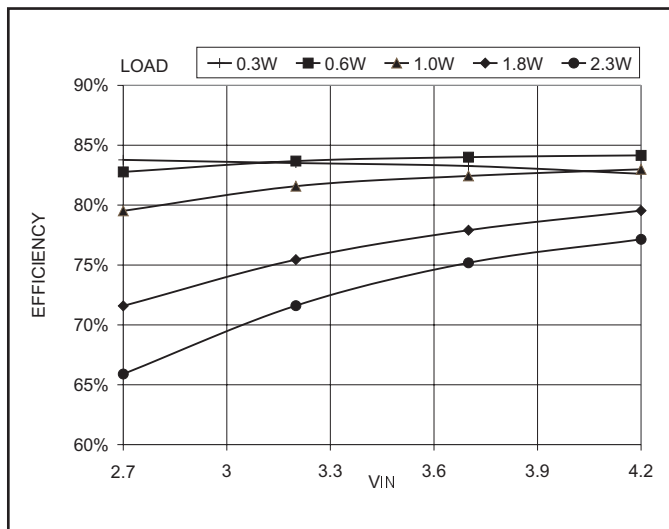**Figure 7. Simple Resistive Level Shifter for the Low Battery Warn Output**

Figure 8. Typical Efficiency as a Function of Input Voltage and Load

PACKAGING INFORMATION

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/Ball Finish	MSL Peak Temp [3]
UCC3954D	OBSOLETE	SOIC	D	8		TBD	Call TI	Call TI
UCC3954DTR	OBSOLETE	SOIC	D	8		TBD	Call TI	Call TI
UCC3954N	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI

[1] The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

[2] Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
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Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

[3] MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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