

3A, 23V, 340K High-Efficiency Synchronous-Rectified Buck Converter

General Description

The uP1707P is a high-efficiency synchronous-rectified buck converter with internal power switch. With internal low $R_{DS(ON)}$ switches, the high-efficiency buck converter is capable of delivering 3A output current over a wide input voltage range from 4.5V to 23V. The output voltage is adjustable from 0.925V to 20V by a voltage divider. Other features for the buck converter include adjust soft-start, chip enable, over-voltage, under-voltage, over-temperature and over-current protections. It is available in a space saving PSOP-8L package.

Applications

- **Battery-Powered Portable Devices**
 - MP3 Players
 - Digital Still Cameras
 - Wireless and DSL Modems
 - Personal Information Appliances
- 802.11 WLAN Power Supplies
- FPGA/ASIC Power Supplies
- Laptop, Palmtops, Notebook Computers
- Portable Information Appliances

Ordering Information

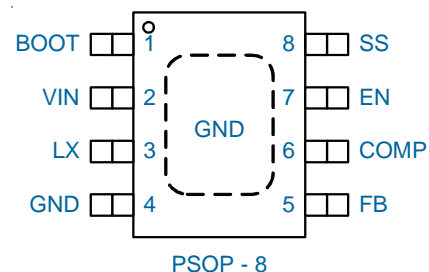
Order Number	Package Type	Top Marking
uP1707PSW8	PSOP-8L	uP1707P

Note: uPI products are compatible with the current IPC/JEDEC J-STD-020 requirement. They are halogen-free, RoHS compliant and 100% matte tin (Sn) plating that are suitable for use in SnPb or Pb-free soldering processes.

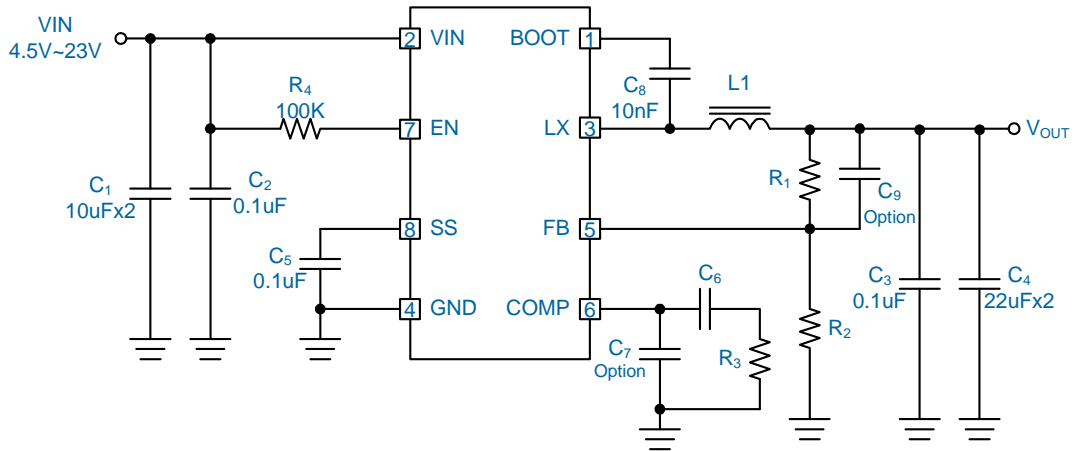
Features

- **4.5V to 23V Input Voltage Range**
- **Adjustable Output from 0.925V to 20V**
- **3A Output Current**
- **Accurate Reference: 0.925V ($\pm 1.5\%$)**
- **Up to 95% Conversion Efficiency**
- **Integrated Low $R_{DS(ON)}$ Upper and Lower MOSFET Switches: 100m Ω**
- **Current Mode PWM Operation**
- **Constant 340kHz Fixed-Frequency Operation**
- **Programmable Soft-Start**
- **Integrated Boot Diode**
- **Over Voltage and Under Voltage Protection**
- **Over Temperature and Over Current Protection**
- **PSOP-8L Package**
- **RoHS Compliant and Halogen Free**

Pin Configuration



Typical Application Circuit

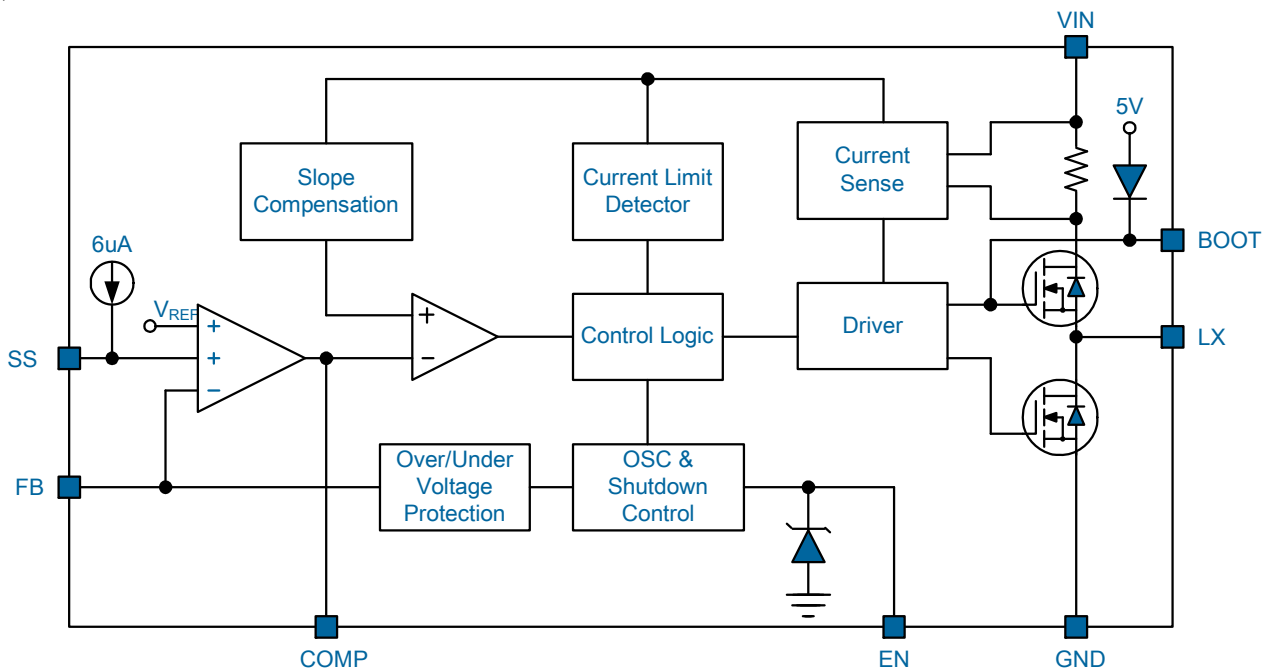


VOUT	L1	R1	R2	R3	C6
1.2V	3.3uH	3.0kΩ	10kΩ	3.0kΩ	3.9nF
1.8V	3.3uH	9.53kΩ	10kΩ	3.0kΩ	3.9nF
2.5V	6.8uH	16.9kΩ	10kΩ	6.2kΩ	3.9nF
3.3V	10uH	26.1kΩ	10kΩ	6.8kΩ	3.9nF
5.0V	15uH	45.3kΩ	10kΩ	13kΩ	3.9nF
8V	22uH	76.8kΩ	10kΩ	15kΩ	3.9nF
10V	22uH	97.6kΩ	10kΩ	20kΩ	3.9nF
15V	33uH	153kΩ	10kΩ	30kΩ	3.9nF

Functional Pin Description

Pin No.	Pin Name	Pin Function
1	BOOT	Bootstrap Supply for the Floating Upper Gate Driver. Connect the bootstrap capacitor C_{BOOT} between BOOT pin and the LX pin to form a bootstrap circuit. The bootstrap capacitor provides the charge to turn on the upper MOSFET. Typical value for C_{BOOT} is 10nF or greater. Ensure that C_{BOOT} is placed near the IC.
2	VIN	Power Supply Input. Input voltage that supplies current to the output voltage and powers the internal control circuit. Bypass the input voltage with a minimum 10uFx2 X5R or X7R ceramic capacitor.
3	LX	Internal Switches Output. Connect this pin to the output inductor.
4	GND	Ground. Ground of the buck converter.
5	FB	Switcher Feedback Voltage. This pin is the inverting input of the error amplifier. FB senses the switcher output through an external resistor divider network.
6	COMP	Compensation. This pin is output of the error amplifier. The current comparator threshold increases with this control voltage. Connect an RC network to ground for control loop compensation.
7	EN	Buck Converter Enable (Active High). Logic low shuts down the converter.
8	SS	Soft-Start Control Pin. Connect a softstart capacitor C_{SS} to this pin. Leave open for no soft-start application. The softstart capacitor is discharged to ground when EN pin is low.
Exposed Pad		Power Ground. The exposed pad is the mainly path for heat convection and should be well soldered to the PCB for best thermal performance.

Functional Block Diagram



Functional Description

The integrated high efficiency synchronous-rectified buck converter with internal power switches. With internal low $R_{DS(ON)}$ switches, it is capable of delivering 3A output current over a wide input voltage range from 4.5V to 23V. The output voltage is adjustable from 0.925V to 20V by a voltage divider. Other features include Programmable soft-start, chip enable, overvoltage, under-voltage, over-temperature and over-current protections.

Input Supply Voltage, VIN

VIN supplies current to internal control circuits and output voltages. The supply voltage range is from 4.5V to 23V. A power on reset (POR) continuously monitors the input supply voltage. The POR level is typically 4.0V at VIN rising. The buck converter draws pulsed current with sharp edges each time the upper switch turns on, resulting in voltage ripples and spikes at supply input. A minimum 10uF \times 2 ceramic capacitor with shortest PCB trace is highly recommended for bypassing the supply input.

Chip Enable/Disable and Soft Start

Pulling EN pin lower than 0.4V shuts down the buck converter and reduces its quiescent current lower than 1uA. In the shutdown mode, both upper and lower switches are turned off. Pulling EN pin higher than 2.7V enables the buck converter and initiates the soft start cycle. The uP1707P features programmable soft start function to limit the inrush current from supply input by a soft start capacitor C_{SS} connected to SS pin as shown in Figure 1. The C_{SS} is charged to VIN by a 6uA current source when EN pin is taken high. The V_{SSE} voltage is clamped to V_{SS} with a threshold voltage of NMOSFET.

The error amplifier is a tri-input device. V_{SSE} or V_{REF} whichever is smaller dominates the non-inverting inputs of the error amplifier. The V_{SSE} voltage starts ramping up when V_{SS} is higher than about 0.7V. The V_{FB} voltage will follow the V_{SSE} and ramp up linearly. When V_{SSE} is higher than V_{REF} , the uP1707P asserts soft start end and the V_{FB} voltage is regulated to V_{REF} . Soft start end also initiates the output under voltage protection

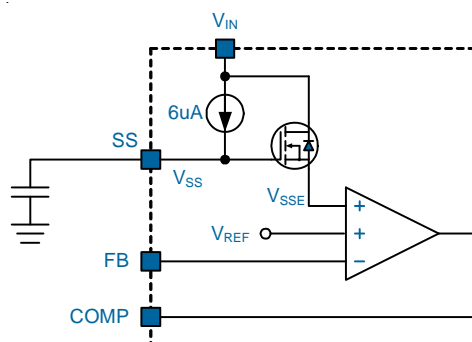


Figure 1. uP1707P Soft Start

Main Control Loop

The uP1707P adopts slope-compensated, current mode PWM control. During normal operation, the uP1707P operates at PWM mode to regulate output voltage by transferring the power to the output voltage cycle by cycle at a constant frequency. The uP1707P turns on the upper switch at each rising edge of the internal oscillator allowing the inductor current to ramp up linearly. The switch remains on until either the current limit is tripped or the PWM comparator turns off the switch for regulating output voltage.

The lower switch turns on with optimal dead time and picks up the inductor current after the upper switch turns off allowing the inductor current to ramp down linearly. The switch remains on until the next rising edge of oscillator turns on the upper switch. The uP1707P regulates the output voltage by controlling the ramp up/down duty cycle of inductor current. The high frequency switching ripple is easily smoothed by the output filter.

The upper switch current is sensed, slope compensated and compared with the error amplifier output COMP to determine the adequate duty cycle. The feedback voltage V_{FB} is sensed through a resistive voltage divider and regulated to internal 0.925V reference voltage. The error amplifier amplifies and compensates voltage variation to get appropriate COMP pin voltage.

When the load current increases, it causes a slight decrease in the feedback voltage relative to the 0.925V reference, which in turn, causes the error amplifier output voltage to increase until the average inductor current matches the new load current.

Output Voltage Setting and Feedback Network

For the adjustable output version, the output voltage can be set from V_{REF} to VIN by a voltage divider as:

$$V_{OUT} = 0.925V \times \frac{R1 + R2}{R2}$$

The internal V_{REF} is 0.925V with 1.5% accuracy. In real applications, a 22pF feed-forward ceramic capacitor is recommended in parallel with R1 for better transient response.

Over Temperature Protection

The OTP is triggered and shuts down the uP1707P if the junction temperature is higher than 160°C. The OTP is a non-latch type protection. The uP1707P automatically initiates another soft start cycle if the junction temperature drops below 130°C.

Absolute Maximum Rating

Supply Input Voltage, V_{IN} (Note 1)	-0.3V to +26.0V
LX Pin Voltage	
DC	-0.3V to $(V_{IN} + 0.3V)$
<50ns	-3.5V to +28V
BOOT Pin Voltage	-0.3V to $(V_{IN} + 6.0V)$
Other Pins	-0.3V to 6.0V
Storage Temperature Range	-65°C to +150°C
Junction Temperature	150°C
Lead Temperature (Soldering, 10 sec)	260°C
ESD Rating (Note 2)	
HBM (Human Body Mode)	2kV
MM (Machine Mode)	200V

Thermal Information

Package Thermal Resistance (Note 3)	
PSOP-8L θ_{JA}	50°C/W
PSOP-8L θ_{JC}	5°C/W
Power Dissipation, P_D @ $T_A = 25^\circ\text{C}$	
PSOP-8L	2.0W

Recommended Operation Conditions

Operating Junction Temperature Range (Note 4)	-40°C to +125°C
Operating Ambient Temperature Range	-40°C to +85°C

Electrical Characteristics

($V_{IN} = 12V$, $T_A = 25^\circ\text{C}$, unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Supply Current						
Supply Current		$V_{EN} = 3.0V$, $V_{FB} = 1.0V$	--	1.3	1.5	mA
Shutdown Supply Current		$V_{EN} = 0V$	--	0.3	3	uA
Input Under Voltage Lockout Threshold		V_{IN} rising	3.8	4.0	4.2	V
Input Under Voltage Lockout Threshold Hysteresis			--	600	--	mV
Reference						
Feedback Voltage	V_{FB}	$4.75V < V_{IN} < 23V$	0.911	0.925	0.939	V
Error Amplifier Voltage Gain	AEA		--	400	--	V/V
Error Amplifier Transconductance	GEA	$\Delta I_C = +/-10uA$	--	820	--	uA/V
COMP to Current Sense Transconductance	GCS		--	4.5	--	A/V

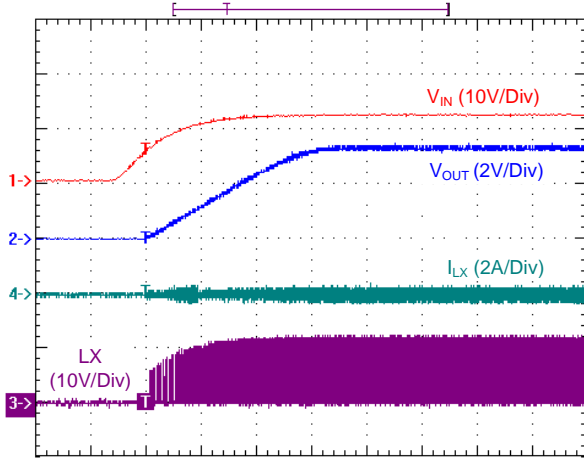
Electrical Characteristics

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Power Switches						
High-Side Switch On Resistance	$R_{DS(ON)}$		--	100	--	m Ω
Low-Side Switch On Resistance	$R_{DS(ON)}$		--	100	--	m Ω
High-Side Switch Leakage Current		$V_{EN} = 0V, V_{SW} = 0V$	--	0	10	μA
Upper Switch Current Limit		Minimum Duty Cycle	4	5.5	--	A
Lower Switch Current Limit		From Drain to Source	--	1.3	--	A
Oscillator						
Oscillation Frequency	FOSC1		300	340	380	kHz
Short Circuit Oscillation Frequency	FOSC2	$V_{FB} = 0V$	--	110	--	kHz
Maximum Duty Cycle	DMAX	$V_{FB} = 1.0V$	--	90	--	%
Minimum On Time	TON		--	220	--	ns
Logic Input						
EN Shutdown Threshold Voltage		V_{EN} Rising	2.0	2.2	2.4	V
EN Shutdown Voltage Hysteresis			--	250	--	mV
EN Lockout Threshold Voltage			2.5	2.7	2.9	V
EN Lockout Voltage Hysteresis			--	450	--	mV
Soft Start						
Soft-Start Current		$V_{SS} = 0V$	5.5	6.0	6.5	μA
Soft-Start period		$C_{SS} = 0.1\mu F$	--	15	--	ms
Protection						
FB Over Voltage Protection			--	1.1	--	V
Over-Temperature Protection			--	160	--	$^{\circ}C$
Over-Temperature Hysteresis			--	30	--	$^{\circ}C$

- Note 1.** Stresses listed as the above "Absolute Maximum Ratings" may cause permanent damage to the device. These are for stress ratings. 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 remain possibility to affect device reliability.
- Note 2.** Devices are ESD sensitive. Handling precaution recommended.
- Note 3.** θ_{JA} is measured in the natural convection at $T_A = 25^{\circ}C$ on a low effective thermal conductivity test board of JEDEC 51-3 thermal measurement standard.
- Note 4.** The device is not guaranteed to function outside its operating conditions.

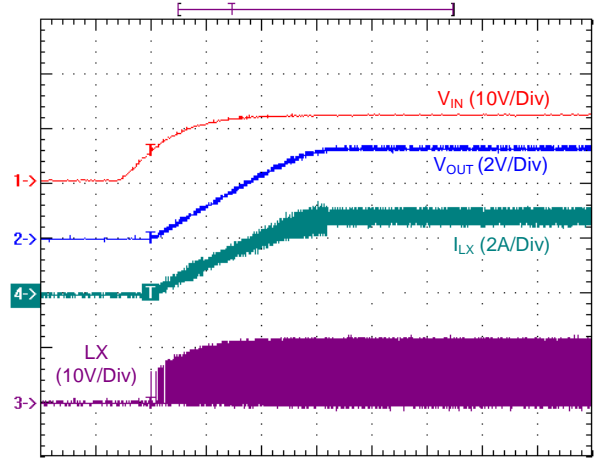
Typical Operation Characteristics

Power On Waveforms



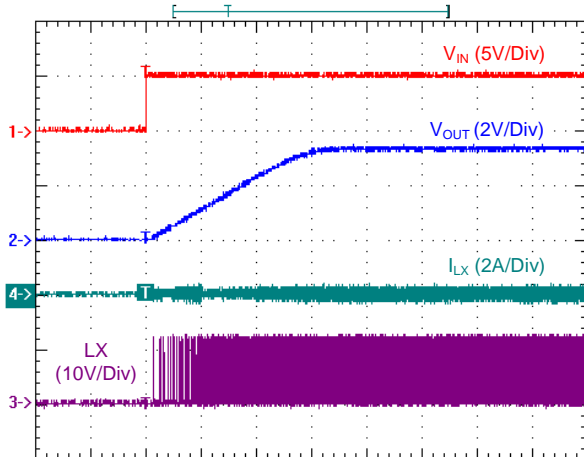
5ms/Div
 $V_{IN} = 12V, V_{OUT} = 3.3V, I_{OUT} = 0A$

Power On Waveforms



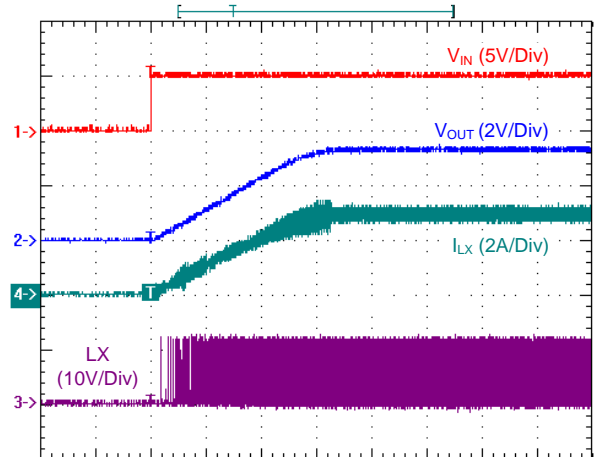
5ms/Div
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Turn On Waveforms



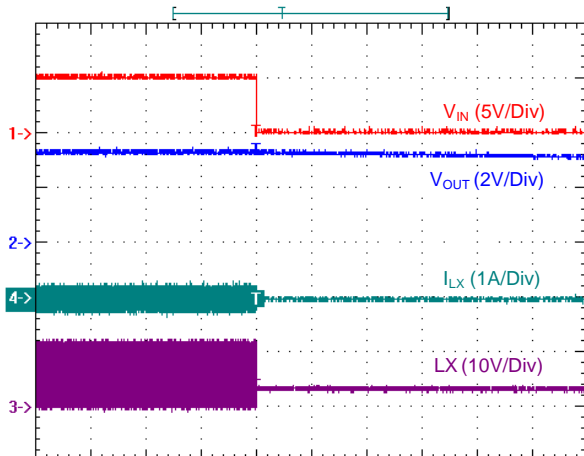
5ms/Div
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Turn On Waveforms



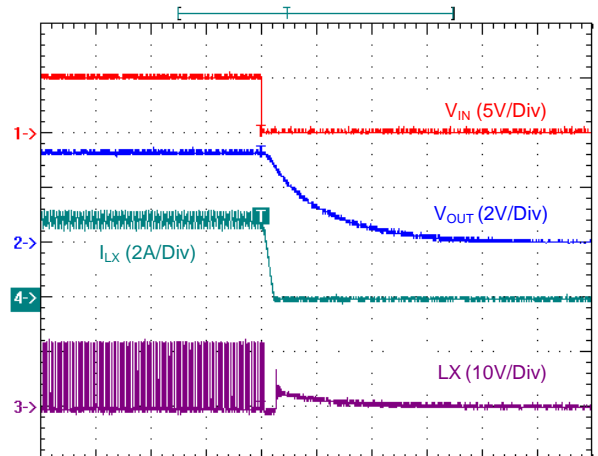
5ms/Div
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Turn Off Waveforms



10ms/Div
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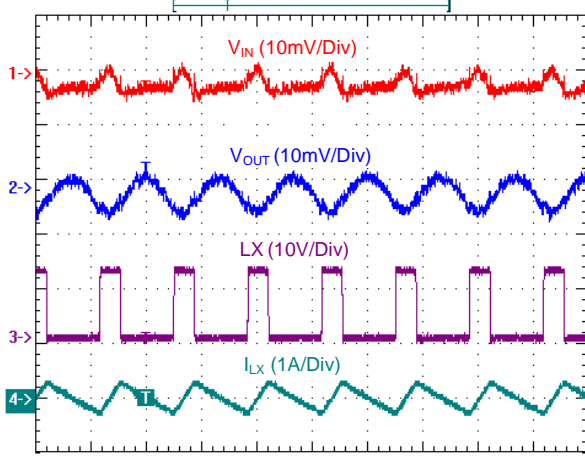
Turn Off Waveforms



50us/Div
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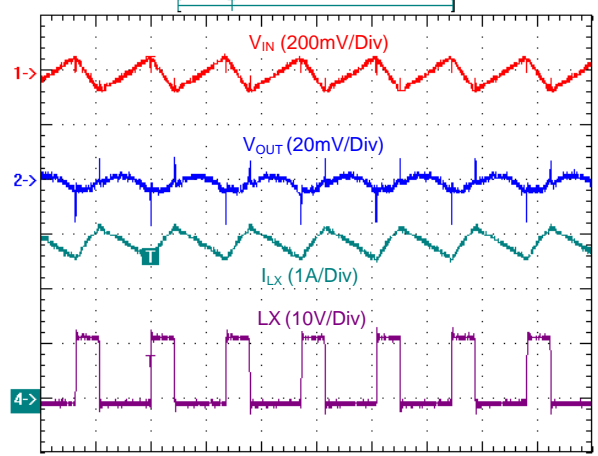
Typical Operation Characteristics

Steady State Waveforms



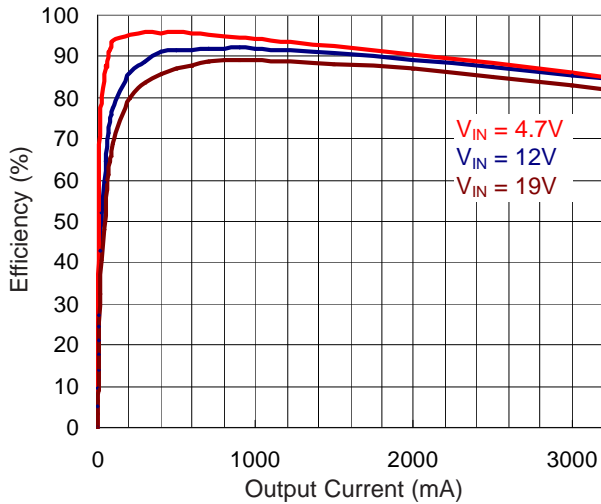
5us/Div
 $V_{IN} = 12V, V_{OUT} = 3.3V, I_{OUT} = 0A$

Power On Waveforms

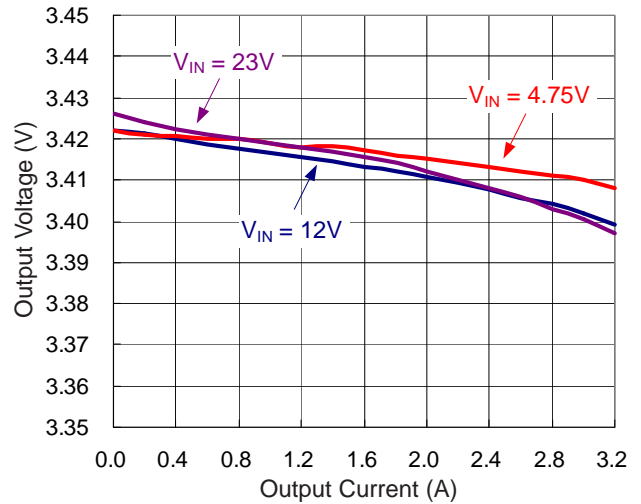


2us/Div
 $V_{IN} = 12V, V_{OUT} = 3.3V, I_{OUT} = 3A$

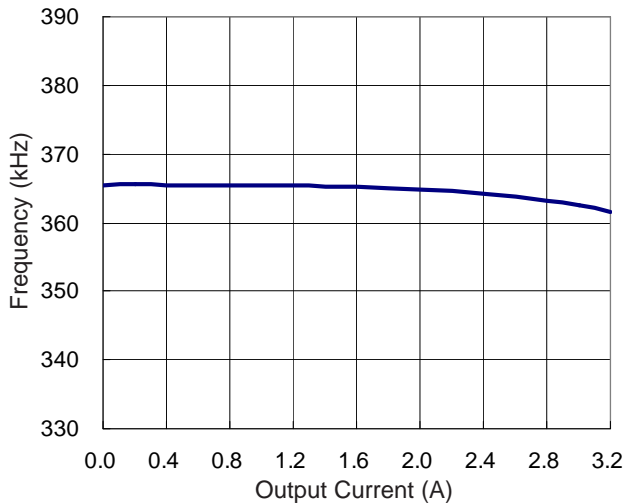
Efficiency vs. Output Current



Output Voltage vs. Output Current



Frequency vs. Output Current



Application Information

Output Inductor Selection

Output inductor selection is usually based the considerations of inductance, rated current value, size requirements and DC resistance (DCR).

The inductance is chosen based on the desired ripple current. Large value inductors result in lower ripple currents and small value inductors result in higher ripple currents. Higher V_{IN} or V_{OUT} also increases the ripple current as shown in the equation below. A reasonable starting point for setting ripple current is $\Delta I_L = 900\text{mA}$ (30% of 3000mA). For most applications, the value of the inductor will fall in the range of 1uH to 10uH.

$$\Delta I_L = \frac{1}{f_{OSC} \times L_{OUT}} \times V_{OUT} \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Maximum current ratings of the inductor are generally specified in two methods: permissible DC current and saturation current. Permissible DC current is the allowable DC current that causes 40°C temperature raise. The saturation current is the allowable current that causes 10% inductance loss. Make sure that the inductor will not saturate over the operation conditions including temperature range, input voltage range, and maximum output current. If possible, choose an inductor with rated current higher than 5.5A so that it will not saturate even under current limit condition.

The size requirements refer to the area and height requirement for a particular design. For better efficiency, choose a low DC resistance inductor. DCR is usually inversely proportional to size.

Different core materials and shapes will change the size, current and price/current relationship of an inductor. Toroid or shielded pot cores in ferrite or permalloy materials are small and don't radiate much energy, but generally cost more than powdered iron core inductors with similar electrical characteristics. The choice of which style inductor to use often depends on the price vs. size requirements and any radiated field/EMI requirements.

Input Capacitor Selection

The buck converter draws pulsed current with sharp edges from the input capacitor resulting in ripple and noise at the input supply voltage. A minimum 10uFx2 X5R or X7R ceramic capacitor is highly recommended to filter the pulsed current. The input capacitor should be placed as near the device as possible to avoid the stray inductance along the connection trace. Y5V dielectrics, aside from losing most of their capacitance over temperature, they also become resistive at high frequencies. This reduces their ability to filter out high frequency noise.

The capacitor with low ESR (equivalent series resistance) provides the small drop voltage to stabilize the input voltage during the transient loading. For input capacitor selection, the ceramic capacitor larger than 10uFx2 is recommend. The capacitor must conform to the RMS current requirement. The maximum RMS ripple current is calculated as:

$$I_{IN(RMS)} = I_{OUT(MAX)} \times \frac{\sqrt{V_{OUT} \times (V_{IN} - V_{OUT})}}{V_{IN}}$$

This formula has a maximum at $V_{IN} = 2 \times V_{OUT}$, where $I_{IN(RMS)} = I_{OUT(MAX)}/2$. This simple worst-case condition is commonly used for design because even significant deviations do not offer much relief. Note that the capacitor manufacturer's ripple current ratings are often based on 2000 hours of life. This makes it advisable to further derate the capacitor, or choose a capacitor rated at a higher temperature than required. Always consult the manufacturer if there is any question.

Output Capacitor Selection

The integrated buck converter is specifically design to operate with minimum 22uFx2 X5R or X7R ceramic capacitor. The value can be increased to improve load/line transient performance. Y5V dielectrics, aside from losing most of their capacitance over temperature, they also become resistive at high frequencies. This reduces their ability to filter out high frequency noise.

The ESR of the output capacitor determines the output ripple voltage and the initial voltage drop following a high slew rate load transient edge. The output ripple voltage can be calculated as:

$$\Delta V_{OUT} = \Delta I_C \times \left(ESR + \frac{1}{8 \times f_{OSC} \times C_{OUT}}\right)$$

where f_{OSC} = operating frequency, C_{OUT} = output capacitance and $\Delta I_C = \Delta I_L$ = ripple current in the inductor.

The ceramic capacitor with low ESR value provides the low output ripple and low size profile. Connect a 1uF/10uF ceramic capacitor at output terminal for good performance and place the input and output capacitors as close as possible to the device.

Using Ceramic Capacitors

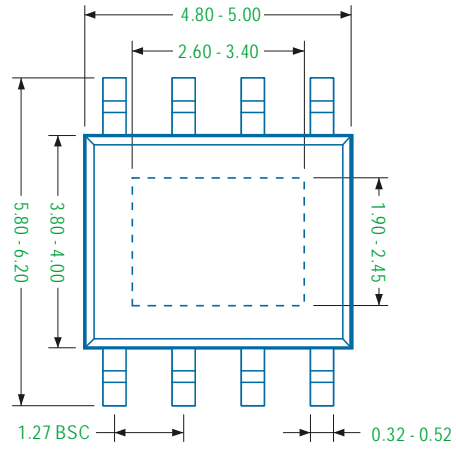
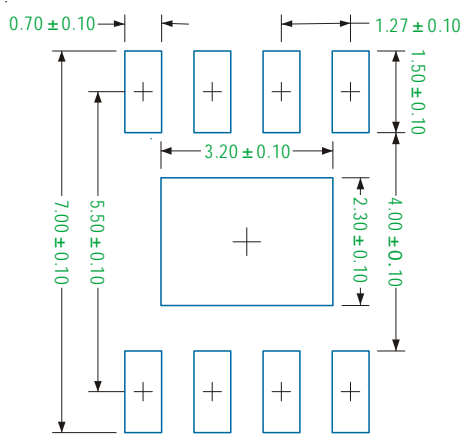
Higher value, lower cost ceramic capacitors are now available in smaller case sizes. Their high ripple current, high voltage rating and low ESR make them ideal for switching regulator applications. Because the control loop does not depend on the output capacitor's ESR for stable operation, ceramic capacitors can be used to achieve very low output ripple and small circuit size.

However, care must be taken when these capacitors are used at the input and the output. When a ceramic capacitor is used at the input and the power is supplied by a wall adapter through long wires, a load step at the output can induce ringing at the input, V_{IN} . At best, this ringing can couple to the output and be mistaken as loop instability. At worst, a sudden inrush of current through the long wires can potentially cause a voltage spike at V_{IN} , large enough to damage the part. When choosing the input and output ceramic capacitors, choose the X5R or X7R dielectric formulations. These dielectrics have the best temperature and voltage characteristics of all the ceramics for a given value and size.

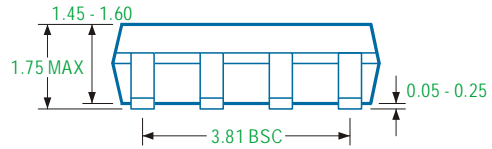
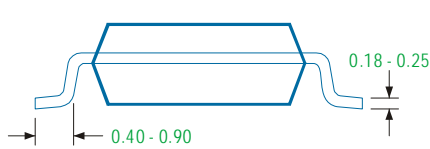
Checking Transient Response

The regulator loop response can be checked by looking at the load transient response. Switching regulators take several cycles to respond to a step in load current. When a load step occurs, V_{OUT} immediately shifts by an amount equal to $(\Delta I_{OUT} \times ESR)$, where ESR is the effective series resistance of C_{OUT} . ΔI_{OUT} also begins to discharge or charge C_{OUT} , which generates a feedback error signal. The regulator loop then acts to return V_{OUT} to its steady state value. During this recovery time V_{OUT} can be monitored for overshoot or ringing that would indicate a stability problem.

PSOP-8L



Recommended Solder Pad Layout



Note

1. Package Outline Unit Description:

BSC: Basic. Represents theoretical exact dimension or dimension target

MIN: Minimum dimension specified.

MAX: Maximum dimension specified.

REF: Reference. Represents dimension for reference use only. This value is not a device specification.

TYP: Typical. Provided as a general value. This value is not a device specification.

2. Dimensions in Millimeters.

3. Drawing not to scale.

4. These dimensions no not include mold flash or protrusions. Mold flash or protrusions shell not exceed 0.15mm.