

# MAXIM

## Buck/Boost Regulating Charge Pump in $\mu$ MAX

MAX1759

### General Description

The MAX1759 is a buck/boost regulating charge pump that generates a regulated output voltage from a single lithium-ion (Li+) cell, or two or three NiMH or alkaline cells for small hand-held portable equipment. The MAX1759 operates over a wide +1.6V to +5.5V input voltage range and generates a fixed 3.3V or adjustable (2.5V to 5.5V) output (Dual Mode™). Maxim's unique charge-pump architecture allows the input voltage to be higher or lower than the regulated output voltage. Despite its high 1.5MHz operating frequency, the MAX1759 maintains low 50 $\mu$ A quiescent supply current.

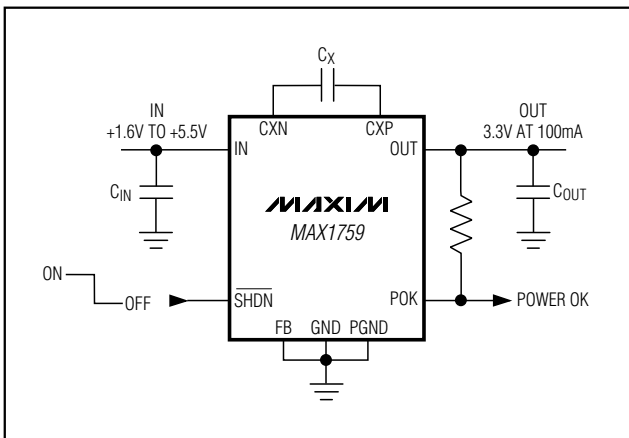
Designed to be an extremely compact buck/boost converter, this device requires only three small ceramic capacitors to build a complete DC-DC converter capable of generating a guaranteed 100mA (min) output current from a +2.5V input. For added flexibility, the MAX1759 also includes an open-drain power-OK (POK) output that signals when the output voltage is in regulation.

The MAX1759 is available in a space-saving 10-pin  $\mu$ MAX package that is 1.09mm high and half the size of an 8-pin SO.

### Applications

- Li+ Battery-Powered Applications
- Miniature Equipment
- Backup Battery Boost Converters
- Translators

### Typical Operating Circuit



Dual Mode is a trademark of Maxim Integrated Products.

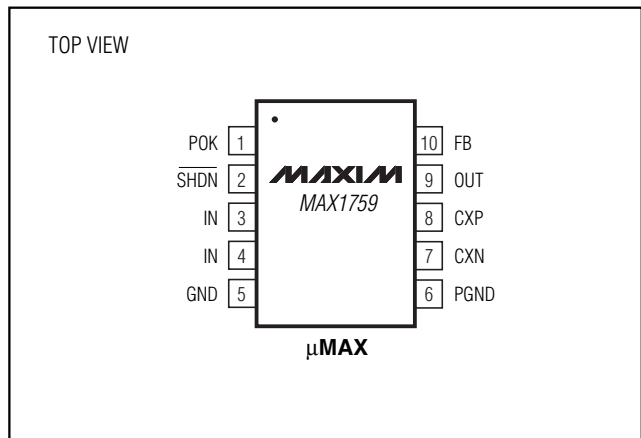
### Features

- ◆ Regulated Output Voltage (Fixed 3.3V or Adjustable 2.5V to 5.5V)
- ◆ 100mA Guaranteed Output Current
- ◆ +1.6V to +5.5V Input Voltage Range
- ◆ Low 50 $\mu$ A Quiescent Supply Current
- ◆ 1 $\mu$ A Shutdown Mode
- ◆ Load Disconnected from Input in Shutdown
- ◆ High 1.5MHz Operating Frequency
- ◆ Uses Small Ceramic Capacitors
- ◆ Short-Circuit Protection and Thermal Shutdown
- ◆ Small 10-Pin  $\mu$ MAX Package

### Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX1759EUB	-40°C to +85°C	10 $\mu$ MAX

### Pin Configuration



# Buck/Boost Regulating Charge Pump in $\mu$ MAX

## ABSOLUTE MAXIMUM RATINGS

IN, OUT, FB, POK,  $\overline{\text{SHDN}}$  to GND ..... -0.3V to +6V  
 PGND to GND .....  $\pm 0.3$ V  
 CXN to GND ..... -0.3V to ( $V_{\text{IN}} + 0.3$ )V  
 CXP to GND ..... -0.3V to ( $V_{\text{OUT}} + 0.3$ )V  
 OUT Short to GND ..... Indefinite  
 Continuous Power Dissipation ( $T_A = +70^\circ\text{C}$ )  
 10-Pin  $\mu$ MAX (derate 5.6mW/ $^\circ\text{C}$  above  $+70^\circ\text{C}$ ) ..... 444mW

Operating Temperature Range .....  $-40^\circ\text{C}$  to  $+85^\circ\text{C}$   
 Junction Temperature .....  $+150^\circ\text{C}$   
 Storage Temperature Range .....  $-65^\circ\text{C}$  to  $+150^\circ\text{C}$   
 Lead Temperature (soldering, 10s) .....  $+300^\circ\text{C}$

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

(Circuit of Figure 1,  $V_{\text{IN}} = V_{\overline{\text{SHDN}}} = 2\text{V}$ , FB = PGND = GND,  $C_{\text{IN}} = 10\mu\text{F}$ ,  $C_X = 0.33\mu\text{F}$ ,  $C_{\text{OUT}} = 10\mu\text{F}$ ,  $T_A = 0^\circ\text{C}$  to  $+85^\circ\text{C}$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ\text{C}$ .)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Input Voltage Range	$V_{\text{IN}}$		1.6		5.5	V
Input Undervoltage Lockout Voltage	$V_{\text{UVLO}}$		0.6	1.0	1.4	V
Output Voltage Adjustment Range		$1.6\text{V} \leq V_{\text{IN}} \leq 5.5\text{V}$	2.5		5.5	V
Output Voltage	$V_{\text{OUT}}$	$2\text{V} \leq V_{\text{IN}} \leq 5.5\text{V}$ , $1\text{mA} \leq I_{\text{LOAD}} \leq 50\text{mA}$	3.17	3.3	3.43	V
		$2.5\text{V} \leq V_{\text{IN}} \leq 5.5\text{V}$ , $1\text{mA} \leq I_{\text{LOAD}} \leq 100\text{mA}$	3.17	3.3	3.43	
Maximum Output Current	$I_{\text{LOAD,MAX}}$	$2.5\text{V} \leq V_{\text{IN}} \leq 5.5\text{V}$	100			mA
Transient Load Current		$I_{\text{LOAD}} \leq 100\text{mA}$ (RMS)		200		mA
Quiescent Supply Current	$I_{\text{Q}}$	$V_{\text{IN}} = V_{\overline{\text{SHDN}}} = 4\text{V}$ , $V_{\text{FB}} = 0$ , stepping down		50	90	$\mu\text{A}$
		$V_{\text{IN}} = V_{\overline{\text{SHDN}}} = 2\text{V}$ , $V_{\text{FB}} = 0$ , stepping up		85	180	
Shutdown Supply Current	$I_{\text{Q,SHDN}}$	$1.6\text{V} \leq V_{\text{IN}} \leq 5.5\text{V}$ , $V_{\overline{\text{SHDN}}} = 0$		1	5	$\mu\text{A}$
Leakage Current into OUT in Shutdown		$V_{\text{IN}} = 2\text{V}$ , $V_{\text{OUT}} = 3.3\text{V}$ , $V_{\overline{\text{SHDN}}} = 0$		1	5	$\mu\text{A}$
$\overline{\text{SHDN}}$ Logic Input Voltage	$V_{\text{IL}}$	$1.6\text{V} \leq V_{\text{IN}} \leq 5.5\text{V}$		$0.25 \cdot V_{\text{IN}}$		V
	$V_{\text{IH}}$	$1.6\text{V} \leq V_{\text{IN}} \leq 5.5\text{V}$	$0.7 \cdot V_{\text{IN}}$			
$\overline{\text{SHDN}}$ Input Leakage Current	$I_{\overline{\text{SHDN}}}$	$V_{\overline{\text{SHDN}}} = 5.5\text{V}$	-1		1	$\mu\text{A}$
FB Regulation Voltage	$V_{\text{FB}}$	$V_{\text{IN}} = 1.65\text{V}$ , $V_{\text{OUT}} = 3.3\text{V}$	1.205	1.235	1.265	V
FB Input Current		$V_{\text{FB}} = 1.27\text{V}$		25	200	nA
FB Dual-Mode Threshold		Internal feedback		100	50	mV
		External feedback	200	100		mV
POK Trip Voltage		Falling edge at FB	1.0	1.1	1.2	V
POK Output Low Voltage	$V_{\text{OL}}$	$I_{\text{SINK}} = 0.5\text{mA}$ , $V_{\text{IN}} = 2\text{V}$		5	100	mV
POK Leakage Current		$V_{\text{POK}} = 5.5\text{V}$ , $V_{\text{FB}} = 1.27\text{V}$		0.01	0.2	$\mu\text{A}$
Switching Frequency	$f_{\text{OSC}}$	$1.6\text{V} \leq V_{\text{IN}} \leq 5.5\text{V}$ , $V_{\text{FB}} = 1\text{V}$	1.2	1.5	1.8	MHz
Output Short-Circuit Current		$V_{\text{OUT}} = 0$ , $2.5\text{V} \leq V_{\text{IN}} \leq 5.5\text{V}$ , foldback current limit		110		mA
Thermal Shutdown Temperature		Rising temperature		160		$^\circ\text{C}$
Thermal Shutdown Hysteresis				20		$^\circ\text{C}$
Efficiency		$V_{\text{IN}} = 3.6\text{V}$ , $I_{\text{LOAD}} = 10\text{mA}$		90		%

# Buck/Boost Regulating Charge Pump in $\mu$ MAX

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## ELECTRICAL CHARACTERISTICS

(Circuit of Figure 1,  $V_{IN} = V_{\overline{SHDN}} = 2V$ ,  $FB = PGND = GND$ ,  $C_{IN} = 10\mu F$ ,  $C_X = 0.33\mu F$ ,  $C_{OUT} = 10\mu F$ ,  $T_A = -40^\circ C$  to  $+85^\circ C$ , unless otherwise noted.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	MAX	UNITS
Input Voltage Range	$V_{IN}$		1.6	5.5	V
Input Undervoltage Lockout Voltage	$V_{UVLO}$		0.6	1.4	V
Output Voltage	$V_{OUT}$	$2V \leq V_{IN} \leq 5.5V$ , $0 \leq I_{LOAD} \leq 50mA$	3.15	3.45	V
		$2.5V \leq V_{IN} \leq 5.5V$ , $0 \leq I_{LOAD} \leq 100mA$	3.15	3.45	V
Output Voltage Adjustment Range		$1.6V \leq V_{IN} \leq 5.5V$	2.5	5.5	V
Maximum Output Current	$I_{LOAD,MAX}$	$2.5V \leq V_{IN} \leq 5.5V$	100		mA
Quiescent Supply Current	$I_Q$	$V_{IN} = V_{\overline{SHDN}} = 4V$ , $V_{FB} = 0$		90	$\mu A$
		$V_{IN} = V_{\overline{SHDN}} = 2.5V$ , $V_{FB} = 0$		180	$\mu A$
Shutdown Supply Current	$I_{Q,SHDN}$	$1.6V \leq V_{IN} \leq 5.5V$ , $V_{\overline{SHDN}} = 0$		6	$\mu A$
Leakage Current into OUT in Shutdown		$V_{IN} = 2V$ , $V_{OUT} = 3.3V$ , $V_{\overline{SHDN}} = 0$		5	$\mu A$
$\overline{SHDN}$ Input Logic Voltage	$V_{IL}$	$1.6V \leq V_{IN} \leq 5.5V$		$0.2 \cdot V_{IN}$	V
	$V_{IH}$	$1.6V \leq V_{IN} \leq 5.5V$	$0.7 \cdot V_{IN}$		V
$\overline{SHDN}$ Input Leakage Current	$I_{\overline{SHDN}}$	$V_{\overline{SHDN}} = 5.5V$	-1	1	$\mu A$
FB Regulation Voltage	$V_{FB}$	$V_{IN} = 1.65V$ , $V_{OUT} = 3.3V$	1.205	1.265	V
FB Input Bias Current		$V_{FB} = 1.27V$		200	nA
FB Dual Mode Threshold		Internal feedback		40	mV
		External feedback	200		mV
POK Trip Voltage		Falling edge at FB	1.0	1.2	V
POK Output Low Voltage	$V_{OL}$	$I_{SINK} = 0.5mA$ , $V_{IN} = 2V$		100	mV
POK Leakage Current		$V_{POK} = 5.5V$		0.2	$\mu A$
Switching Frequency	$f_{OSC}$	$1.6V \leq V_{IN} \leq 5.5V$ , $V_{FB} = 1V$	1.1	1.9	MHz

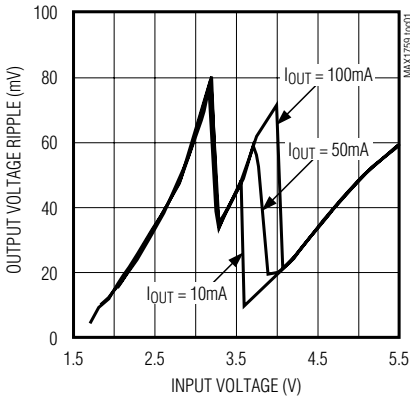
**Note 1:** Specifications to  $-40^\circ C$  are guaranteed by design and are not production tested.

# Buck/Boost Regulating Charge Pump in $\mu$ MAX

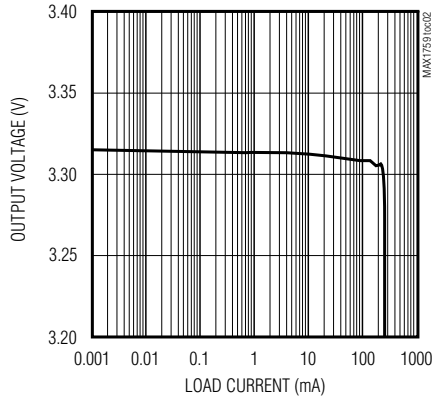
## Typical Operating Characteristics

(Circuit of Figure 1,  $C_{IN} = 10\mu F$ ,  $C_X = 0.33\mu F$ ,  $C_{OUT} = 10\mu F$ ,  $V_{OUT} = 3.3V$ ,  $V_{IN} = 2.5V$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)

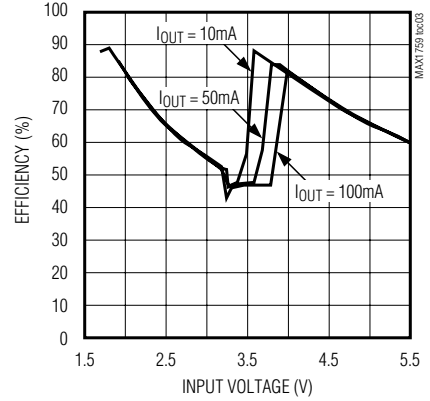
**OUTPUT VOLTAGE RIPPLE vs. INPUT VOLTAGE**



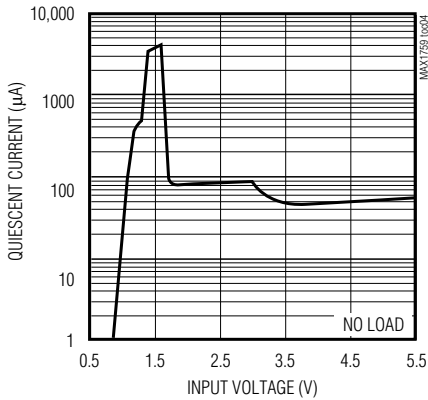
**OUTPUT VOLTAGE vs. LOAD CURRENT**



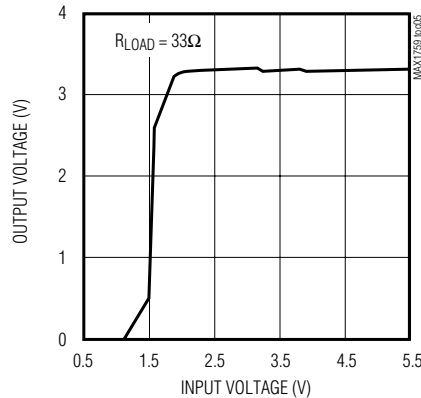
**EFFICIENCY vs. INPUT VOLTAGE**



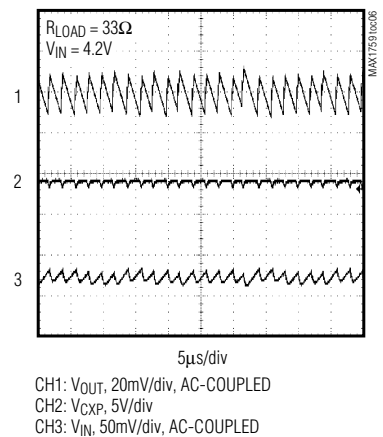
**QUIESCENT CURRENT vs. INPUT VOLTAGE**



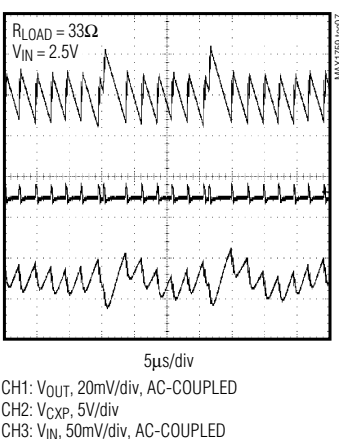
**STARTUP INPUT VOLTAGE (VOUT < VIN)**



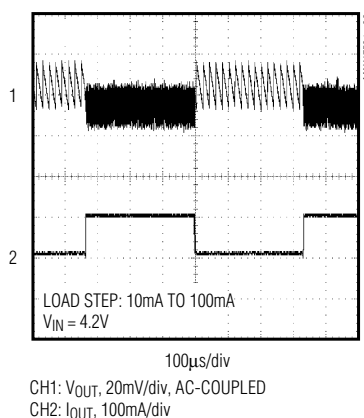
**TYPICAL SWITCHING WAVEFORMS (VOUT < VIN)**



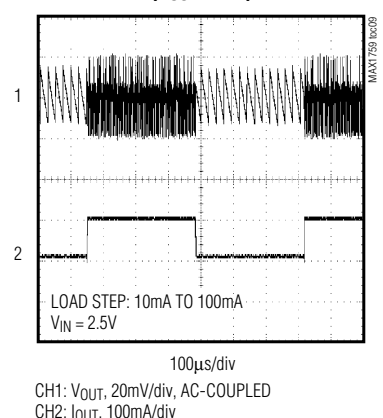
**TYPICAL SWITCHING WAVEFORMS (VOUT > VIN)**



**LOAD-TRANSIENT RESPONSE (VOUT < VIN)**



**LOAD-TRANSIENT RESPONSE (VOUT > VIN)**



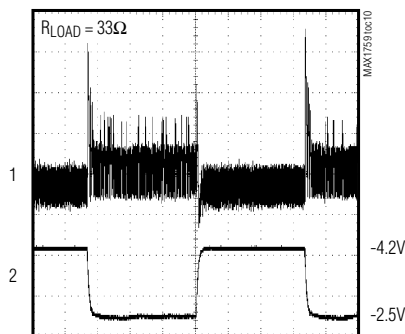
# Buck/Boost Regulating Charge Pump in $\mu$ MAX

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## Typical Operating Characteristics (continued)

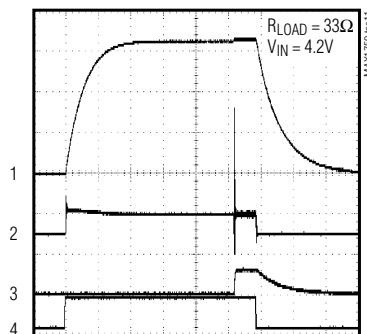
(Circuit of Figure 1,  $C_{IN} = 10\mu\text{F}$ ,  $C_X = 0.33\mu\text{F}$ ,  $C_{OUT} = 10\mu\text{F}$ ,  $V_{OUT} = 3.3\text{V}$ ,  $V_{IN} = 2.5\text{V}$ ,  $T_A = +25^\circ\text{C}$ , unless otherwise noted.)

**LINE-TRANSIENT RESPONSE**



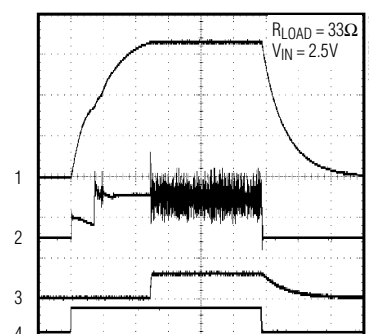
100 $\mu\text{s/div}$   
CH1:  $V_{OUT}$ , 20mV/div, AC-COUPLED  
CH2:  $V_{IN}$ , 1V/div, AC-COUPLED

**TURN-ON/OFF RESPONSE  
( $V_{IN} = 4.2\text{V}$ )**



500 $\mu\text{s/div}$   
CH1:  $V_{OUT}$ , 1V/div  
CH2:  $I_{IN}$ , 200mA/div  
CH3:  $V_{POK}$ , 5V/div  
CH4:  $V_{SHDN}$ , 5V/div

**TURN-ON/OFF RESPONSE  
( $V_{IN} = 2.5\text{V}$ )**



500 $\mu\text{s/div}$   
CH1:  $V_{OUT}$ , 1V/div  
CH2:  $I_{IN}$ , 200mA/div  
CH3:  $V_{POK}$ , 5V/div  
CH4:  $V_{SHDN}$ , 5V/div

## Pin Description

PIN	NAME	FUNCTION
1	POK	Open-Drain Power-OK Output. POK is high impedance when output voltage is in regulation. POK sinks current when $V_{FB}$ falls below 1.1V. Connect a 10k $\Omega$ to 1M $\Omega$ pull-up resistor from POK to $V_{OUT}$ for a logic signal. Ground POK or leave unconnected if not used. POK is high impedance in shutdown.
2	$\overline{\text{SHDN}}$	Shutdown Input. Drive high for normal operation; drive low for shutdown mode. OUT is high impedance in shutdown.
3, 4	IN	Input Supply. Connect both pins together and bypass to GND with a ceramic capacitor (see <i>Capacitor Selection</i> section).
5	GND	Ground. Connect GND to PGND with a short trace.
6	PGND	Power Ground. Charge-pump current flows through this pin.
7	CXN	Negative Terminal of the Charge-Pump Transfer Capacitor
8	CXP	Positive Terminal of the Charge-Pump Transfer Capacitor
9	OUT	Power Output. Bypass to GND with an output filter capacitor.
10	FB	Dual-Mode Feedback. Connect FB to GND for 3.3V output. Connect to an external resistor divider to adjust the output voltage from 2.5V to 5.5V.

# Buck/Boost Regulating Charge Pump in $\mu$ MAX

## Detailed Description

The MAX1759's unique charge-pump architecture allows the input voltage to be higher or lower than the regulated output voltage. Internal circuitry senses  $V_{IN}$  and  $V_{OUT}$  and determines whether  $V_{IN}$  must be stepped up or stepped down to produce the regulated output. When  $V_{IN}$  is lower than  $V_{OUT}$ , the charge pump operates as a regulated step-up voltage doubler. When  $V_{IN}$  is higher than  $V_{OUT}$ , the charge pump operates as a step-down gated switch.

In voltage step-down mode (i.e., the input voltage is greater than the output voltage) with a light load, the controller connects CXN to PGND, and shuttles charge to the output by alternately connecting CXP from IN to OUT (see Figures 1 and 2). Although  $V_{IN}$  is greater than  $V_{OUT}$ , this scheme may not allow the MAX1759 to regulate the output under heavy loads. In this case, the MAX1759 will automatically switch to step-up mode. In step-up mode, the output is kept in regulation by modulating the charge delivered by the transfer capacitor ( $C_x$ ) to the load (see Figure 2). When lightly loaded, the charge pump switches only as necessary to supply the load, resulting in low quiescent current. Output voltage ripple does not increase with light loads.

### Shutdown Mode

Driving  $\overline{\text{SHDN}}$  low places the MAX1759 in shutdown mode. This disables the charge-pump switches, oscillator, and control logic, reducing quiescent current to  $1\mu\text{A}$ . The output is high impedance in shutdown and is disconnected from the input. The POK output is high impedance in shutdown.

### Undervoltage Lockout

The MAX1759 undervoltage lockout feature deactivates the device when the input voltage falls below 1V.

### Power-OK Output

POK is an open-drain output that sinks current when the regulator feedback voltage falls below 1.1V. The feedback voltage can be either the internal resistor-divider feedback voltage when in fixed output mode (FB tied to GND) or an external feedback voltage from an external resistive divider in adjustable output mode. A  $10\text{k}\Omega$  to  $1\text{M}\Omega$  pull-up resistor from POK to OUT may be used to provide a logic output. Connect POK to GND or leave unconnected if not used.

### Soft-Start and Short-Circuit Protection

The MAX1759 features foldback short-circuit protection. This circuitry provides soft-start by limiting inrush current during startup and limits the output current to  $110\text{mA}$  (typ) if the output is short-circuited to ground.

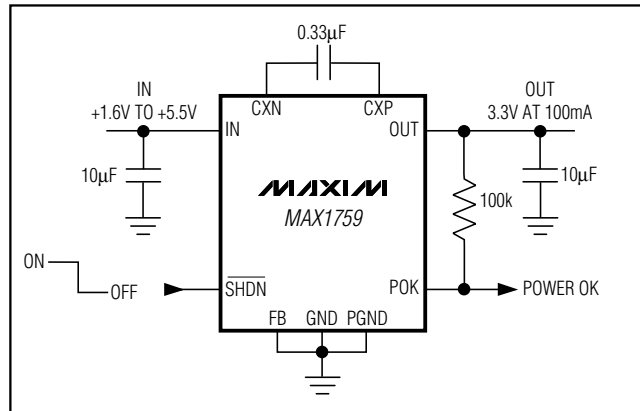


Figure 1. Typical Application Circuit

### Thermal Shutdown

The MAX1759 features thermal shutdown with temperature hysteresis. When the die temperature exceeds  $160^\circ\text{C}$ , the device shuts down. When the die cools by  $20^\circ\text{C}$ , the MAX1759 turns on again. If high die temperature is caused by output overload and the load is not removed, the device will turn off and on, resulting in a pulsed output.

## Design Procedure

### Setting the Output Voltage

The MAX1759 dual-mode feedback controller selects between the internally set 3.3V regulated output or an external resistive divider that allows adjustment of the output voltage from 2.5V to 5.5V. Connect FB to GND for a regulated 3.3V output. For an adjustable output, connect a resistive divider between OUT and GND. To ensure feedback-loop stability and to minimize error due to FB pin bias currents, the resistive divider current should be approximately  $15\mu\text{A}$ . In the following equation, choose  $R_2$  in the  $50\text{k}\Omega$  to  $100\text{k}\Omega$  range, and calculate  $R_1$  from the following formula (Figure 3):

$$R_1 = R_2 [(V_{OUT} / V_{FB}) - 1]$$

and

$$V_{OUT} = V_{FB} (R_1 + R_2) / R_2$$

where  $V_{OUT}$  is the desired output voltage from 2.5V to 5.5V, and  $V_{FB}$  is the internal regulation voltage, nominally 1.235V.

The circuit of Figure 3 generates a regulated 2.5V, using external standard 1% resistor values. Surface-mount resistors should be placed close to the MAX1759, less than 5mm away from FB (see the *PC Board Layout* section).

# Buck/Boost Regulating Charge Pump in $\mu$ MAX

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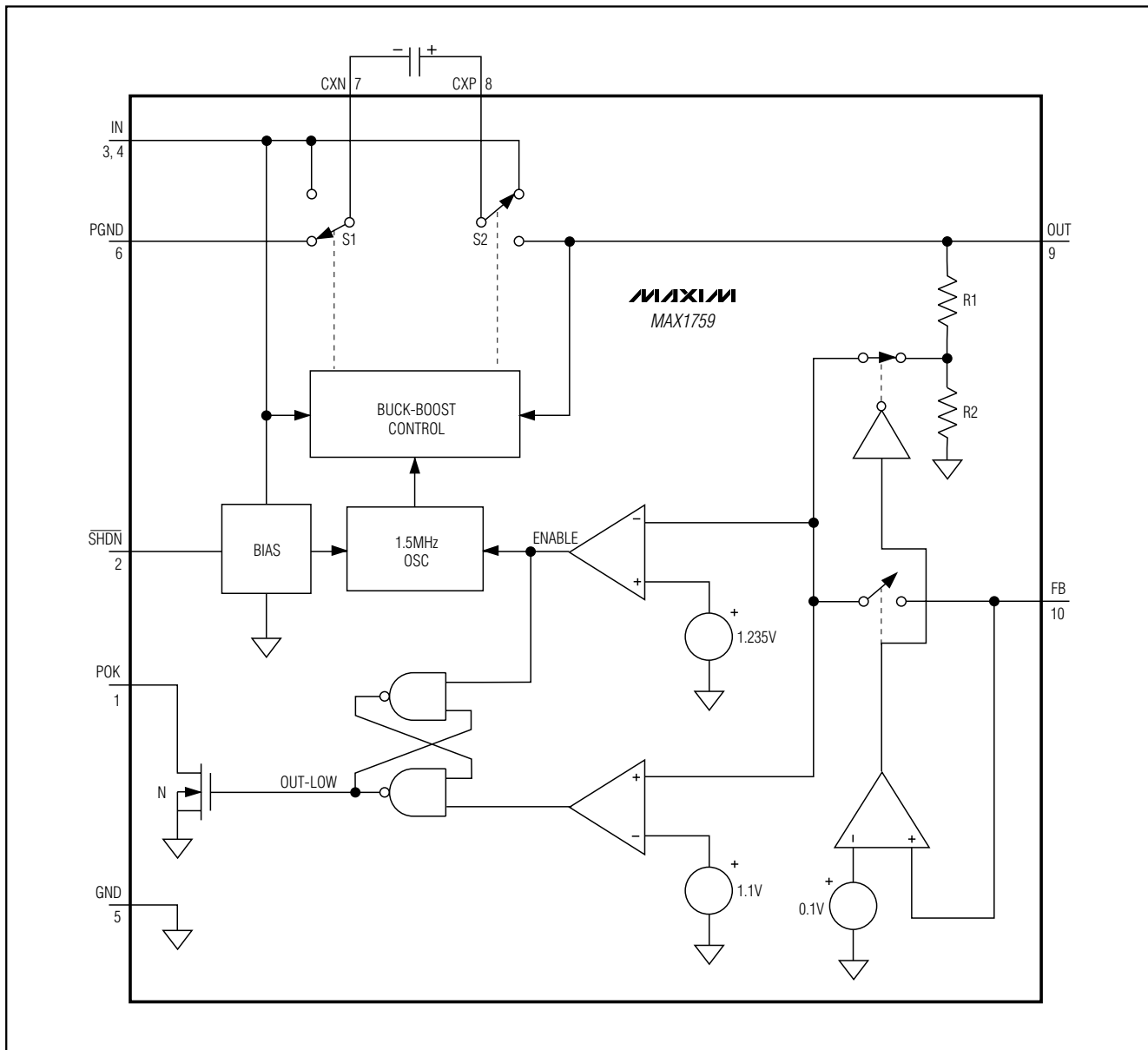


Figure 2. Functional Diagram

# Buck/Boost Regulating Charge Pump in $\mu$ MAX

## Capacitor Selection

Optimize the charge-pump circuit for physical size, output current, and output ripple by selecting capacitors  $C_{IN}$ ,  $C_X$ , and  $C_{OUT}$ . See Table 1 for suggested capacitor values.

Note that capacitors must have low ESR ( $\leq 20\text{m}\Omega$ ) to maintain low output ripple. Ceramic capacitors are recommended. In cost-sensitive applications where high output current is needed, the output capacitor may be a combination of a  $1\mu\text{F}$  ceramic in parallel with a  $10\mu\text{F}$  tantalum capacitor. The ceramic capacitor's low ESR will help keep output ripple within acceptable levels.

## Output Voltage Ripple

The MAX1759 proprietary control scheme automatically chooses between voltage doubling and voltage step-down to maintain output voltage regulation over various load currents and  $V_{IN}$  to  $V_{OUT}$  voltage differentials.

When  $V_{IN}$  is lower than  $V_{OUT}$ , the charge pump always operates in voltage-doubler mode. It regulates the output voltage by modulating the charge delivered by the transfer capacitor.

When  $V_{IN}$  is higher than  $V_{OUT}$ , the charge pump operates in voltage step-down mode, but may revert to voltage-doubler mode if necessary to maintain regulation under load. While operating in step-down mode, the output voltage ripple is typically much lower than it is in voltage-doubler mode (see *Typical Operating Characteristics*).

## Output Current

The MAX1759 is guaranteed to deliver a regulated 3.3V at 100mA continuous, from a +2.5V input. Peaks up to 200mA are acceptable as long as the current is  $\leq 100\text{mA}$  (RMS).

## Applications Information

### PC Board Layout

The MAX1759 is a high-frequency switched-capacitor voltage regulator. For best circuit performance, use a ground plane and keep  $C_{IN}$ ,  $C_X$ ,  $C_{OUT}$ , and feedback resistors (if used) close to the device. If using external feedback, keep the feedback node as small as possible by positioning the feedback resistors very close to FB. Suggested PC component placement and board layout are shown in Figures 4a and 4b.

## Chip Information

TRANSISTOR COUNT: 1802

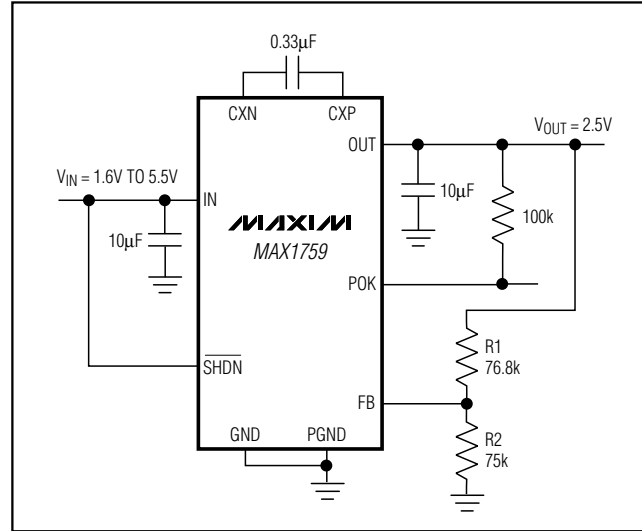


Figure 3. Using External Feedback for Regulated 2.5V Output

Table 1. Capacitor Selection

OUTPUT CURRENT (mA)	CAPACITOR VALUE			OUTPUT RIPPLE (mV)	
	$C_{IN}$ ( $\mu\text{F}$ )	$C_X$ ( $\mu\text{F}$ )	$C_{OUT}$ ( $\mu\text{F}$ )	$V_{IN} = 2.5\text{V}$	$V_{IN} = 4.2\text{V}$
100	10	0.33	10	40	20
100	4.7	0.22	4.7	80	60
50	2.2	0.1	2.2	100	80



# Buck/Boost Regulating Charge Pump in $\mu$ MAX

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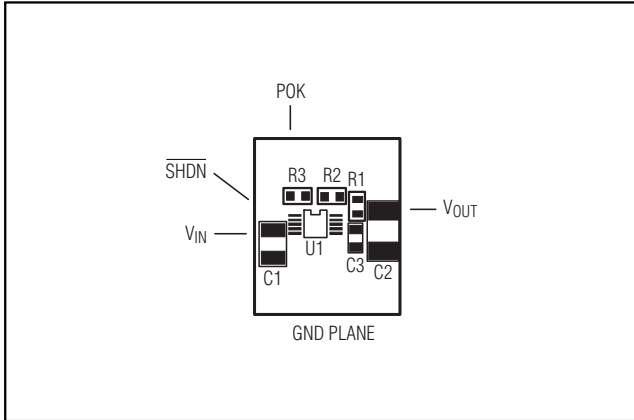


Figure 4a. MAX1759 Component Placement Guide

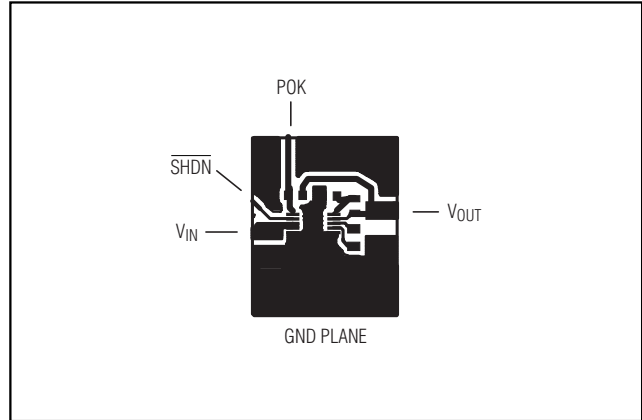
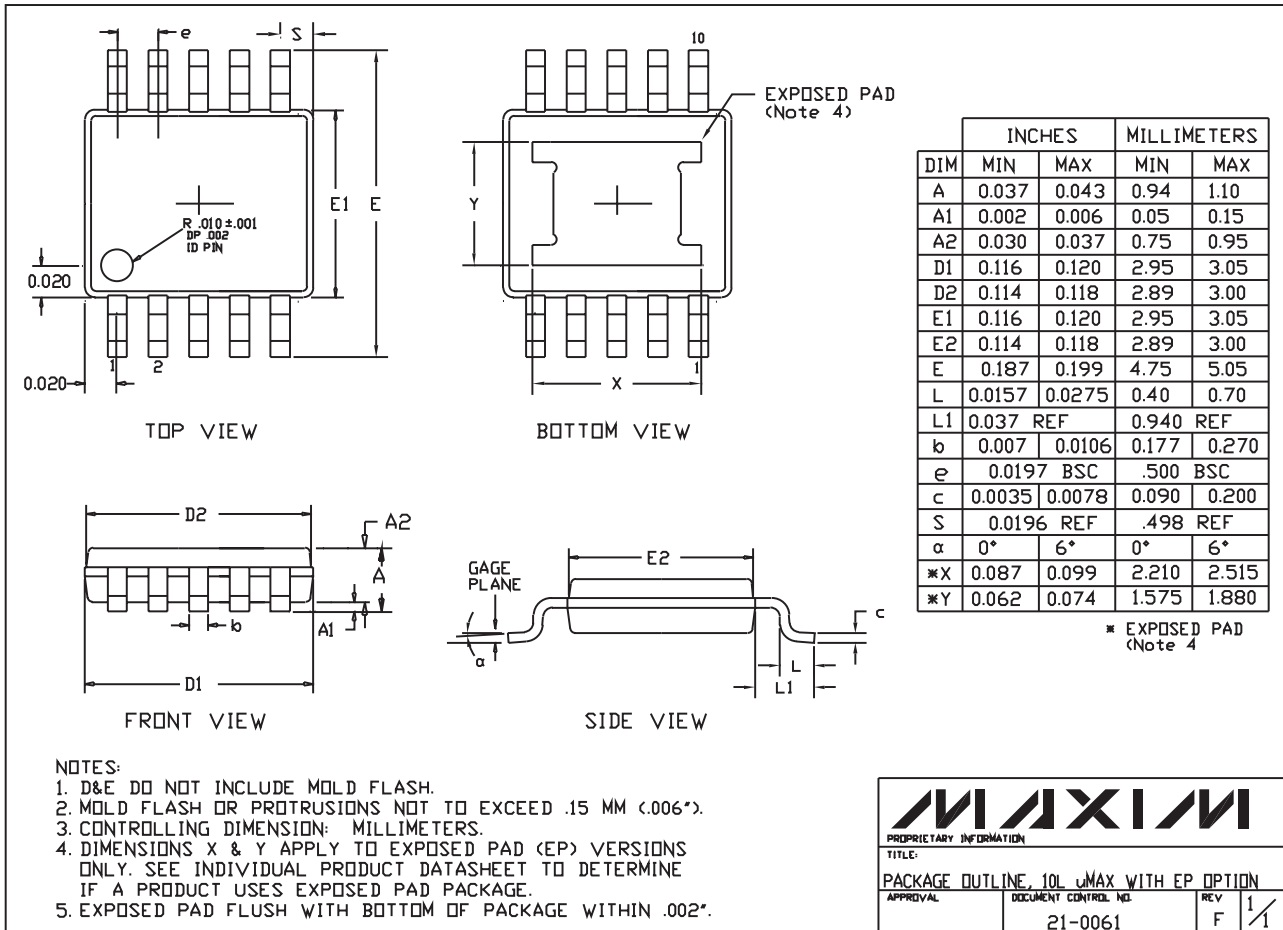


Figure 4b. MAX1759 Recommended PC Board Layout

# Buck/Boost Regulating Charge Pump in $\mu$ MAX

## Package Information



**Note:** The MAX1759 does not have an exposed pad.

# ***Buck/Boost Regulating Charge Pump in $\mu$ MAX***

NOTES

**MAX1759**

# **Buck/Boost Regulating Charge Pump in $\mu$ MAX**

## **NOTES**

*Maxim cannot assume responsibility for use of any circuitry other than circuitry entirely embodied in a Maxim product. No circuit patent licenses are implied. Maxim reserves the right to change the circuitry and specifications without notice at any time.*

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