

# MAXIM

## High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

### General Description

The MAX1642/MAX1643 are high-efficiency, low-voltage, step-up DC-DC converters intended for devices powered by a single alkaline cell. They feature low quiescent supply currents and are supplied in the ultra-small  $\mu$ MAX package, which is only 1.1mm high. The guaranteed start-up voltage is 0.88V.

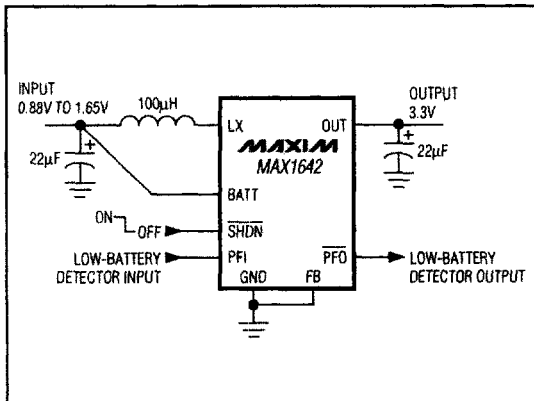
Each device consists of an internal 1 $\Omega$ , N-channel MOSFET power switch; a built-in synchronous rectifier that acts as the catch diode; an oscillator; a reference; and pulse-frequency-modulation (PFM) control circuitry. Both devices feature an independent undervoltage comparator (PFI/PFO). The MAX1642 also includes a 2 $\mu$ A logic-controlled shutdown mode. The MAX1643 offers a dedicated low-battery detector (BATTLO) in lieu of shutdown.

The output voltage for each device is preset to 3.3V  $\pm$ 4%, or can be adjusted from +2V to +5.2V using only two resistors.

### Applications

Pagers  
Remote Controls  
Pointing Devices  
Personal Medical Monitors  
Single-Cell Battery-Powered Devices

### Typical Operating Circuit



### Features

- ◆ Built-In Synchronous Rectifier
- ◆ 0.88V Guaranteed Start-Up
- ◆ Ultra-Small  $\mu$ MAX Package: 1.1mm High
- ◆ 83% Efficiency
- ◆ 4 $\mu$ A Quiescent Supply Current into BATT Pin
- ◆ 2 $\mu$ A Logic-Controlled Shutdown (MAX1642)
- ◆ Two Undervoltage Detectors (MAX1643)
- ◆ 2V to 5.2V Output Range
- ◆ 20mA Output Current at 1.2V Input
- ◆ Reverse Battery Protection

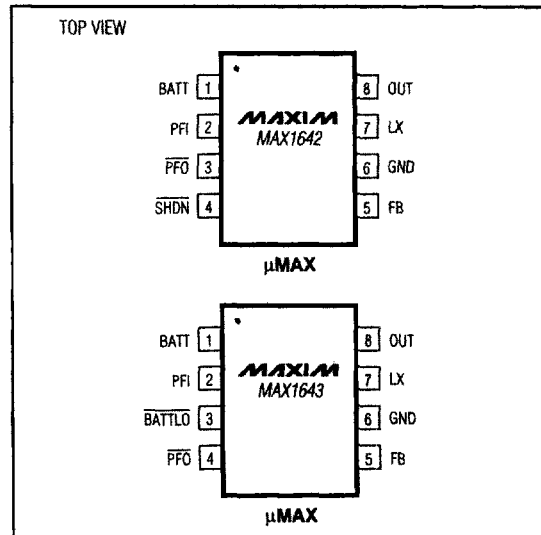
### Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX1642C/D	0°C to +70°C	Dice*
MAX1642EUA	-40°C to +85°C	8 $\mu$ MAX
MAX1643C/D	0°C to +70°C	Dice*
MAX1643EUA	-40°C to +85°C	8 $\mu$ MAX

\*Dice are tested at  $T_A = +25^\circ\text{C}$ .

Note: To order these devices shipped in tape and reel, add a -T to the part number.

### Pin Configurations



# High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

## ABSOLUTE MAXIMUM RATINGS

BATT to GND	-0.3V to 6.0V	Continuous Power Dissipation	
BATT Forward Current	0.5A	$\mu$ MAX (derate 4.1mW/°C above 70°C)	330mW
OUT to GND	-0.3V to 6.0V	Operating Temperature Range	
OUT, LX Current	1A	MAX1642EUA/MAX1643EUA	-40°C to +85°C
LX to GND	-0.3V to 6.0V	Junction Temperature	+150°C
SHDN, FB, BATTLO, PFO to GND	-0.3V to 6.0V	Storage Temperature Range	-65°C to +165°C
PFI to GND	-0.3V to V <sub>BATT</sub>	Lead Temperature (soldering, 10sec)	+300°C
Reverse Battery Current (T <sub>A</sub> = +25°C) (Note 1)	220mA		

**Note 1:** The reverse battery current is measured from the *Typical Operating Circuit's* input terminal to GND when the battery is connected backward. A reverse current of 220mA will not exceed package dissipation limits but, if left for an extended time (more than 10 minutes), may degrade performance.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## ELECTRICAL CHARACTERISTICS

(V<sub>BATT</sub> = V<sub>SHDN</sub> = 1.3V, I<sub>LOAD</sub> = 0mA, FB = GND, T<sub>A</sub> = 0°C to +85°C, unless otherwise noted. Typical values are at T<sub>A</sub> = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Minimum Operating Input Voltage	V <sub>BATT(MIN)</sub>			0.7		V
Maximum Operating Input Voltage					1.65	V
Start-Up Voltage (Note 2)		R <sub>L</sub> = 3k $\Omega$ , T <sub>A</sub> = +25°C	0.88			V
Start-Up Voltage Tempco				-2		mV/°C
Output Voltage	V <sub>OUT</sub>	V <sub>FB</sub> < 0.1V	3.16	3.30	3.44	V
Output Voltage Range		External feedback	2.0		5.2	V
FB Set Voltage	V <sub>FB</sub>	External feedback	1.18	1.225	1.27	V
N-Channel On-Resistance		V <sub>OUT</sub> = 3.3V		1	1.5	$\Omega$
P-Channel On-Resistance		V <sub>OUT</sub> = 3.3V		1.5	2.2	$\Omega$
P-Channel Catch-Diode Voltage		I <sub>DIODE</sub> = 100mA, P-channel switch off		0.8		V
On-Time Constant	K	0.9V < V <sub>BATT</sub> < 1.5V (t <sub>ON</sub> = K / V <sub>BATT</sub> )	17	25	35	V- $\mu$ s
Off-Time Tracking Ratio (Note 3)	RATIO	0.9V < V <sub>BATT</sub> < 1.5V, V <sub>OUT</sub> = 3.3V	1		1.5	
Quiescent Current into OUT	I <sub>QOUT</sub>	V <sub>OUT</sub> = 3.5V		11	18	$\mu$ A
Quiescent Current into BATT	I <sub>QBATT</sub>			4	6.5	$\mu$ A
Shutdown Current into OUT	I <sub>SHDN,OUT</sub>	V <sub>OUT</sub> = 3.5V (MAX1642)		0.1	1	$\mu$ A
Shutdown Current into BATT	I <sub>SHDN,BATT</sub>	V <sub>BATT</sub> = 1.0V (MAX1642)		2	3.5	$\mu$ A
Efficiency	$\eta$	I <sub>LOAD</sub> = 20mA		80		%
FB Input Current		V <sub>FB</sub> = 1.3V			10	nA
PFI Trip Voltage		Falling PFI, hysteresis = 1%	590	614	632	mV
PFI Input Current		V <sub>PFI</sub> = 650mV			10	nA
PFO, BATTLO Low Output Voltage	V <sub>OL</sub>	V <sub>PFI</sub> = 0V, V <sub>OUT</sub> = 3.3V, I <sub>SINK</sub> = 1mA			0.4	V
PFO, BATTLO Leakage Current		V <sub>PFI</sub> = 650mV, V <sub>PFO</sub> = 6V			1	$\mu$ A
BATTLO Trip Voltage		V <sub>OUT</sub> = 3.3V, hysteresis = 2% (MAX1643)	0.96	1.0	1.04	V
SHDN Input Low Voltage	V <sub>IL</sub>	% of V <sub>BATT</sub> (MAX1642)			20	%
SHDN Input High Voltage	V <sub>IH</sub>	% of V <sub>BATT</sub> (MAX1642)	80			%
SHDN Input Current		(MAX1642)			10	nA

# High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

MAX1642/MAX1643

## ELECTRICAL CHARACTERISTICS

( $V_{BATT} = V_{SHDN} = 1.3V$ ,  $I_{LOAD} = 0mA$ ,  $FB = GND$ ,  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted.) (Note 4)

PARAMETER	SYMBOL	CONDITIONS	MIN	MAX	UNITS
Output Voltage	$V_{OUT}$	$V_{FB} < 0.1V$	2.99	3.56	V
FB Set Voltage	$V_{FB}$	External feedback	1.11	1.32	V
N-Channel On-Resistance		$V_{OUT} = 3.3V$		1.5	$\Omega$
P-Channel On-Resistance		$V_{OUT} = 3.3V$		2.2	$\Omega$
On-Time Constant	K	$0.9V < V_{BATT} < 1.5V$ ( $t_{ON} = K / V_{BATT}$ )	12.4	38.2	V- $\mu s$
Quiescent Current into OUT	$I_{QOUT}$	$V_{OUT} = 3.5V$		18	$\mu A$
Quiescent Current into BATT	$I_{QBATT}$			6.5	$\mu A$
Shutdown Current into OUT	$I_{SHDN,OUT}$	$V_{OUT} = 3.5V$ (MAX1642)		1	$\mu A$
Shutdown Current into BATT	$I_{SHDN,BATT}$	$V_{BATT} = 1.0V$ (MAX1642)		3.5	$\mu A$
PFI Trip Voltage		Falling PFI, hysteresis = 1%	550	662	mV
$\overline{BATTLO}$ Trip Voltage		Falling $V_{BATT}$ , $V_{OUT} = 3.3V$ , hysteresis = 2% (MAX1643)	0.93	1.06	V

**Note 2:** Start-up guaranteed by correlation to measurements of device parameters (i.e., switch on-resistance, on-times, off-times, and output voltage trip points).

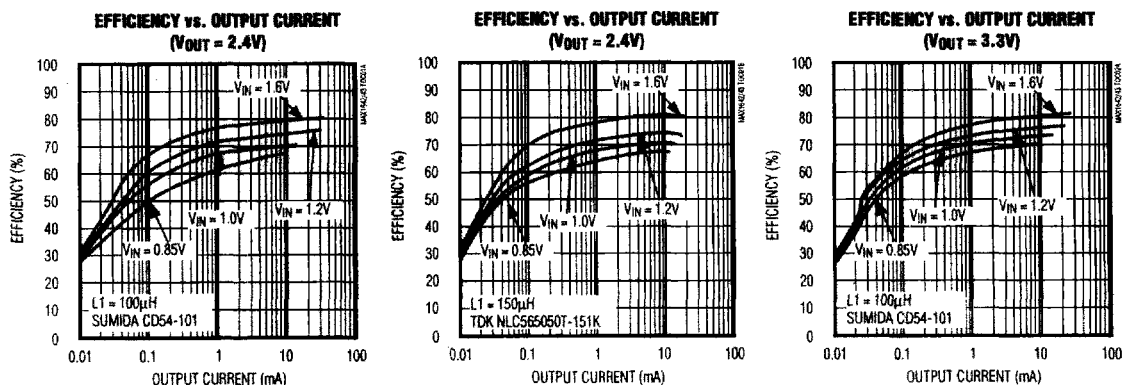
**Note 3:**  $t_{OFF} = \left[ \frac{t_{ON} \times V_{BATT}}{V_{OUT} - V_{BATT}} \right] \times \text{RATIO}$ . This guarantees discontinuous conduction.

**Note 4:** Specifications to  $-40^{\circ}C$  are guaranteed by design, not production tested.

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## Typical Operating Characteristics

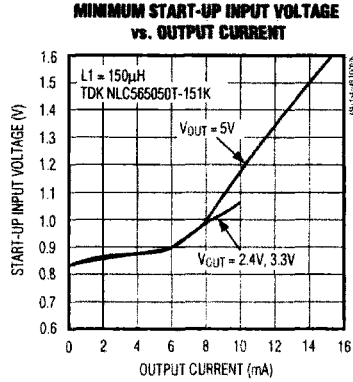
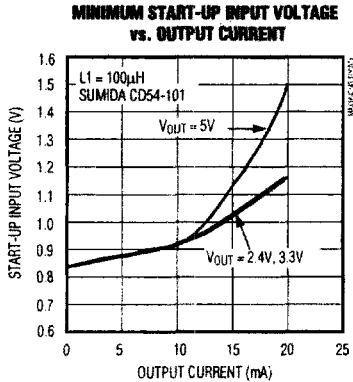
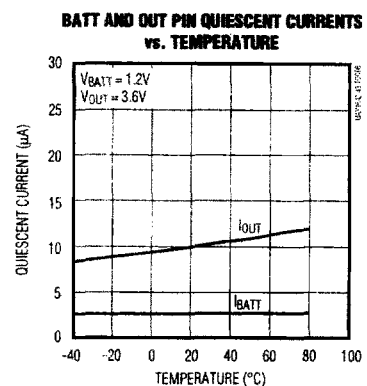
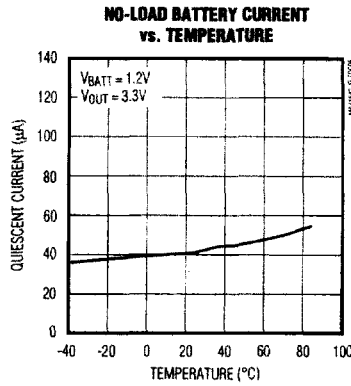
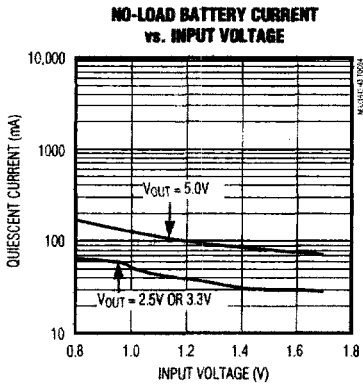
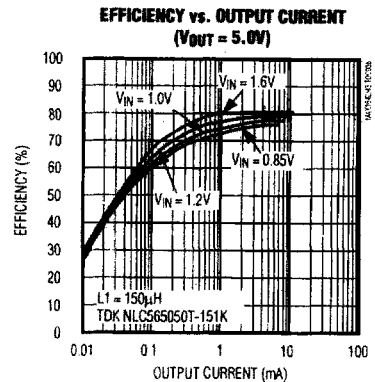
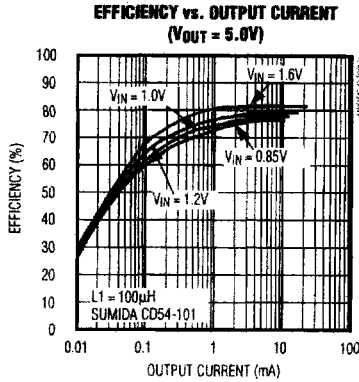
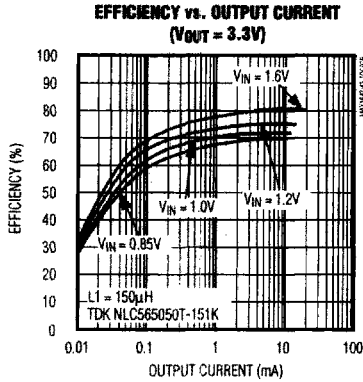
(Circuit of Figure 4,  $V_{BATT} = 1.2V$ ,  $R1 + R2 = 1M\Omega$ ,  $T_A = +25^{\circ}C$ , unless otherwise noted.)



# High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

## Typical Operating Characteristics (continued)

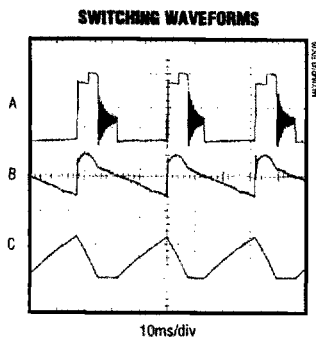
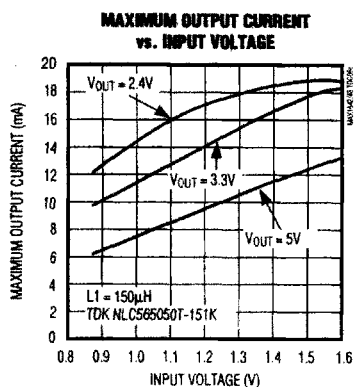
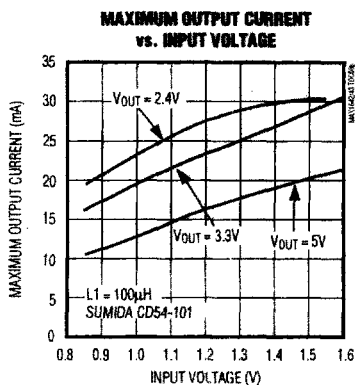
(Circuit of Figure 4,  $V_{BATT} = 1.2V$ ,  $R1 + R2 = 1M\Omega$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)



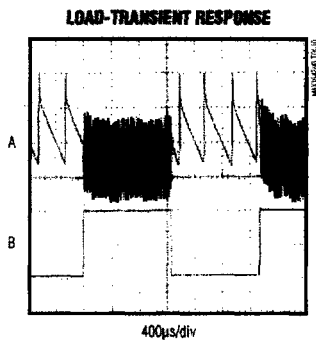
# High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

## Typical Operating Characteristics (continued)

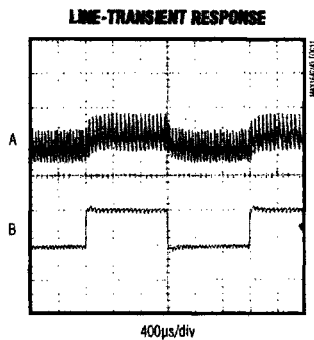
(Circuit of Figure 4,  $V_{BATT} = 1.2V$ ,  $R1 + R2 = 1M\Omega$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)



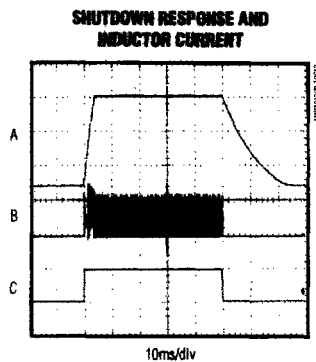
$V_{OUT} = 3.3V$ ,  $V_{IN} = 1.2V$ ,  $I_{OUT} = 12mA$   
A: LX, 2V/div,  $L1 = TDK NLC565050T-151K$   
B: OUT, 20mV/div, 3.3V DC OFFSET  
C: INDUCTOR CURRENT, 100mA/div



$V_{OUT} = 3.3V$ ,  $V_{BATT} = 1.2V$   
A: OUT, 20mV/div, 3.3V DC OFFSET  
B: LOAD, 2mA to 20mA, 10mA/div



$V_{OUT} = 3.3V$ , LOAD = 15mA  
A: OUT, 50mV/div, 3.3V DC OFFSET  
B:  $V_{BATT}$ , 1V to 1.5V, 500mV/div



$V_{OUT} = 3.3V$ ,  $V_{BATT} = 1.2V$ ,  $I_{OUT} = 5mA$   
A: OUT, 1V/div  
B: INDUCTOR CURRENT, 200mA/div  
C: SHDN, 2V/div

MAX1642/MAX1643

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# High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

## Pin Description

PIN		NAME	FUNCTION
MAX1642	MAX1643		
1	1	BATT	IC Battery-Power Input. Sense input for $\overline{\text{BATTLO}}$ comparator (MAX1643 only).
2	2	PFI	Power-Fail Input. When the voltage on PFI drops below 614mV, $\overline{\text{PFO}}$ sinks current.
—	3	$\overline{\text{BATTLO}}$	Open-Drain Battery-Low Output. When the voltage at BATT drops below 1V, $\overline{\text{BATTLO}}$ sinks current.
3	4	$\overline{\text{PFO}}$	Open-Drain Power-Fail Output. Sinks current when PFI drops below 614mV.
4	—	$\overline{\text{SHDN}}$	Active-Low Shutdown Input. Connect to BATT for normal operation.
5	5	FB	Feedback Input for adjustable-output operation. Connect FB to an external resistor voltage divider between OUT and GND. Connect to GND for fixed-output operation.
6	6	GND	Ground
7	7	LX	N-Channel MOSFET Switch Drain and P-Channel Synchronous-Rectifier Drain
8	8	OUT	Power Output. Feedback input for fixed 3.3V operation and IC power input. Connect filter capacitor close to OUT.

## Detailed Description

The MAX1642/MAX1643 each consist of an internal  $1\Omega$ , N-channel MOSFET power switch, a built-in synchronous rectifier that acts as the catch diode, an oscillator, a reference, and PFM control circuitry (Figure 1).

These devices are optimized for applications with power-management features that operate from one alkaline cell, such as pagers, remote controls, and battery-powered instruments. They are designed to meet the specific demands of the operating states characteristic of such systems:

- 1) *Primary battery is good and the load is active:* In this state, the system draws tens of milliamperes, and the MAX1642/MAX1643 typically offer 80% efficiency.
- 2) *Primary battery is good and the load is sleeping:* In this state, the load is drawing hundreds of microamperes, and the DC-DC converter IC draws very low quiescent current. In many applications, the load is expected to be in this state most of the time.

## Operating Principle

The MAX1642/MAX1643 employ a proprietary pulse-frequency-modulation (PFM) control scheme that combines the ultra-low quiescent current traditional of pulse-skipping PFM converters with the high-load efficiency of pulse-width-modulation (PWM) converters. The on-time and minimum off-times are varied as a function of the input and output voltages:

$$t_{\text{ON}} = \frac{K}{V_{\text{BATT}}}$$

$$t_{\text{OFF(MIN)}} = \frac{1.2 \times K}{V_{\text{OUT}} - V_{\text{BATT}}}$$

where K is typically 25V- $\mu\text{s}$ . This enables the MAX1642/MAX1643 to maintain high efficiency over a wide range of loads and input/output voltages. The DC-DC converter is powered from the OUT pin.

# High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

MAX1642/MAX1643

When the error comparator detects that the output voltage is too low, it turns on the internal N-channel MOSFET switch until the on-time is satisfied (see Figure 1 and the Standard Application Circuits, Figures 2 and 3). During the on-time, current ramps up in the inductor, storing energy in a magnetic field. When the MOSFET turns off, during the second half of each cycle, the magnetic field collapses, causing the inductor voltage to force current through the synchronous rectifier, transferring the stored energy to the output filter capacitor and load. The output filter capacitor stores charge while current from the inductor is high, then holds up the output voltage until the second half of the next switching cycle, smoothing power flow to the load.

### Bootstrap DC-DC Block

The bootstrap block contains a low-voltage start-up oscillator. This oscillator pumps up the output voltage to approximately 1.7V, where the main DC-DC converter can operate. The oscillator is powered from the BATT input and drives an NPN switch. During start-up,

the P-channel synchronous rectifier remains off and either its body diode or an external diode is used as an output rectifier. Reduce the load as needed to allow start-up with input voltages below 2V (see *Typical Operating Characteristics*).

### Shutdown (MAX1642)

Pulling  $\overline{\text{SHDN}}$  low places the MAX1642 in shutdown mode ( $\text{I}_{\text{SHDN}} = 2\mu\text{A}$  typical). In shutdown, the internal switching MOSFET turns off,  $\overline{\text{PFO}}$  goes high-impedance, and the synchronous rectifier turns off to prevent reverse current from flowing from the output back to the input. However, there is still a forward current path through the synchronous-rectifier body diode from the input to the output. Thus, in shutdown, the output remains one diode drop below the battery voltage ( $\text{V}_{\text{BATT}}$ ). To disable the shutdown feature, connect  $\overline{\text{SHDN}}$  (a logic input) to BATT.

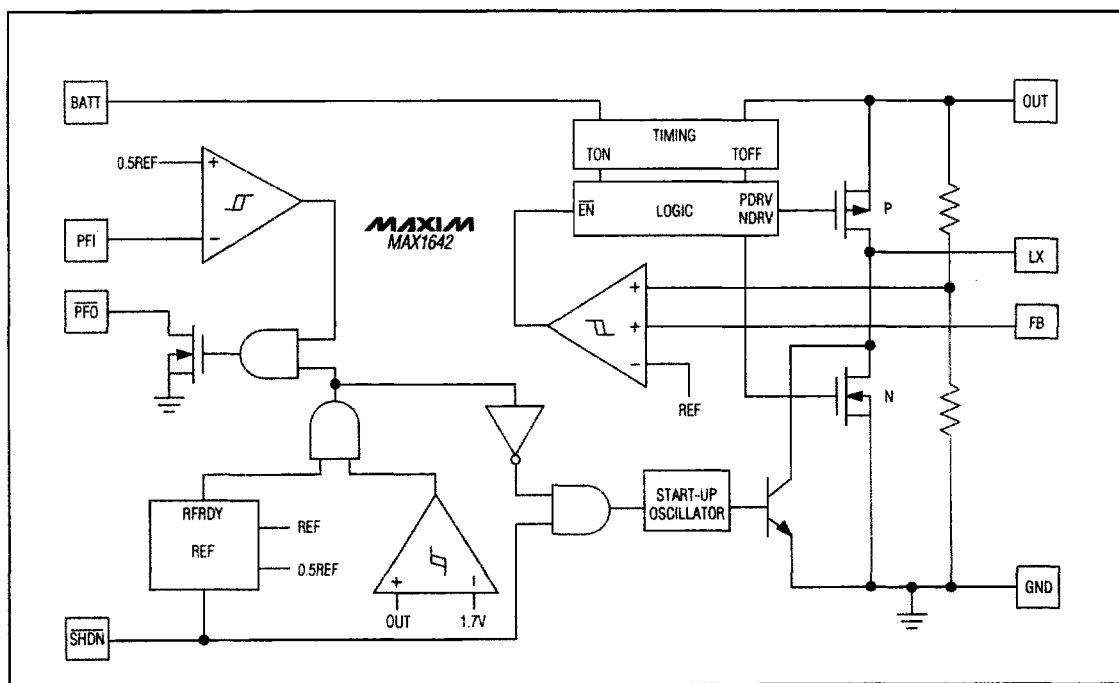


Figure 1. MAX1642 Functional Diagram

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# High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

## BATTLO (MAX1643)

The MAX1643 contains an on-chip comparator for low-battery detection. If the voltage at BATT drops below 1V, BATTLO sinks current. BATTLO is an open-drain output. In combination with PFI/PFO, this allows monitoring of both the input and output voltages.

## Reverse-Battery Protection

The MAX1642/MAX1643 can sustain/survive single-cell battery reversal up to the package power-dissipation limit. An internal  $5\Omega$  resistor in series with a diode limits reverse current to less than 220mA, which prevents damage to the MAX1642/MAX1643. Prolonged operation above 220mA reverse-battery current can degrade the devices' performance.

## Design Information

### Output Voltage Selection

The MAX1642/MAX1643 operate with a  $3.3V \pm 4\%$  or adjustable output. To select fixed-voltage operation, connect FB to GND. For an adjustable output between 2V and 5.2V, connect FB to a resistor voltage divider between OUT and GND (Figure 4). FB regulates to 1.23V.

Since FB leakage is 10nA max, select feedback resistor R2 in the 100k $\Omega$  to 1M $\Omega$  range. R1 is given by:

$$R1 = R2 \left( \frac{V_{OUT}}{V_{REF}} - 1 \right)$$

where  $V_{REF} = 1.23V$ .

### Power-Fail Detection

The MAX1642/MAX1643 have an on-chip comparator for power-fail detection. This comparator can detect loss of power at the input or output. If the voltage at PFI falls below 614mV, the PFO output sinks current to GND. Hysteresis at the power-fail input is 1%. The power-fail monitor's threshold is set by two resistors: R3 and R4 (Figure 5). Set the threshold using the following equation:

$$R3 = R4 \left( \frac{V_{TH}}{V_{PFI}} - 1 \right)$$

where  $V_{TH}$  is the desired threshold of the power-fail detector, and  $V_{PFI}$  is the 614mV reference of the power-fail comparator. Since PFI leakage is 10nA max, select feedback resistor R4 in the 100k $\Omega$  to 1M $\Omega$  range.

### Low-Battery Start-Up

The MAX1642/MAX1643 are bootstrapped circuits with a low-voltage start-up oscillator. They can start under low-load conditions at lower battery voltages than at full load. Once started, the output can maintain the load as

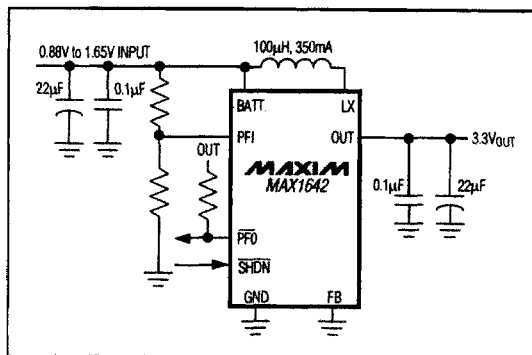


Figure 2. MAX1642 3.3V Standard Application Circuit

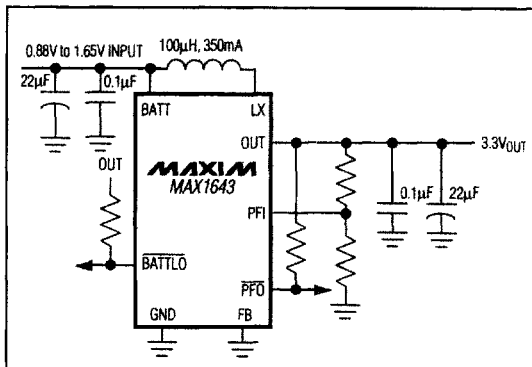


Figure 3. MAX1643 3.3V Standard Application Circuit

the battery voltage decreases below the start-up voltage (see *Typical Operating Characteristics*).

### Inductor Selection

A 100 $\mu$ H inductor is recommended for most applications. The use of lower inductor values (down to 68 $\mu$ H) increases maximum output current. Higher values (up to 220 $\mu$ H) reduce peak inductor current and consequent ripple and noise. The inductor's saturation-current rating must exceed the peak current limit synthesized by the MAX1642/MAX1643's timing algorithms:

$$I_{PEAK} = \frac{K_{MAX}}{L_{MIN}}$$

where  $K_{MAX} = 35V\text{-}\mu$ s. The maximum recommended  $I_{PEAK}$  is 350mA. For best efficiency, inductor series resistance should be less than 1 $\Omega$ .



# High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

MAX1642/MAX1643

## Capacitor Selection

Choose input and output capacitors to service input and output peak currents with acceptable voltage ripple. A 22 $\mu$ F, 6V, low-ESR, surface-mount tantalum output filter capacitor typically provides 60mV output ripple when stepping up from 1.3V to 3.3V at 20mA. The input filter capacitor ( $C_{IN}$ ) also reduces peak currents drawn from the battery and improves efficiency.

Low equivalent series resistance (ESR) capacitors are recommended. Capacitor ESR is a major contributor to output ripple (usually more than 60%). Ceramic capacitors have the lowest ESR, but low-ESR tantalums represent a good balance between cost and performance. Low-ESR aluminum electrolytic capacitors are tolerable, and standard aluminum electrolytic capacitors should be avoided. Do not exceed tantalum capacitors' ripple-current ratings; select capacitors with a rating exceeding the peak inductor current ( $I_{PEAK}$ ).

## PC Board Layout and Grounding

High switching frequencies and large peak currents make PC board layout an important part of design. Poor design can result in excessive EMI on the feedback paths and voltage gradients in the ground plane. Both of these factors can result in instability or regulation errors. The OUT pin must be bypassed directly to GND as close to the IC as possible (within 0.2 in. or 5mm).

Place power components—such as the MAX1642/MAX1643, inductor, input filter capacitor, and output filter capacitor—as close together as possible. Keep their traces short, direct, and wide ( $\geq 50$  mil or 1.25mm), and place their ground pins close together in a star-ground configuration. Keep the extra copper on the board and integrate it into ground as a pseudo-ground plane. On multilayer boards, route the star ground using component-side copper fill, then connect it to the internal ground plane using vias.

Place the external voltage-feedback network very close to the FB pin (within 0.2 in. or 5mm). Noisy traces, such as from the LX pin, should be kept away from the voltage-feedback network and separated from it using grounded copper. The evaluation kit manual shows an example PC board layout, routing, and pseudo-ground plane.

## Noise and Voltage Ripple

EMI and output voltage ripple can be minimized by following a few simple design rules.

- 1) Place the DC-DC converter and digital circuitry on an opposite corner of the PC board, away from sensitive RF and analog input stages.

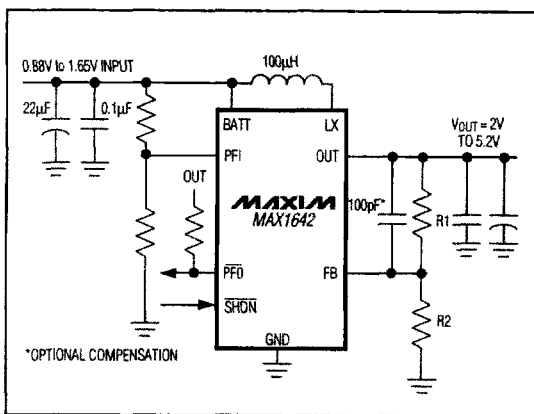


Figure 4. Adjustable-Output Circuit

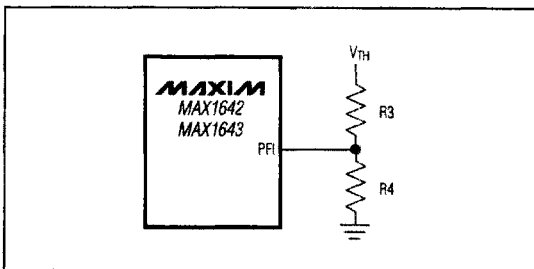


Figure 5. Power-Fail Detection Circuit

- 2) Use a closed-core inductor, such as toroid or shielded bobbin, to minimize fringe magnetic fields.
- 3) Choose the largest inductor value that satisfies the load requirement to minimize peak switching current and resulting ripple and noise.
- 4) Use low-ESR input and output filter capacitors.
- 5) Follow sound circuit-board layout and grounding rules (see the *PC Board Layout and Grounding* section).
- 6) Where necessary, add LC pi filters, linear post-regulators such as the MAX8863 and MAX8864 (SOT23 package), or shielding. The LC pi filter's cutoff frequency should be at least a decade or two below the DC-DC converter's switching frequency for the specified load and input voltage.

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# High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

**MAX1642/MAX1643**

**Table 1. Component Suppliers**

SUPPLIER		PHONE	FAX
AVX	USA	(803) 946-0690 (800) 282-4975	(803) 626-3123
Coilcraft	USA	(847) 639-6400	(847) 639-1469
Coiltronics	USA	(561) 241-7876	(561) 241-9339
Dale	USA	(605) 668-4131	(605) 665-1627
Nichicon	USA	(847) 843-7500	(847) 843-2798
	Japan	81-7-5231-8461	81-7-5256-4158
Sanyo	USA	(619) 661-6835	(619) 661-1055
	Japan	81-7-2070-6306	81-7-2070-1174
Sprague	USA	(603) 224-1961	(603) 224-1430
Sumida	USA	(847) 956-0666	(847) 956-0702
	Japan	81-3-3607-5111	81-3-3607-5144
TDK	USA	(847) 390-4373	(847) 390-4428

## Chip Information

TRANSISTOR COUNT: 594  
SUBSTRATE CONNECTED TO GND

**Table 2. Surface-Mount Inductor Information**

INDUCTANCE ( $\mu$ H)	VENDOR/PART	INDUCTOR SPECIFICATION	
		RESISTANCE ( $\Omega$ )	I <sub>SAT</sub> (mA)
68	Coilcraft DO1608-683	0.75	400
	Sumida CD54-680	0.46	610
100	Coilcraft DO1608-104	1.1	310
	Sumida CD54-101	0.7	520
	TDK NLC565050T-101K	1.6	250
150	Coilcraft DO1608-154	1.7	270
	Sumida CD54-151	1.1	400
	TDK NLC565050T-151K	2.2	210
220	Coilcraft DO1608-224	2.3	220
	Sumida CD54-221	1.57	350