GENERAL DESCRIPTION

The PC8609 is a synchronous step-up converter with 0.65μA ultra low quiescent current. It is designed for products powered by alkaline battery, NiMH rechargeable battery, Li-Mn battery or rechargeable Li-Ion battery, for which high efficiency under light load condition is critical to achieve long battery life operation.

The PC8609 step-up converter only consumes 0.65μA quiescent current under light load condition and can achieve up to 75% efficiency at 10μA load with fixed output voltage version. It can also support up to 300mA output current from 3.3V to 5V conversion, and achieve up to 93% efficiency at 200mA load.

The PC8609 also offers both down mode andpass-through operation for different applications.In down mode, the output voltage can still be regulated at target value even when input voltage is higher than output voltage. In pass-through mode, the output voltage follows input voltage. The PC8609 exits down mode and enters into pass-through mode when $V_{IN} > V_{OUT} + 0.3V$.

The PC8609 supports true shutdown function when it is disabled, which disconnects the load from the input supply to reduce the current consumption. The PC8609 offers both adjustable output voltage version and fixed output voltage versions. It is available in Green WLCSP-1.22×0.83-6B and TDFN-2×2-6AL packages.

FEATURES

- **Operating Input Voltage Range: 0.9V to 5.2V**
- **Ultra Low Quiescent Current**
  - **0.6μA Ultra Low I_Q into VOUT Pin**
  - **0.05μA Ultra Low I_Q into VIN Pin**
- **1.2MHz Fixed Frequency Operation**
- **Adjustable Output Voltage from 2.5V to 5.2V**
- **Fixed Output Voltage Versions Available**
- **Power-Save Mode for Improved Efficiency at Low Output Power**
- **Regulated Output Voltage in Down Mode**
- **True Disconnection During Shutdown**
- **Up to 75% Efficiency at 10μA Load with Fixed Output Voltage Version**
- **Up to 93% Efficiency from 10mA to 300mA Load**
- **-40℃ ℃ Rangeto +85 Operating Ambient Temperature**
- **Available in Green WLCSP-1.22×0.83-6B and TDFN-2×2-6AL Packages**

APPLICATIONS

Memory LCD Bias
Optical Heart Rate Monitor LED Bias
Wearable Applications
Low Power Wireless Applications
Portable Products
Battery Powered Systems

TYPICAL APPLICATION

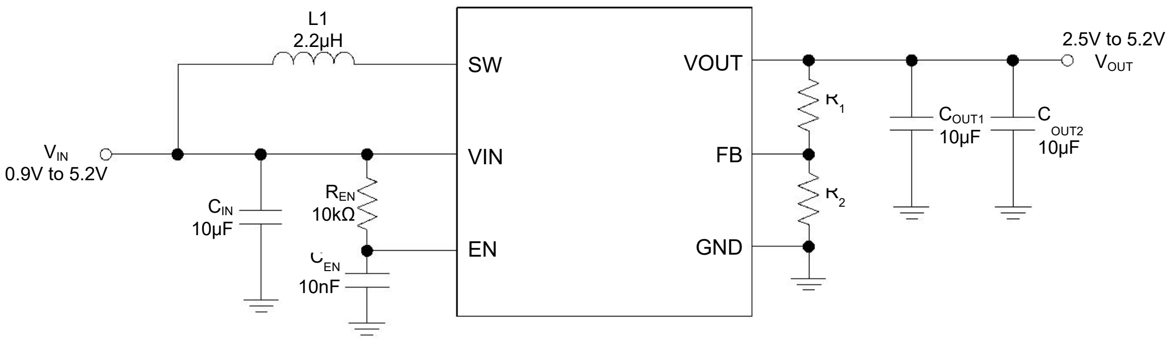


Figure 1. Typical Application Circuit

ABSOLUTE MAXIMUM RATINGS

VIN, SW, VOUT, FB, EN to GND...................... -0.3V to 6.0V
Package Thermal Resistance
WLCSP-1.22×0.83-6B, θ_{JA} .... 143℃/W
TQFN-2×2-6AL, θ_{JA} .... 105℃/W
Junction Temperature..+150℃
Storage Temperature..................................-65℃ to +150℃
Lead Temperature (Soldering, 10s)............................+260℃
ESD Susceptibility
HBM..4000V
MM...400V
CDM 1000V

RECOMMENDED OPERATING CONDITIONS

Input Voltage Range.......................................0.9V [1] to 5.2V
Output Voltage Range ....2.5V to 5.2V
Operating Ambient Temperature Range........-40℃ to +85℃
Operating Junction Temperature Range......-40℃ to +125℃

NOTE 1: Refer to the “Startup and Low Supply Voltage Operation” for detailed description.

OVERSTRESS CAUTION

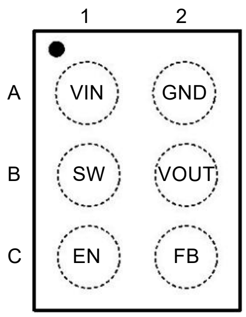
Stresses beyond those listed in Absolute Maximum Ratings may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect reliability. Functional operation of the device at any conditions beyond those indicated in the Recommended Operating Conditions section is not implied.

ESD SENSITIVITY CAUTION

This integrated circuit can be damaged by ESD if you don’t pay attention to ESD protection. Yellow-Top recommends that all integrated circuits be handled with appropriate precautions. Failureto observe proper handlingand installation procedures can cause damage. ESD damage can range from subtle performance degradation tocomplete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

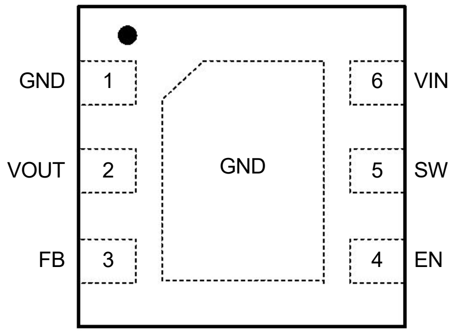
PIN CONFIGURATIONS

(TOP VIEW)



WLCSP-1.22×0.83-6B

(TOP VIEW)



TDFN-2×2-6AL

PIN DESCRIPTION

PIN		NAME	TYPE	FUNCTION
WLCSP-1.22×0.83-6B	TDFN-2×2-6AL			
A1	6	VIN	P	Power Supply Input.
A2	1	GND	G	Ground.
B1	5	SW	O	Switch Pin of the Converter. It is connected to the inductor.
B2	2	VOUT	O	Boost Converter Output.
C1	4	EN	I	Enable Logic Input. Logic high voltage enables the device; logic low voltage disables the device. Do not leave it floating.
C2	3	FB	I	Voltage Feedback of Adjustable Output Voltage. Connect to the center tap of a resistor divider to program the output voltage. Connect to the GND pin or keep floating for fixed output voltage versions.
—	Exposed Pad	GND	—	Connect to GND.

NOTE: I: input, O: output, G: ground, P: power for the circuit.

ELECTRICAL CHARACTERISTICS

(V_{IN} = 0.9V to 5.2V, C_{IN} = 10μF, C_{OUT} = 20μF, Full = -40℃ to +85℃, typical values are at V_{IN} = 3.7V, T_A = +25℃, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	TEMP	MIN	TYP	MAX	UNITS
Power Supply							
Input Voltage Range	V_{IN}		+25℃	0.9		5.2	V
Quiescent Current into VIN Pin	I_Q	No load, not switching	Full		0.05	0.2	μA
Quiescent Current into VOUT Pin		No load, not switching, boost or down mode	Full		0.6	1.1	μA
Shutdown Current into VIN Pin	I_{SD}	EN = GND, V_{IN} = 3.6V	Full		0.1	1	μA
Output							
Output Voltage Range	V_{OUT}		Full	2.5		5.2	V
Output Voltage		PC8609 -5.0, V_{IN} < V_{OUT}, PWM mode	Full	4.85	5.00	5.09	V
		PC8609 -5.0, V_{IN} < V_{OUT}, PFM mode	+25℃		5.08		V
		PC8609 -4.5, V_{IN} < V_{OUT}, PWM mode	Full	4.37	4.50	4.58	V
		PC8609 -4.5, V_{IN} < V_{OUT}, PFM mode	+25℃		4.57		V
		PC8609 -3.6, V_{IN} < V_{OUT}, PWM mode	Full	3.50	3.60	3.67	V
		PC8609 -3.6, V_{IN} < V_{OUT}, PFM mode	+25℃		3.65		V
		PC8609 -3.3, V_{IN} < V_{OUT}, PWM mode	Full	3.21	3.30	3.35	V
		PC8609 -3.3, V_{IN} < V_{OUT}, PFM mode	+25℃		3.35		V
		PC8609 -3.0, V_{IN} < V_{OUT}, PWM mode	Full	2.92	3.00	3.05	V
		PC8609 -3.0, V_{IN} < V_{OUT}, PFM mode	+25℃		3.04		V
		PC8609 -2.5, V_{IN} < V_{OUT}, PWM mode	Full	2.44	2.50	2.54	V
		PC8609 -2.5, V_{IN} < V_{OUT}, PFM mode	+25℃		2.54		V
Feedback Reference Voltage	V_{REF}	V_{IN} < V_{OUT}, PWM mode	Full	0.975	1.000	1.025	V
		V_{IN} < V_{OUT}, PFM mode	+25℃		1.020		V
Output Over-Voltage Protection Threshold	V_{OVP}	V_{OUT} rising	+25℃	5.50	5.8	5.95	V
OVP Hysteresis			+25℃		100		mV
Leakage Current into FB Pin	I_{FB_LKG}	V_{FB} = 1.1V	Full		10	50	nA
Switching							
Switching Frequency	f_{SW}	V_{IN} = 3.7V	Full	1	1.2	1.35	MHz
Power Switch							
Low-side Switch On-Resistance	$R_{DS(ON)\_LS}$	V_{OUT} = 5.0V (TDFN)	+25℃		280	400	mΩ
		V_{OUT} = 5.0V (WLCSP)	+25℃		220	310	mΩ
		V_{OUT} = 3.3V (TDFN)	+25℃		340	480	mΩ
		V_{OUT} = 3.3V (WLCSP)	+25℃		290	390	mΩ
Rectifier On-Resistance	$R_{DS(ON)\_HS}$	V_{OUT} = 5.0V (TDFN)	+25℃		270	350	mΩ
		V_{OUT} = 5.0V (WLCSP)	+25℃		250	350	mΩ
		V_{OUT} = 3.3V (TDFN)	+25℃		350		mΩ
		V_{OUT} = 3.3V (WLCSP)	+25℃		330		mΩ
Current Limit Threshold	I_{LIM}	V_{OUT} > 2.5V, boost operation	+25℃	0.89	1.3	1.62	A
		V_{OUT} = 2.5V, boost operation	+25℃	0.57	0.8	1.06	A

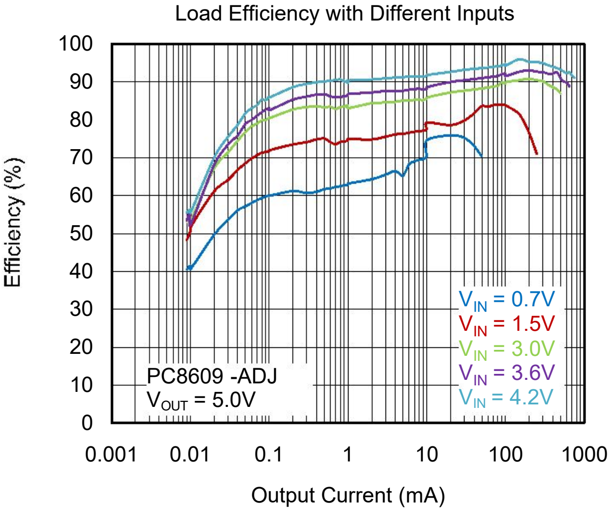
ELECTRICAL CHARACTERISTICS (continued)

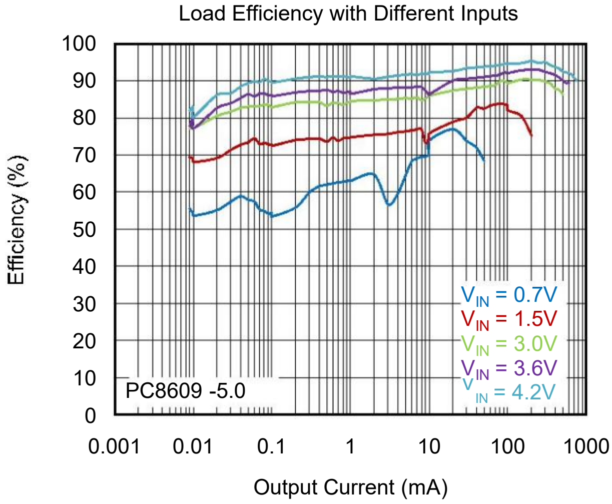
(V_{IN} = 0.9V to 5.2V, C_{IN} = 10μF, C_{OUT} = 20μF, Full = -40℃ to +85℃, typical values are at V_{IN} = 3.7V, T_A = +25℃, unless otherwise noted.)

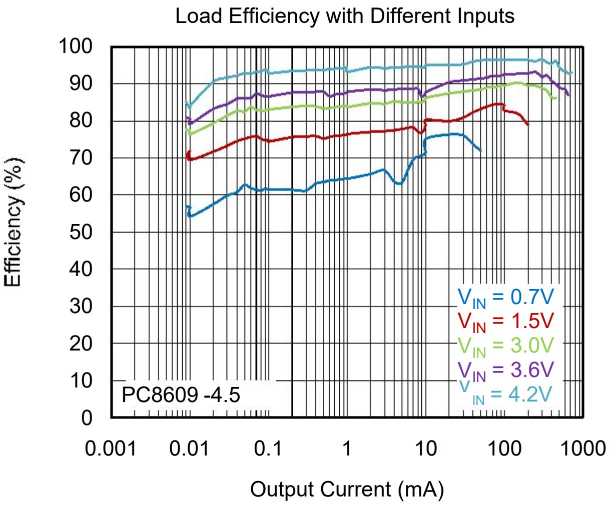
PARAMETER	SYMBOL	CONDITIONS	TEMP	MIN	TYP	MAX	UNITS
Control Logic							
EN Input Low Voltage Threshold	V_{IL}	V_{IN} ≤ 1.5V	Full			0.18 × V_{IN}	V
		V_{IN} > 1.5V	Full			0.4	V
EN Input High Voltage Threshold	V_{IH}	V_{IN} ≤ 1.5V	Full	0.8 × V_{IN}			V
		V_{IN} > 1.5V	Full	1.2			V
Leakage Current into EN Pin	I_{EN_LKG}	V_{EN} = 5.0V	+25℃			300	nA
Over-Temperature Protection					150		℃
Over-Temperature Hysteresis					25		℃

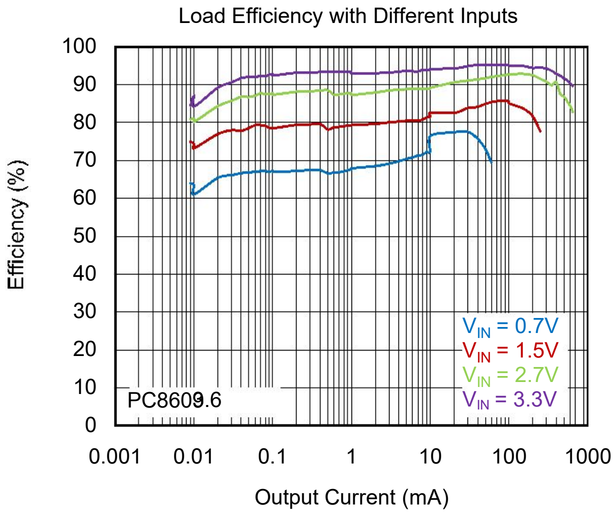
TYPICAL PERFORMANCE CHARACTERISTICS

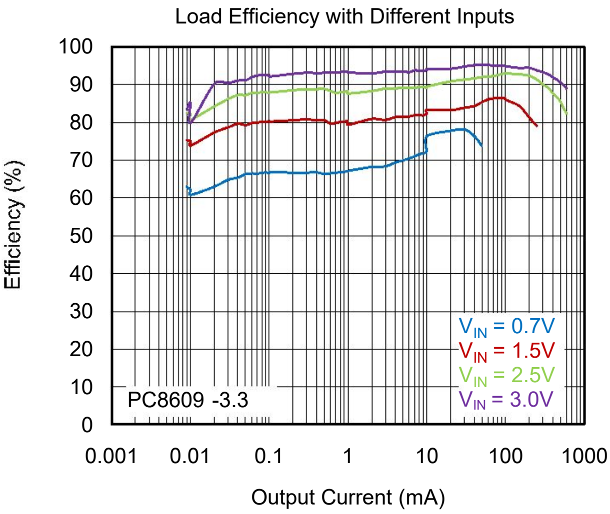
T_A = +25℃, C_{IN} = 10μF, C_{OUT} = 20μF, unless otherwise noted.

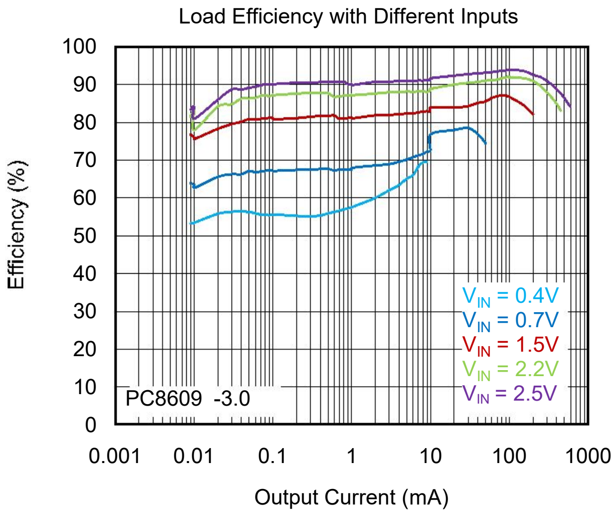








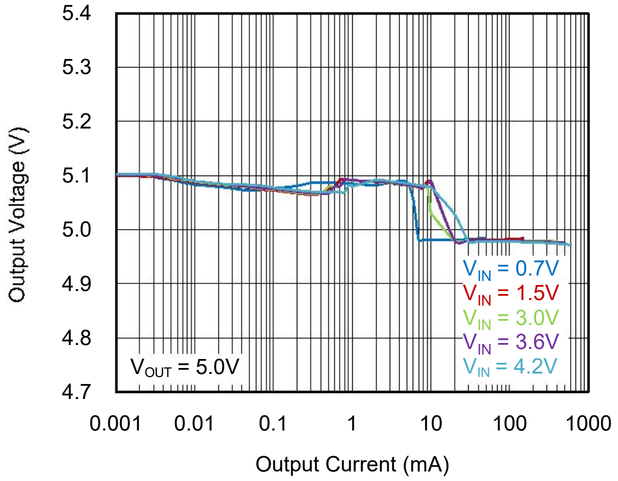




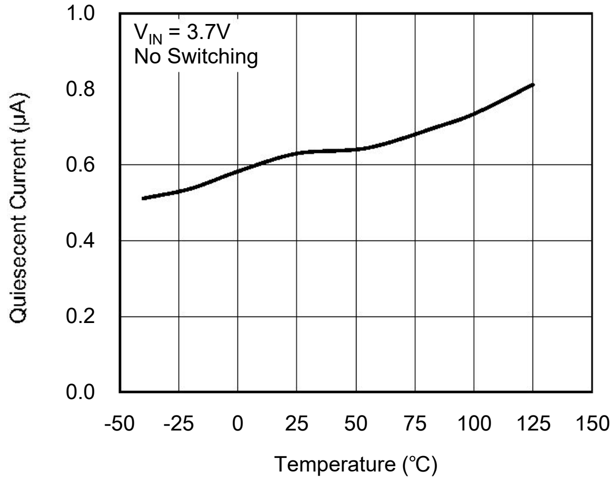
TYPICAL PERFORMANCE CHARACTERISTICS (continued)

T_A = +25℃, C_{IN} = 10μF, C_{OUT} = 20μF, unless otherwise noted.

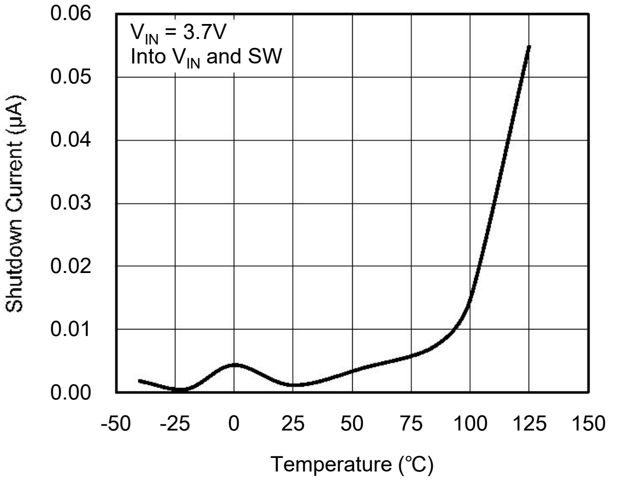
Load Regulation



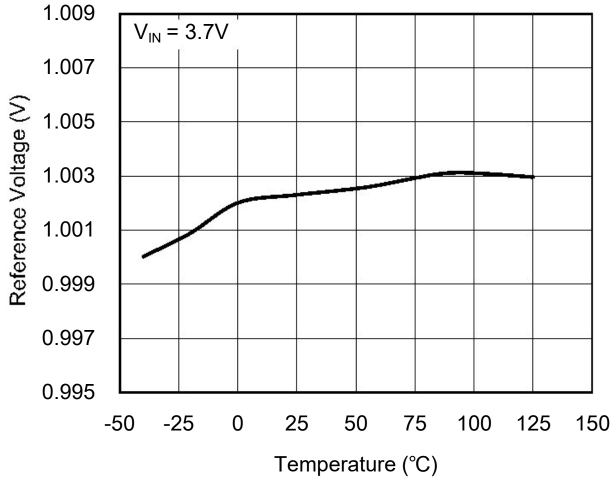
Quiescent Current into VOUT Pin vs. Temperature



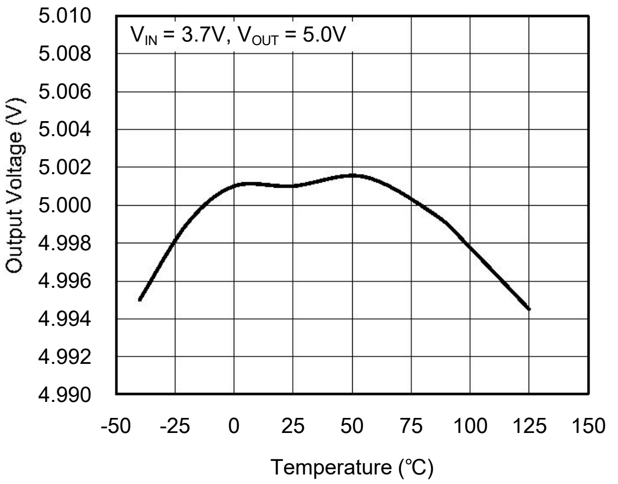
Shutdown Current vs. Temperature



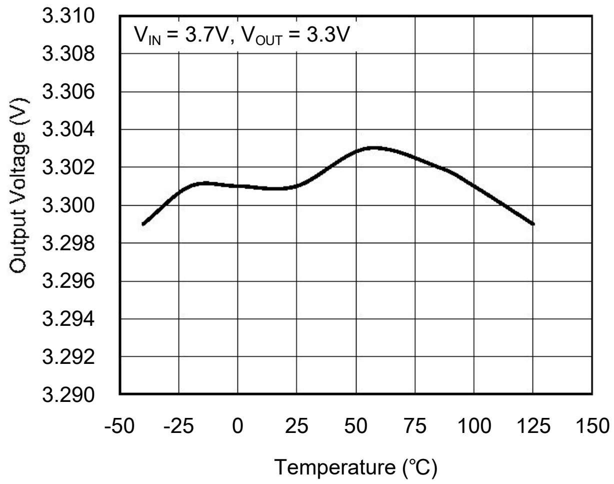
Reference Voltage vs. Temperature



Output Voltage vs. Temperature



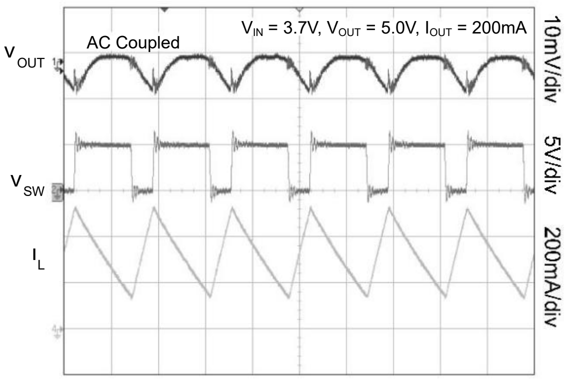
Output Voltage vs. Temperature



TYPICAL PERFORMANCE CHARACTERISTICS (continued)

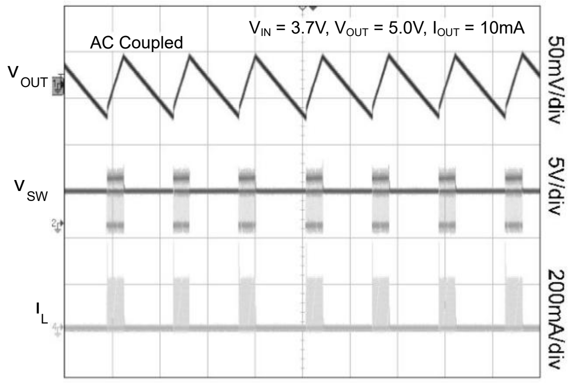
T_A = +25℃, C_{IN} = 10μF, C_{OUT} = 20μF, unless otherwise noted.

Switching Waveform at Heavy Load



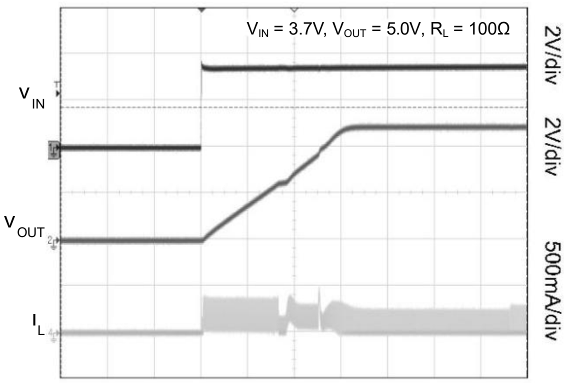
Time (500ns/div)

Switching Waveform at Light Load



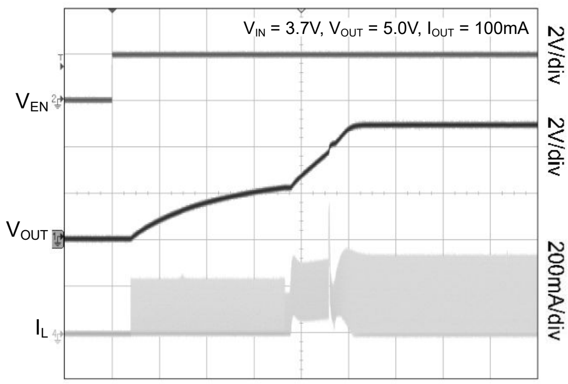
Time (50μs/div)

Startup by VIN Pin



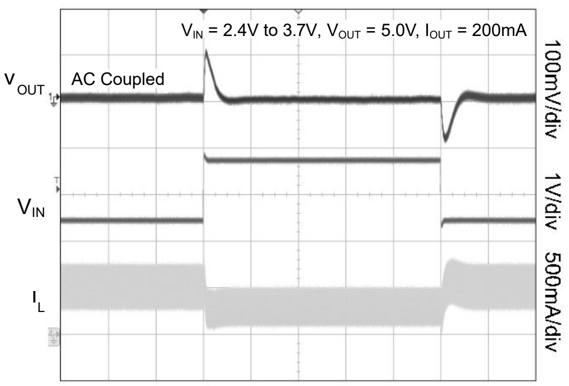
Time (500μs/div)

Startup by EN Pin



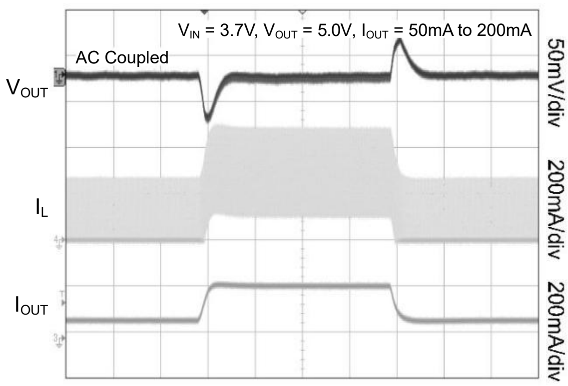
Time (500μs/div)

Line Transient Response



Time (200μs/div)

Load Transient Response

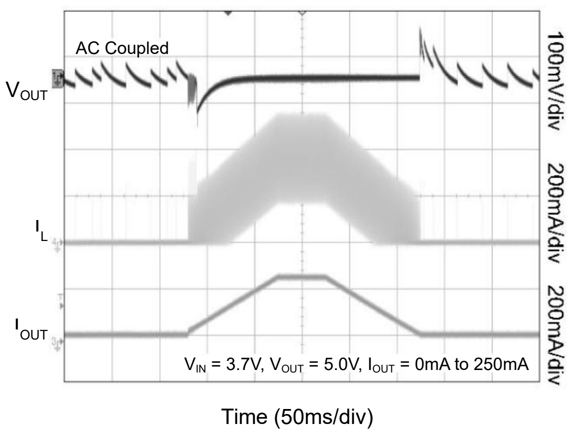


Time (200μs/div)

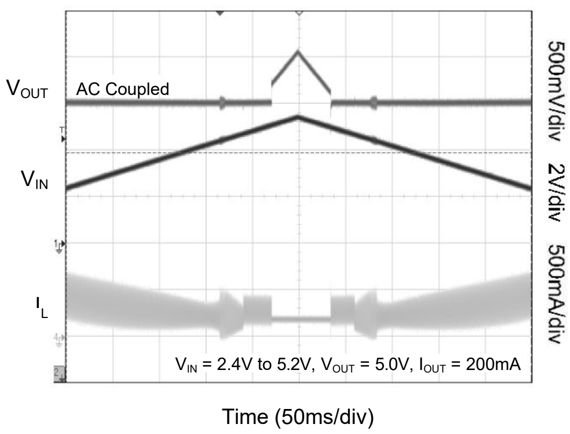
TYPICAL PERFORMANCE CHARACTERISTICS (continued)

T_A = +25℃, C_{IN} = 10μF, C_{OUT} = 20μF, unless otherwise noted.

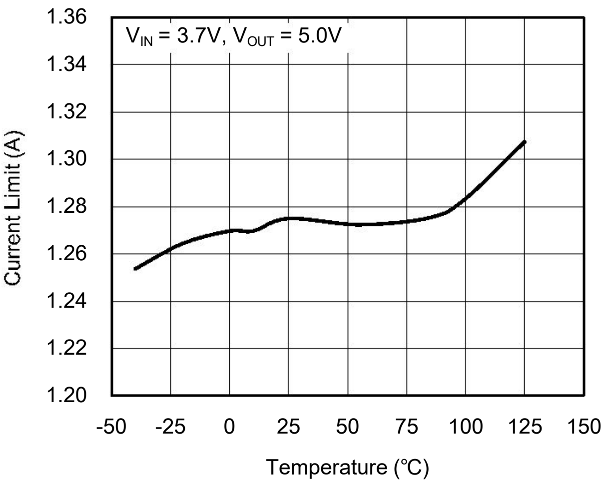
Load Regulation



Line Regulation



Current Limit vs. Temperature



FUNCTIONAL BLOCK DIAGRAM

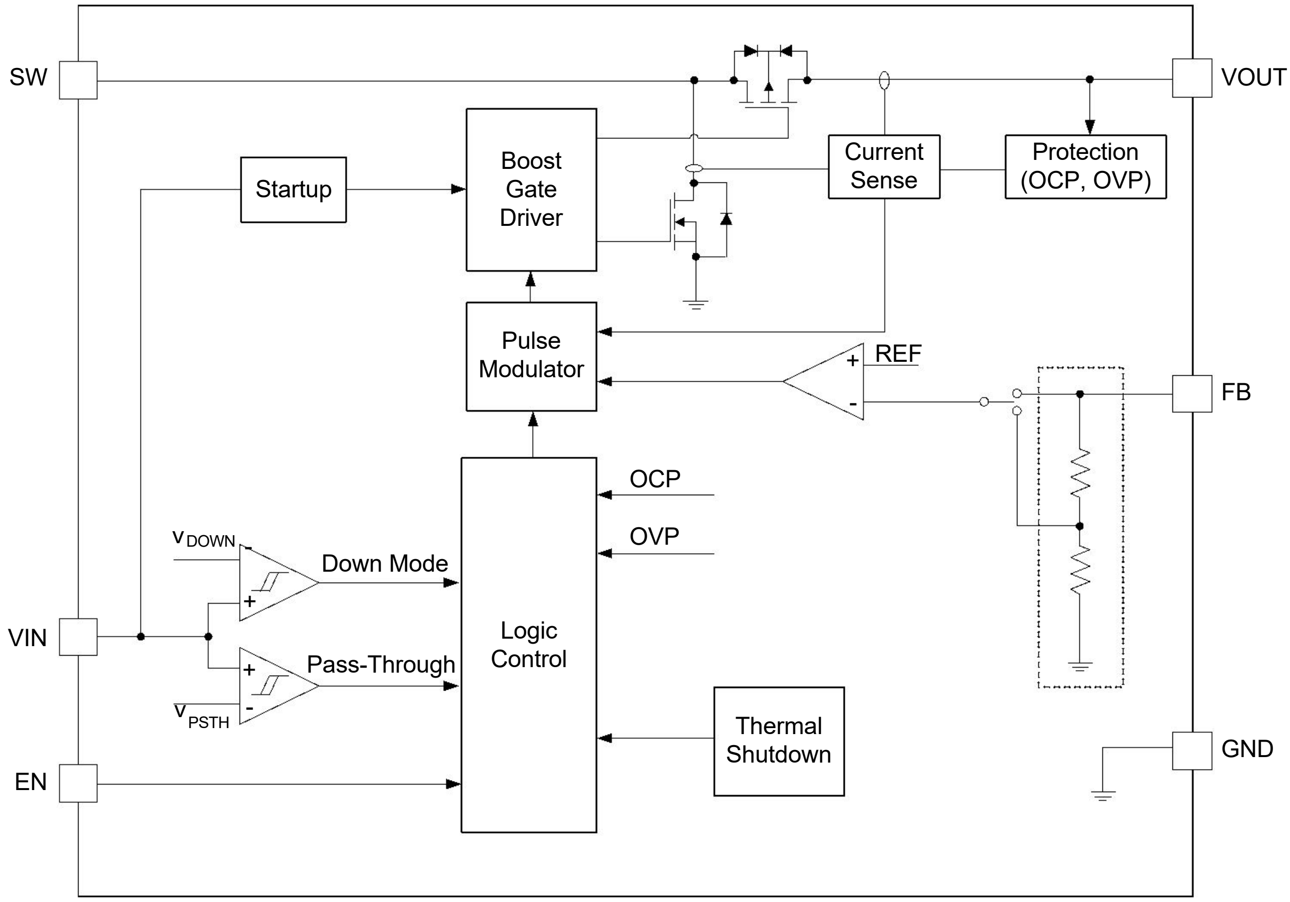


Figure 2. Block Diagram

DETAILED DESCRIPTION

The PC8609 synchronous step-up converter is designed for alkaline battery, coin-cell battery, Li-Ion or Li-Polymer battery powered systems, which requires long battery running time and tiny solution size. The PC8609 can operate with a wide input voltage from 0.9V to 5.2V. It only consumes 0.65μA quiescent current and can achieve high efficiency under light load condition.

The PC8609 operates in peak current mode with typical 1.3A peak switch current limit. The PC8609 provides the true shutdown function and the load is completely disconnected from the input so as to minimize the leakage current. It also adopts down mode and pass-through operation when input voltage is close to or higher than the regulated output voltage. The PC8609 is available in both adjustable and fixed output voltage versions. Adjustable version offers programmable output voltage for flexible applications while fixed versions offer minimal solution size and achieve up to 75% high efficiency under 10μA load.

Enable and Disable

When the EN pin is pulled to high, the PC8609 is enabled. When the EN pin is pulled to low, the PC8609 goes into shutdown mode. In shutdown mode, the device stops switching and the rectifying PMOS fully turns off, providing the completed disconnection between input and output. Less than 1μA input current is consumed in shutdown mode. In particular, it is recommended to avoid pulling EN high to start the boost when the power supply voltage is higher than 5.2V. See Figure 1, a RC network of 10kΩ and 10nF at EN pin is suggested to ensure the EN active signal a bit later than the spike of the power supply.

Startup and Low Supply Voltage Operation

The PC8609 is able to start up with 0.9V input voltage with larger than 3kΩ load. However, if the load during startup is too heavy that the PC8609 fails to charge the output voltage to above 2.2V, then it won't be able to start up successfully.

The PC8609 may not be shut down by pulling the EN to logic low when the supply voltage is below 0.85V, while the supply voltage can drop to as low as 0.4V for maintain the output voltage with light loadings.

Current Limit Operation

The PC8609 employs cycle-by-cycle over-current protection (OCP) function. If the inductor peak current reaches the current limit threshold I_{LIM}, the main switch turns off so as to stop further increase of the input current. In this case the output voltage will decrease until the power balance between input and output is achieved. If the output drops below the input voltage, the PC8609 enters into down mode. The peak current is still limited by I_{LIM} cycle-by-cycle in down mode. If the output drops below 2.2V, the PC8609 enters into startup process again. In pass-through operation, current limit function is not enabled.

Output Short-to-Ground Protection

The PC8609 starts to limit the switch current to about 200mA when the output voltage is below 2.2V. If short-to-ground condition occurs, switch current is limited at about 200mA. Once the short circuit is released, the PC8609 goes back to soft start again
and regulates the output voltage.

Over-Voltage Protection

PC8609 has an output over -voltage protection(OVP)to protect the device in case that the external feedback resistor divider is wrongly connected. When the output voltage of the PC8609 exceeds the OVP threshold of 5.8V, the device stops switching. Once the output voltage falls 0.1V below the OVP threshold, the device starts operating again.

Power-Save Mode Operation under Light Load Condition

The step-up converter of PC8609 enters into power-save mode operation under light load condition.

Down Mode Regulation and Pass-Through Operation

The PC8609 features down mode and pass-through operation when input voltage is close to or higher than output voltage.

DETAILED DESCRIPTION (continued)

In the down mode, output voltage is regulated at target value even when $V_{IN} > V_{OUT}$. The control circuit changes the behavior of the rectifying PMOS by pulling its gate to input voltage instead of to ground. In this way, the voltage drop across the PMOS is increasing as high as to regulate the output voltage. The power loss also increases in this mode, which needs to be taken into account for thermal consideration.

In the pass-through operation, the step-up converter stops switching. The rectifying PMOS constantly turns on and low-side switch constantly turns off. The output voltage is the input voltage minus the voltage drop across the DC resistance (DCR) of the inductor and the on-resistance of the rectifying PMOS.

With V_{IN} ramping up, the goes into down mode first when $V_{IN} > V_{OUT}$ - 100mV. It stays in down mode until $V_{IN} > V_{OUT}$ + 0.3V and then goes automatically into pass-through operation. In the pass-through operation, output voltage follows input voltage. The PC8609 exits pass-through mode and goes back to down mode when V_{IN} ramps down to 101% of the target output voltage. It stays in down mode until input voltage falls 150mV below the output voltage, returning to boost operation.

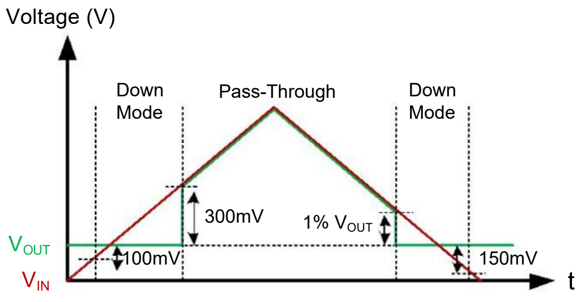


Figure 3. Down Mode and Pass-Through Operation

Thermal Shutdown

A thermal shutdown function is implemented to prevent damage caused by excessive heat and power dissipation. Once a temperature of typically +150°C is exceeded, the device is shut down. The device is released from shutdown automatically when the junction temperature decreases by 25℃.

APPLICATION INFORMATION

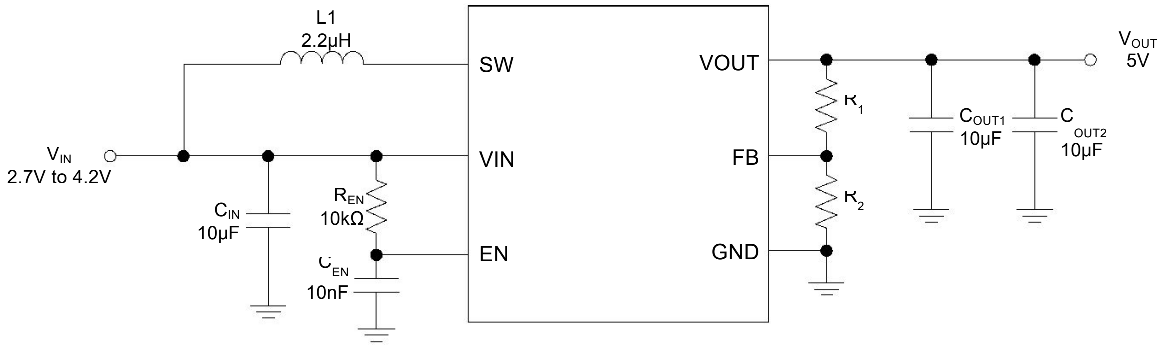


Figure 4. 5V Output Boost Converter

Design Requirements

A typical application example is the memory LCD, which normally requires 5V output as its bias voltage and only consumes less than 1mA current. The following design procedure can be used to select external component values for the .

Table 1. Design Requirements

PARAMETERS	VALUES
Input Voltage	2.7V ~ 4.2V
Output Voltage	5V
Output Current	1mA
Output Voltage Ripple	±50mV

Programming the Output Voltage

There are two ways to set the output voltage of the PC8609 . For adjustable output voltage version, select the external resistor divider R_1 and R_2, as shown

$$V_{OUT} = V_{REF} \times \frac{R_1 + R_2}{R_2} \quad (1)$$

For fixed output voltage versions, the FB pin should be connected to GND or kept floating. The PC8609 offers diverse fixed voltage versions.

In this example, 5V output is required to bias the memory LCD. For the best accuracy, the current following through R_2 should be 100 times larger than FB pin leakage current. Changing R_2 towards a lower value increases the robustness against noise injection. Changing R_2 towards higher values reduces the FB divider current for achieving the highest efficiency at low load currents. 1MΩ and 249kΩ resistors are selected for R_1 and R_2 in this example. High accuracy resistors are recommended for better output voltage accuracy.

Maximum Output Current

The maximum output capability of the PC8609 is determined by the input to output ratio and the current limit of the step-up converter. It can be estimated by Equation 2.

$$I_{OUT(MAX)} = \frac{V_{IN} \cdot (I_{LIM} - \frac{I_{LH}}{2}) \cdot \eta}{V_{OUT}} \quad (2)$$

where η is the conversion efficiency, using 85% for estimation; I_{LH} is the current ripple value and I_{LIM} is the switch current limit.

Minimum input voltage, maximum boost output voltage and minimum current limit I_{LIM} should be used as the worst case condition for the estimation.

APPLICATION INFORMATION (continued)

Inductor Selection

Because the selection of the inductor affects steady state operation, transient behavior, and loop stability, the inductor is the most important component in power regulator design. There are three important inductor specifications, inductor value, saturation current, and DC resistance (DCR).

The device has been optimized to operate with inductance values between 1μH and 2.2μH. For best stability consideration, a 2.2μH inductor is recommended for V_{OUT} > 3.0V condition while choosing a 1μH inductor for applications under V_{OUT} ≤ 3.0V condition.

Table 2. List of Inductors

V_{OUT} (V)	Inductance (μH)	Saturation Current (A)	DC Resistance (MΩ)	Size (L × W × H)	Part Number	Manufacturer
> 3.0	2.2	1.95	80	2.5 × 2.0 × 1.2	74404024022	Würth Elektronik
	2.2	1.7	92	2.5 × 2.0 × 1.1	LQH2HPN2R2MJR	muRata
	2.2	1.45	163	2.0 × 1.6 × 1.0	VLS201610CX-2R2M	TDK
≤ 3.0	1.0	2.6	37	2.5 × 2.0 × 1.2	74404024010	Würth Elektronik
	1.0	2.3	48	2.5 × 2.0 × 1.0	MLP2520W1R0MT0S1	TDK
	1.0	1.5	80	2.0 × 1.2 × 1.0	LQM21PN1R0MGH	muRata

Capacitor Selection

For best output and input voltage filtering, low ESR X5R or X7R ceramic capacitors are recommended.

The input capacitor minimizes input voltage ripple, suppresses input voltage spikes and provides a stable system rail for the device. An input capacitor value of 10μF is normally recommended to improve transient behavior of the regulator and EMI behavior of the total power supply circuit. A ceramic capacitor placed as close as possible to the VIN and GND pins of the device is recommended.

For the output capacitor of VOUT pin, small ceramic capacitors are recommended, placed as close as possible to the VOUT and GND pins of the device. If, for any reason, the application requires the use of large capacitors which cannot be placed close to the device, the use of a small ceramic capacitor with a capacitance value of 1μF in parallel to the large one is recommended. This small capacitor should be placed as close as possible to the VOUT and GND pins of the device.

From the power stage point of view, the output capacitor sets the corner frequency of the converter while the inductor creates a right-half-plane-zero. Consequently, with a larger inductor, a larger output capacitor must be used. The device has been optimized to operate with inductance values between 1μH and 2.2μH, so the minimal output capacitor value is 20μF (nominal value). Increasing the output capacitor makes the output ripple smaller in PWM mode.

When selecting capacitors, ceramic capacitor's derating effect under bias should be considered. Choose the right nominal capacitance by checking capacitor's DC bias characteristics. In this example, GRM188R60J106ME84D, which is a 10μF ceramic capacitor with high effective capacitance value at DC biased condition, is selected for V_{OUT} rail.

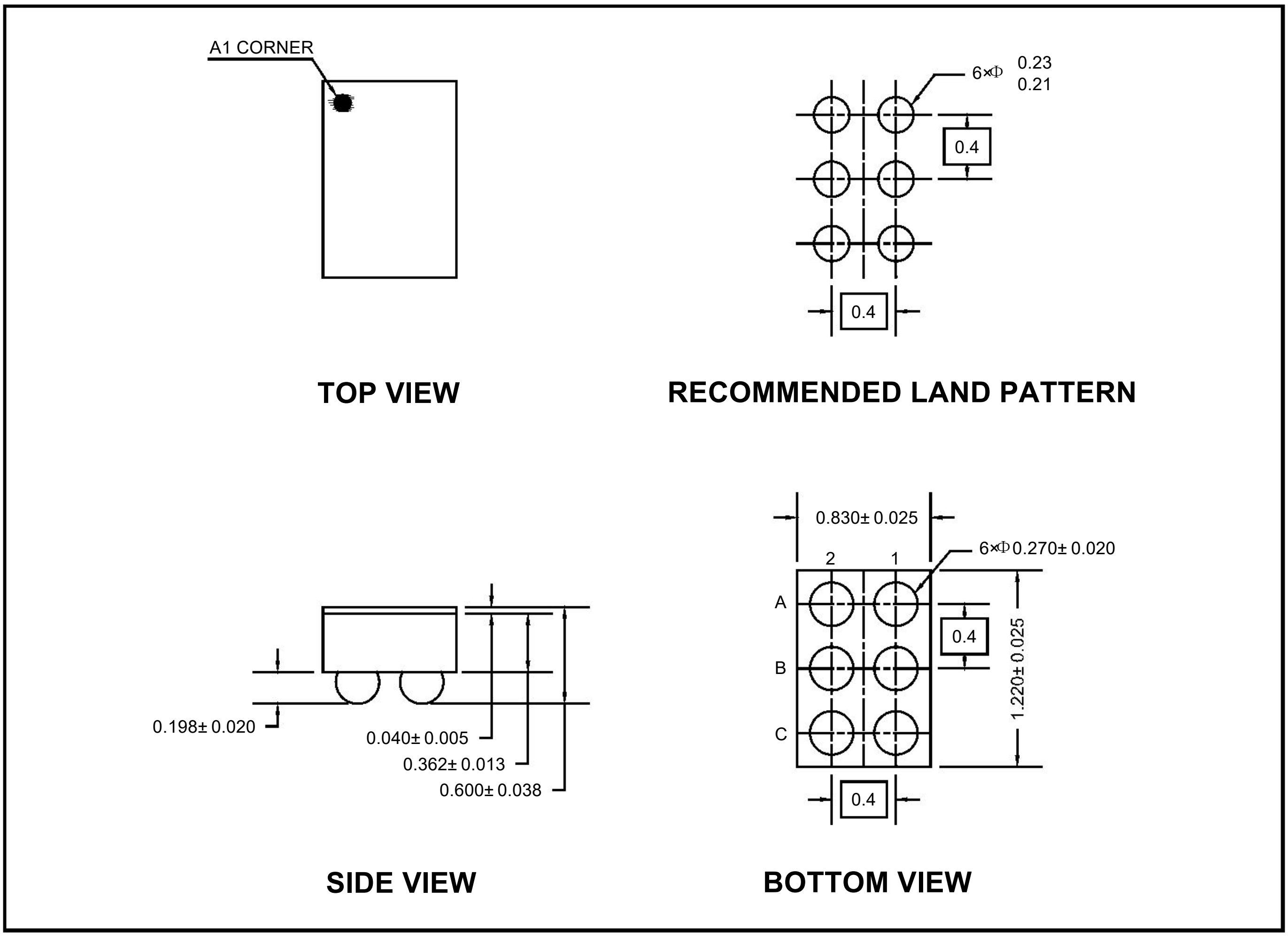
In the case of load hot-plugging, the input capacitance of load device needs to be less than 1/10 of the output capacitance of PC8609.

Layout

As for all switching power supplies, the layout is an important step in the design, especially at high peak currents and high switching frequencies. If the layout is not carefully done, the regulator could show stability problems as well as EMI problems. Therefore, use wide and short traces for the main current path and for the power ground paths. The input and output capacitor, as well as the inductor should be placed as close as possible to the device.

PACKAGE OUTLINE DIMENSIONS

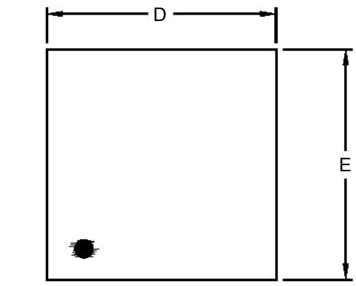
WLCSP-1.22×0.83-6B



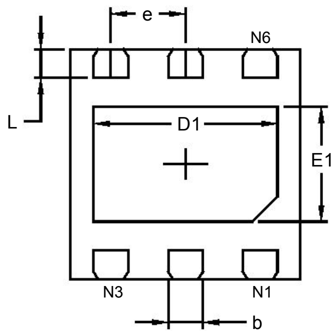
NOTE: All linear dimensions are in millimeters.

PACKAGE OUTLINE DIMENSIONS

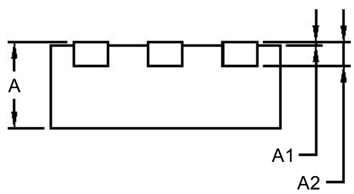
TDFN-2×2-6AL



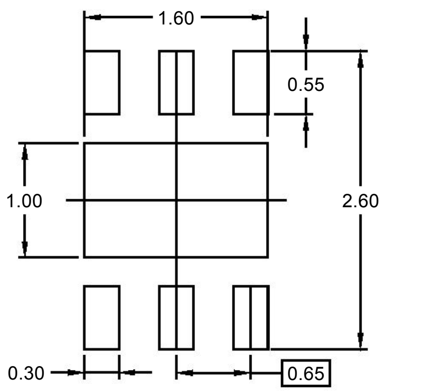
TOP VIEW



BOTTOM VIEW



SIDE VIEW



RECOMMENDED LAND PATTERN (Unit: mm)

Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A2	0.203 REF		0.008 REF	
D	1.900	2.100	0.075	0.083
D1	1.500	1.700	0.059	0.067
E	1.900	2.100	0.075	0.083
E1	0.900	1.100	0.035	0.043
b	0.250	0.350	0.010	0.014
e	0.650 BSC		0.026 BSC	
L	0.174	0.326	0.007	0.013