TEXAS INSTRUMENTS

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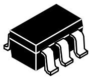


TPS61070
TPS61071

SLVS510–JUNE 2004

90% EFFICIENT SYNCHRONOUS BOOST CONVERTER WITH 600-mA SWITCH

FEATURES

- **90% Efficient Synchronous Boost Converter**
  - **75-mA Output Current at 3.3 V From 0.9-V Input**
  - **150-mA Output Current at 3.3 V From 1.8-V Input**
- **Device Quiescent Current: 19 µA (Typ)**
- **Input Voltage Range: 0.9 V to 5.5 V**
- **Adjustable Output Voltage Up to 5.5 V**
- **Power-Save Mode Version Available for Improved Efficiency at Low Output Power**
- **Load Disconnect During Shutdown**
- **Overtemperature Protection**
- **Small 6-Pin Thin SOT23 Package**

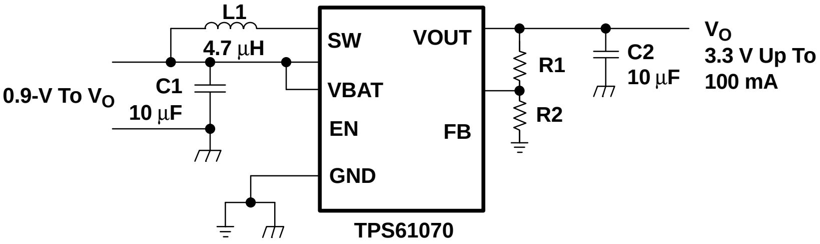
APPLICATIONS

- **All One-Cell, Two-Cell, and Three-Cell Alkaline, NiCd or NiMH or Single-Cell Li Battery-Powered Products**
- **Portable Audio Players**
- **PDAs**
- **Cellular Phones**
- **Personal Medical Products**
- **White LED Lighting**

DESCRIPTION

The TPS6107x devices provide a power supply solution for products powered by either a one-cell, two-cell, or three-cell alkaline, NiCd or NiMH, or one-cell Li-ion or Li-polymer battery. Output currents can go as high as 75 mA while using a single-cell alkaline, and discharge it down to 0.9 V. It can also be used for generating 5 V at 200 mA from a 3.3-V rail or a Li-ion battery. The boost converter is based on a fixed frequency, pulse-width-modulation (PWM) controller using a synchronous rectifier to obtain maximum efficiency. At low load currents the TPS61070 enters the power-save mode to maintain a high efficiency over a wide load current range. At the TPS61071 the power-save mode is disabled, forcing the converter to operate at a fixed switching frequency. The maximum peak current in the boost switch is typically limited to a value of 600 mA.

The TPS6107x output voltage is programmed by an external resistor divider. The converter can be disabled to minimize battery drain. During shutdown, the load is completely disconnected from the battery. The device is packaged in a 6-pin thin SOT23 package (DDC).



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

AVAILABLE OUTPUT VOLTAGE OPTIONS

T_A	OUTPUT VOLTAGE DC/DC	POWER-SAVE MODE	PACKAGE MARKING	PACKAGE	PART NUMBER(1)
- 40°C to 85°C	Adjustable	Enabled	AUH	6-Pin TSOT23	TPS61070DDC
	Adjustable	Disabled	AUJ		TPS61071DDC

(1) The DDC package is available taped and reeled. Add R suffix to device type (e.g., TPS61070DDCR) to order quantities of 3000 devices per reel.

ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range (unless otherwise noted)(1)

	TPS6107x
Input voltage range on SW, VOUT, VBAT, EN, FB	-0.3 V to 7 V
Operating virtual junction temperature range, T_J	-40°C to 150°C
Storage temperature range T_{stg}	-65°C to 150°C

(1) 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 under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

DISSIPATION RATINGS TABLE

PACKAGE	THERMAL RESISTANCE Θ_{JA}	POWER RATING $T_A \leq 25°C$	DERATING FACTOR ABOVE $T_A = 25°C$
DDC	76 °C/W	1315 mW	13 mW/°C

RECOMMENDED OPERATING CONDITIONS

	MIN	NOM	MAX	UNIT
Supply voltage at VBAT, V_I	0.9		5.5	V
Operating free air temperature range, T_A	-40		85	°C
Operating virtual junction temperature range, T_J	-40		125	°C

ELECTRICAL CHARACTERISTICS

over recommended free-air temperature range and over recommended input voltage range (typical at an ambient temperature range of 25°C) (unless otherwise noted)

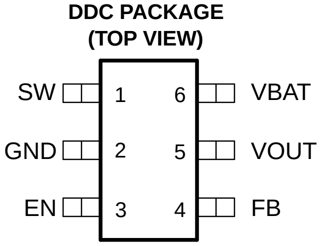
DC/DC STAGE

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_I	Minimum input voltage range for start-up		R_L = 270 Ω		1.1	1.2	V
	Input voltage range, after start-up		T_A = 25°C	0.9		5.5	
V_O	TPS61070 output voltage range			1.8		5.5	V
$V_{(FB)}$	TPS61070 feedback voltage			495	500	505	mV
f	Oscillator frequency			960	1200	1440	kHz
$I_{(SW)}$	Switch current limit		VOUT= 3.3 V	500	600	700	mA
	Start-up current limit				0.5 x I_{SW}		mA
	SWN switch-on resistance		VOUT= 3.3 V		480		mΩ
	SWP switch-on resistance		VOUT= 3.3 V		600		mΩ
	Total accuracy (including line and load regulation)					3%	
	Line regulation					1%	
	Load regulation					1%	
	Quiescent current	VBAT	I_O = 0 mA, $V_{(EN)}$ = VBAT = 1.2 V, VOUT = 3.3 V, T_A = 25°C		0.5	1	µA
		VOUT			19	30	µA
	Shutdown current		$V_{(EN)}$ = 0 V, VBAT = 1.2 V, T_A = 25°C		0.05	0.5	µA

CONTROL STAGE

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{(UVLO)}$	Undervoltage lockout threshold	$V_{(LBI)}$ voltage decreasing		0.8		V
V_{IL}	EN input low voltage				0.2 × VBAT	V
V_{IH}	EN input high voltage		0.8 × VBAT			V
	EN input current	Clamped on GND or VBAT		0.01	0.1	µA
	Overtemperature protection			140		°C
	Overtemperature hysteresis			20		°C

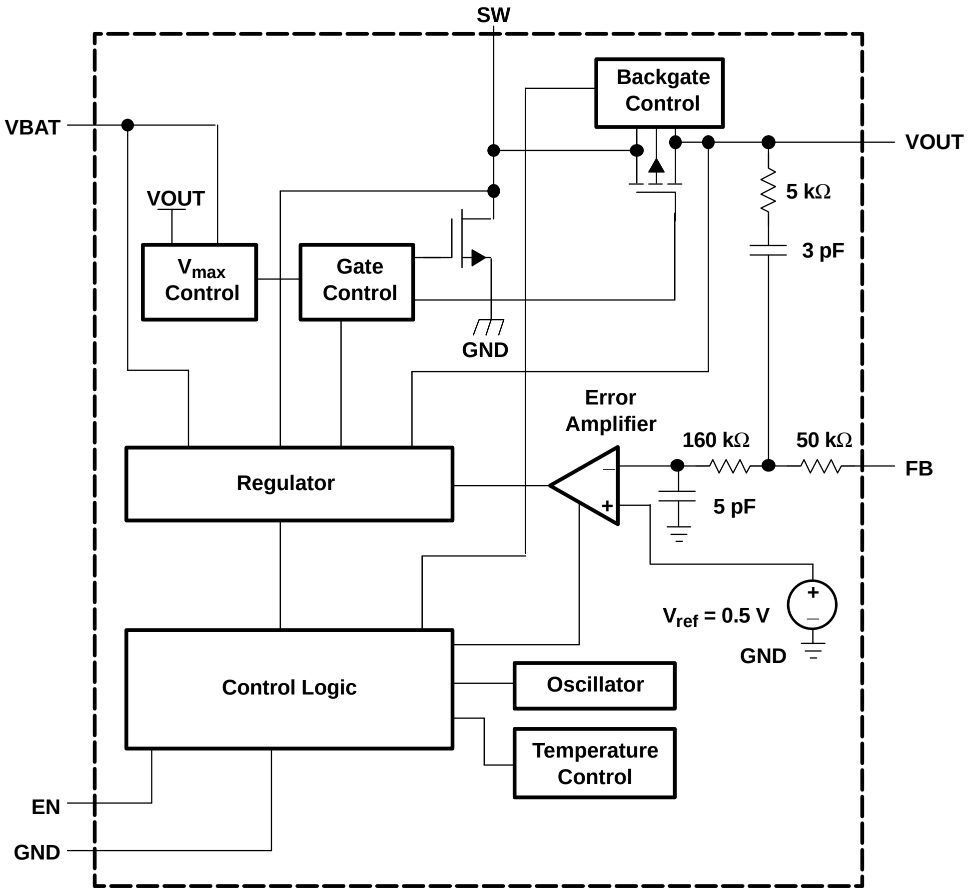
PIN ASSIGNMENTS



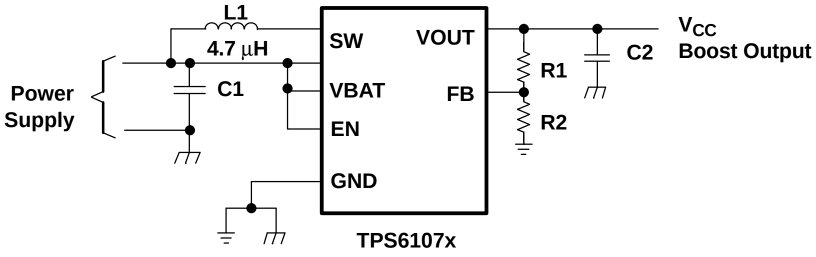
Terminal Functions

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
EN	3	I	Enable input (1/VBAT enabled, 0/GND disabled)
FB	4	I	Voltage feedback for programming the output voltage
GND	2		IC ground connection for logic and power
SW	1	I	Boost and rectifying switch input
VBAT	6	I	Supply voltage
VOUT	5	O	Boost converter output

FUNCTIONAL BLOCK DIAGRAM (TPS61070)



PARAMETER MEASUREMENT INFORMATION



List of Components:
U1 = TPS61070DDC
L1 = Wurth Elektronik 744031004
C1 = 2 x 4.7 ΩF, 0603, X7R/X5R Ceramic
C2 = 4 x 4.7 ΩF, 0603, X7R/X5R Ceramic

TYPICAL CHARACTERISTICS

Table of Graphs

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Maximum output current	vs Input voltage	1
Efficiency	vs Output current	2
	vs Output current	3
	vs Output current	4
	vs Input voltage	5
	vs Input voltage	6
Output voltage	vs Output current	7
	vs Output current	8
No load supply current into VOUT	vs Input voltage	9
Waveforms	Output voltage in continuous mode (TPS61071)	10
	Output voltage in continuous mode (TPS61071)	11
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	Load transient response (TPS61071)	14
	Load transient response (TPS61071)	15
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	Start-up after enable (TPS61071)	21

TYPICAL CHARACTERISTICS

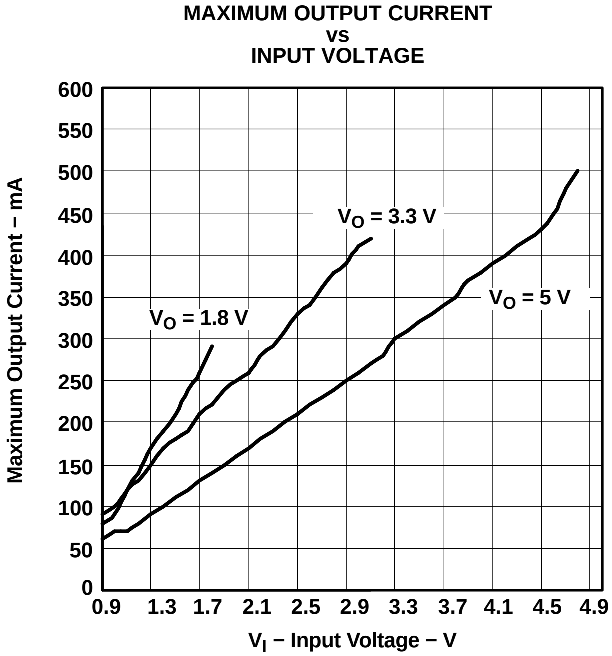

MAXIMUM OUTPUT CURRENT
vs
INPUT VOLTAGE

Figure 1.

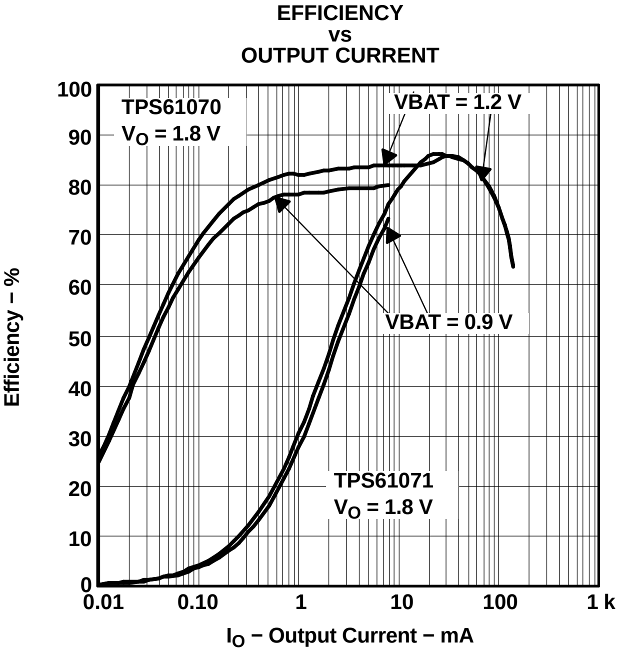

EFFICIENCY
vs
OUTPUT CURRENT

Figure 2.

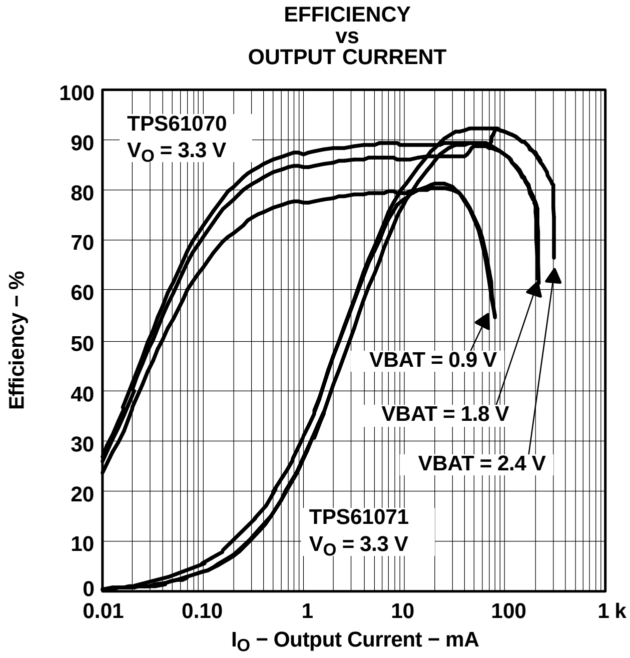

EFFICIENCY
vs
OUTPUT CURRENT

Figure 3.

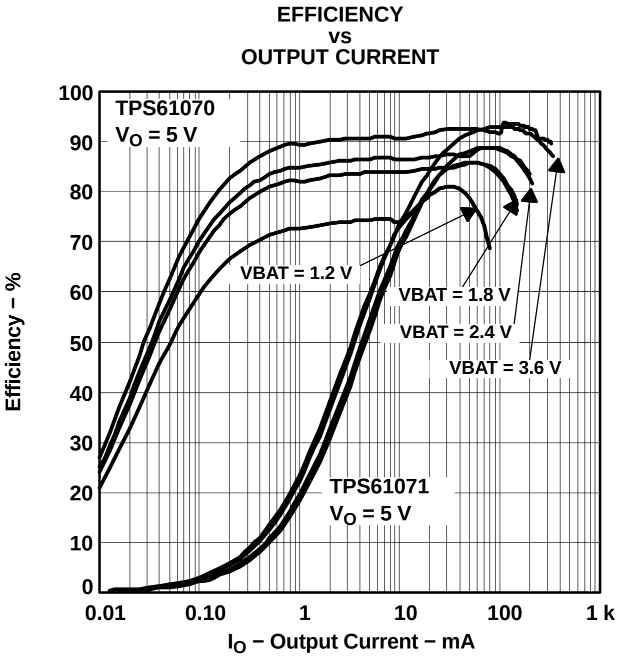

EFFICIENCY
vs
OUTPUT CURRENT

Figure 4.

TYPICAL CHARACTERISTICS (continued)

EFFICIENCY
vs
INPUT VOLTAGE

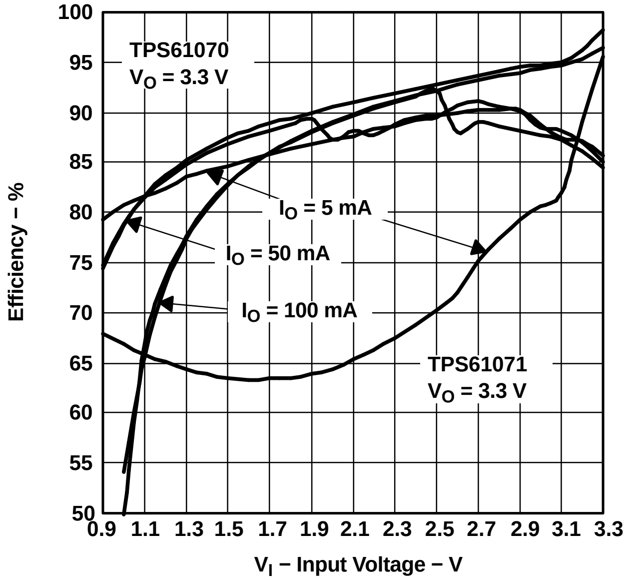


Figure 5.

EFFICIENCY
vs
INPUT VOLTAGE

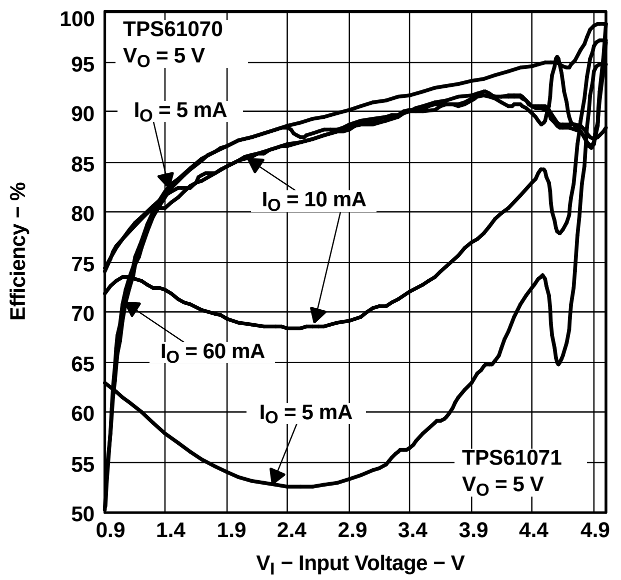


Figure 6.

OUTPUT VOLTAGE
vs
OUTPUT CURRENT

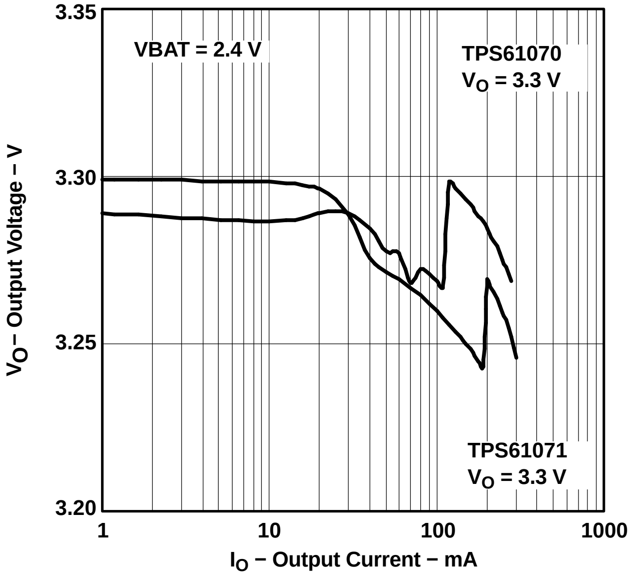


Figure 7.

OUTPUT VOLTAGE
vs
OUTPUT CURRENT

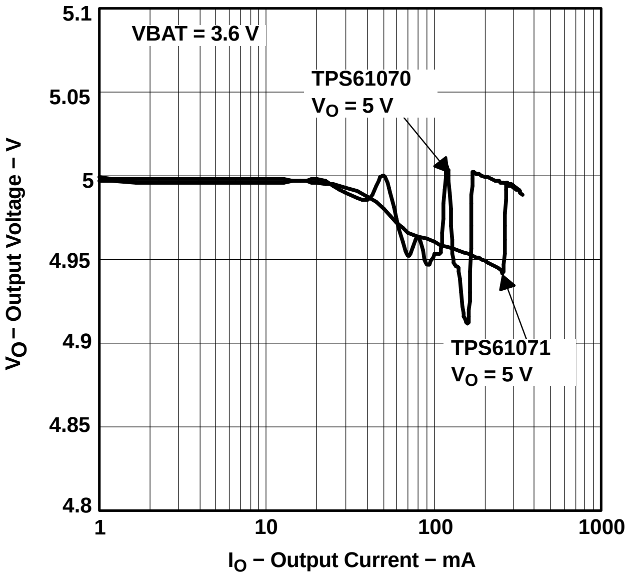


Figure 8.

TYPICAL CHARACTERISTICS (continued)

NO LOAD SUPPLY CURRENT INTO VOUT
vs
INPUT VOLTAGE

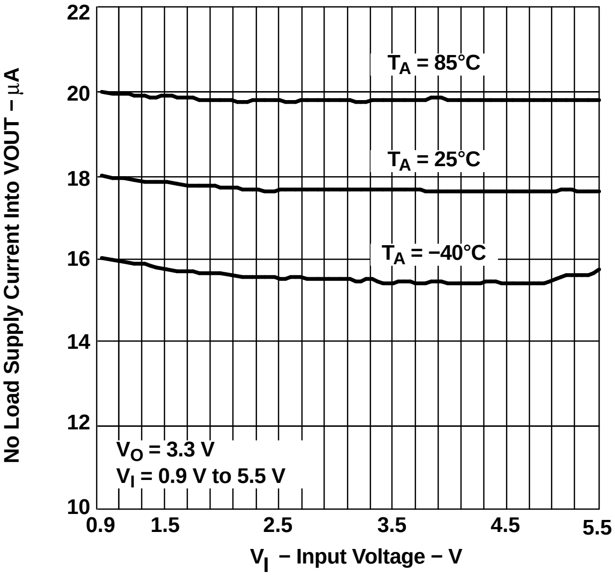


Figure 9.

TPS61071
OUTPUT VOLTAGE IN CONTINUOUS MODE

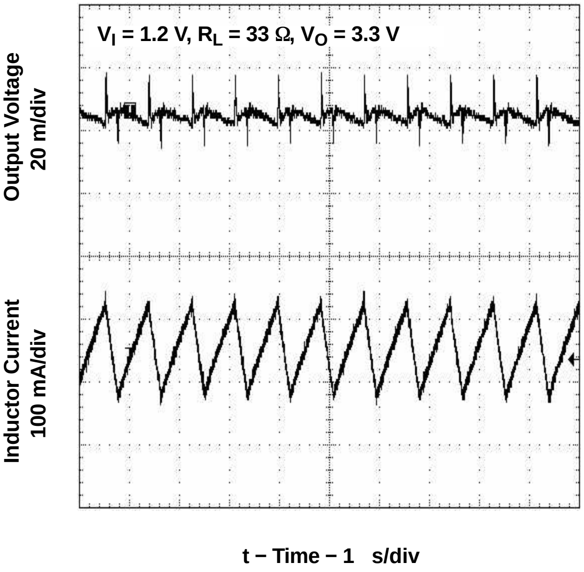


Figure 10.

TPS61071
OUTPUT VOLTAGE IN CONTINUOUS MODE

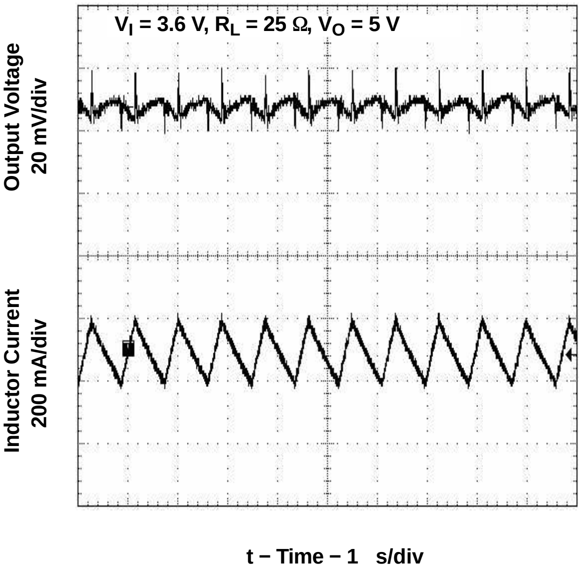


Figure 11.

TPS61070
OUTPUT VOLTAGE IN POWER-SAVE MODE

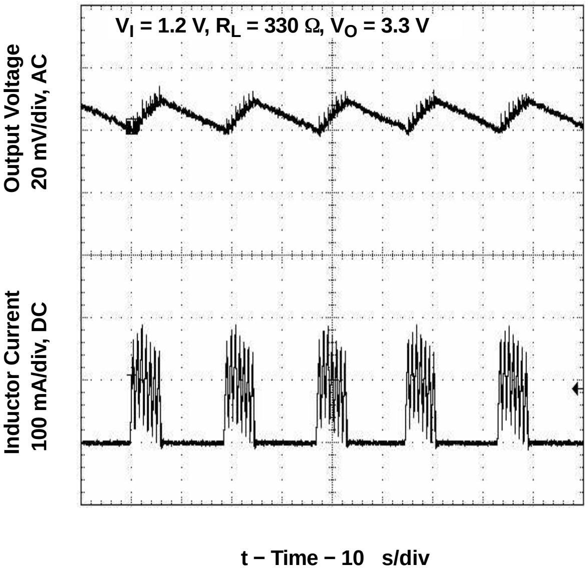
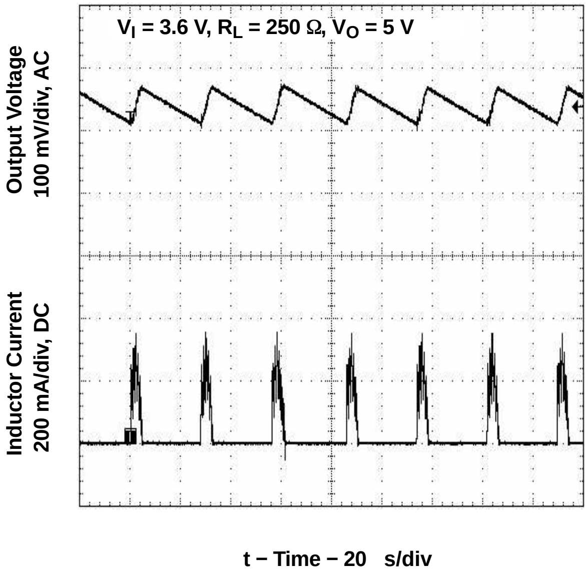


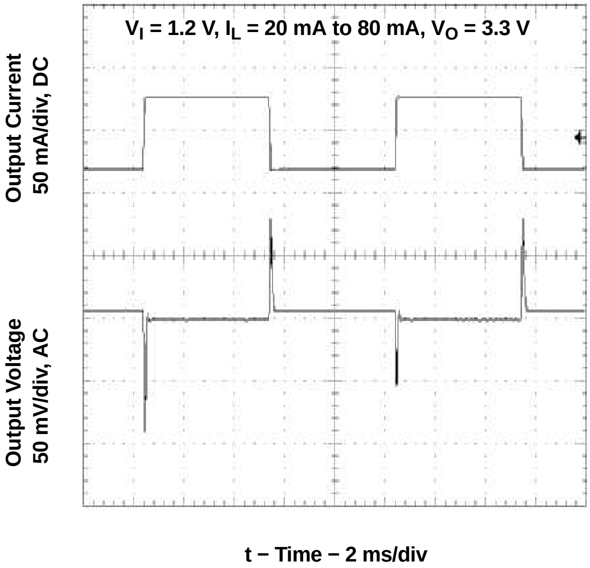
Figure 12.

TYPICAL CHARACTERISTICS (continued)



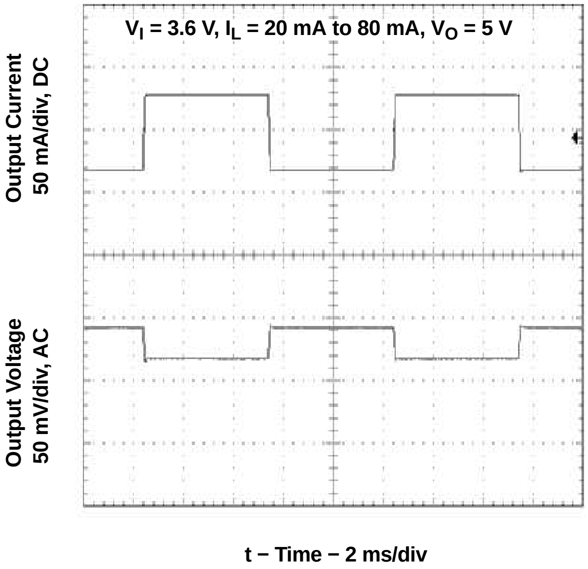
TPS61070
OUTPUT VOLTAGE IN POWER-SAVE MODE

Figure 13.



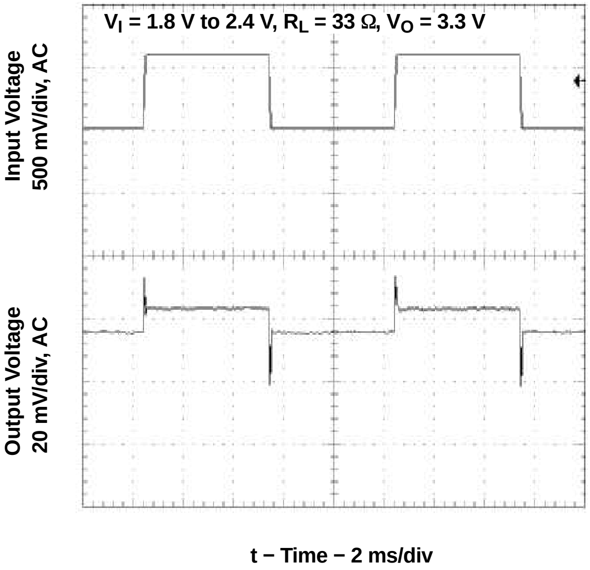
TPS61071
LOAD TRANSIENT RESPONSE

Figure 14.



TPS61071
LOAD TRANSIENT RESPONSE

Figure 15.



TPS61071
LINE TRANSIENT RESPONSE

Figure 16.

TYPICAL CHARACTERISTICS (continued)

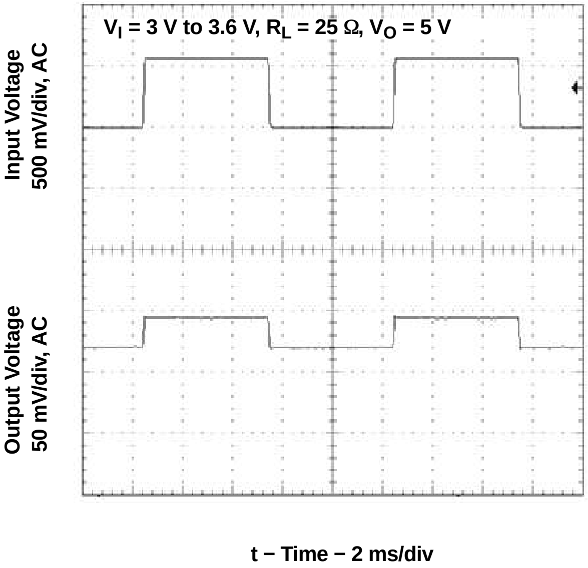

TPS61071
LINE TRANSIENT RESPONSE

Figure 17.

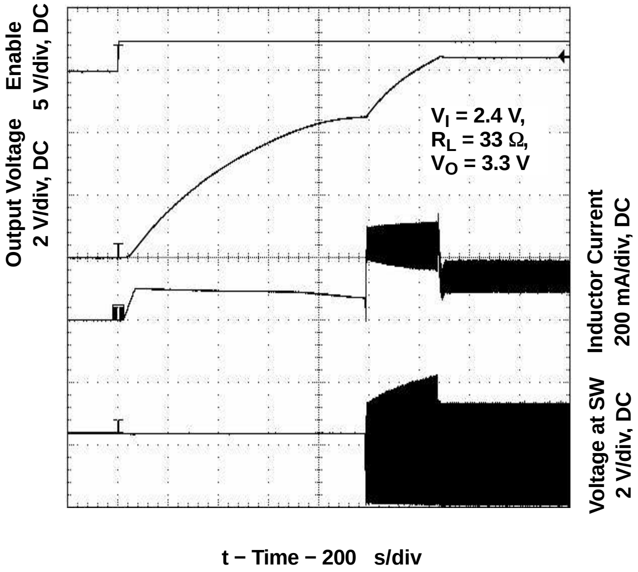

TPS61070
START-UP AFTER ENABLE

Figure 18.

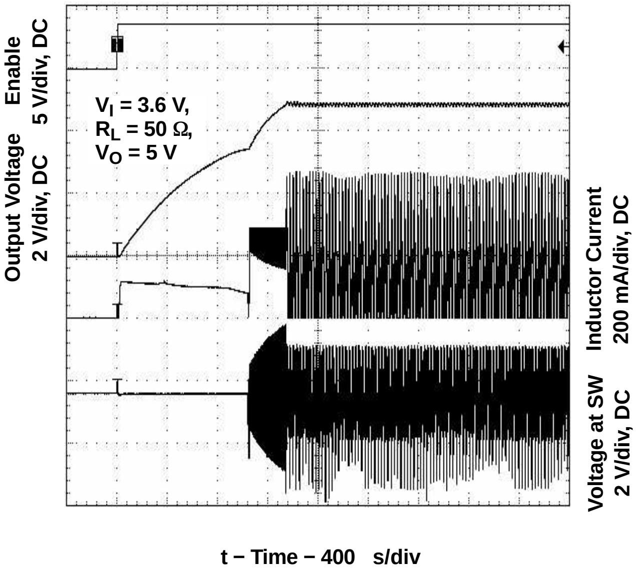

TPS61070
START-UP AFTER ENABLE

Figure 19.

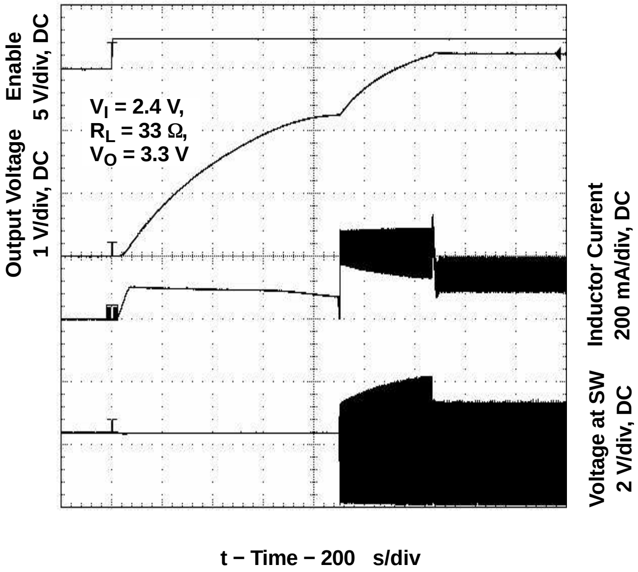

TPS61071
START-UP AFTER ENABLE

Figure 20.

TYPICAL CHARACTERISTICS (continued)

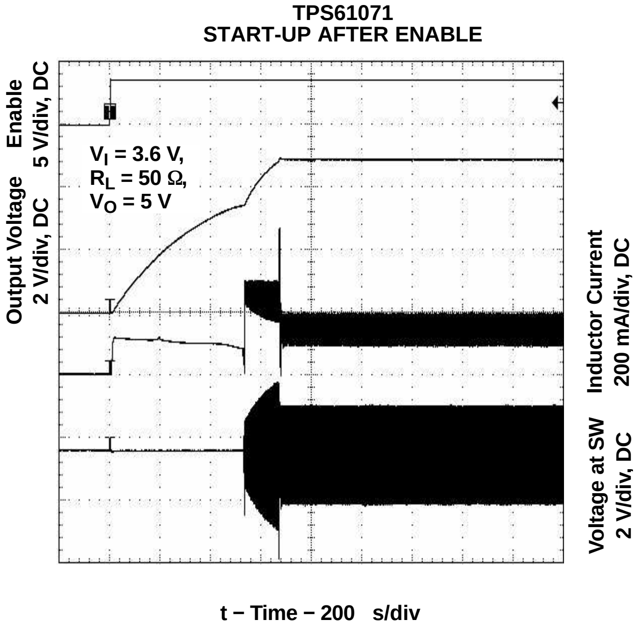


Figure 21.

DETAILED DESCRIPTION

CONTROLLER CIRCUIT

The controller circuit of the device is based on a fixed frequency multiple feedforward controller topology. Input voltage, output voltage, and voltage drop on the NMOS switch are monitored and forwarded to the regulator. So, changes in the operating conditions of the converter directly affect the duty cycle and must not take the indirect and slow way through the control loop and the error amplifier. The control loop, determined by the error amplifier, only has to handle small signal errors. The input is the feedback voltage on the FB pin. It is compared with the internal reference voltage to generate an accurate and stable output voltage.

The peak current of the NMOS switch is also sensed to limit the maximum current flowing through the switch and the inductor. The typical peak-current limit is set to 600 mA. An internal temperature sensor prevents the device from overheating due to excessive power dissipation.

Synchronous Rectifier

The device integrates an N-channel and a P-channel MOSFET transistor to realize a synchronous rectifier. Because the commonly used discrete Schottky rectifier is replaced with a low $r_{DS(on)}$ PMOS switch, the power conversion efficiency reaches values above 90%. A special circuit is applied to disconnect the load from the input during shutdown of the converter. In conventional synchronous rectifier circuits, the backgate diode of the high-side PMOS is forward biased in shutdown and allows current flowing from the battery to the output. However, this device uses a special circuit which takes the cathode of the backgate diode of the high-side PMOS and disconnects it from the source when the regulator is not enabled (EN = low).

The benefit of this feature for the system design engineer is that the battery is not depleted during shutdown of the converter. No additional components must be added to the design to make sure that the battery is disconnected from the output of the converter.

Device Enable

The device is put into operation when EN is set high. It is put into a shutdown mode when EN is set to GND. In shutdown mode, the regulator stops switching, all internal control circuitry including the low-battery comparator is switched off, and the load is isolated from the input (as described in the *Synchronous Rectifier Section*). This also means that the output voltage can drop below the input voltage during shutdown. During start-up of the converter, the duty cycle and the peak current are limited in order to avoid high-peak currents drawn from the battery.

Undervoltage Lockout

An undervoltage lockout function prevents the device from operating if the supply voltage on VBAT is lower than approximately 0.8 V. When in operation and the battery is being discharged, the device automatically enters the shutdown mode if the voltage on VBAT drops below approximately 0.8 V. This undervoltage lockout function is implemented in order to prevent the malfunctioning of the converter.

Soft Start

When the device enables, the internal start-up cycle starts with the first step, the precharge phase. During precharge, the rectifying switch is turned on until the output capacitor is charged to a value close to the input voltage. The rectifying switch is current limited during this phase. This also limits the output current under short-circuit conditions at the output. After charging the output capacitor to the input voltage, the device starts switching. If the input voltage is below 1.8 V, the device works with a fixed duty cycle of 70% until the output voltage reaches 1.8 V. Then the duty cycle is set depending on the input output voltage ratio. Until the output voltage reaches its nominal value, the boost switch current limit is set to 50% of its nominal value to avoid high-peak currents at the battery during start-up. As soon as the output voltage is reached, the regulator takes control, and the switch current limit is set back to 100%.

DETAILED DESCRIPTION (continued)

Power-Save Mode

The TPS61070 is capable of operating in two different modes. At light loads, when the inductor current becomes zero, it automatically enters the power-save mode to improve efficiency. In the power-save mode, the converter only operates when the output voltage trips below a set threshold voltage. It ramps up the output voltage with one or several pulses and returns to the power-save mode once the output voltage exceeds the set threshold voltage. If output power demand increases and the inductor current no longer goes below zero, the device again enters the fixed PWM mode. In this mode, there is no difference between the PWM only version TPS61071 and the power-save mode enabled version TPS61070.

APPLICATION INFORMATION

DESIGN PROCEDURE

The TPS6107x dc/dc converters are intended for systems powered by a single-cell, up to triple-cell alkaline, NiCd, NiMH battery with a typical terminal voltage between 0.9 V and 5.5 V. They can also be used in systems powered by one-cell Li-ion or Li-polymer with a typical voltage between 2.5 V and 4.2 V. Additionally, any other voltage source with a typical output voltage between 0.9 V and 5.5 V can power systems where the TPS6107x is used. Due to the nature of boost converters, only the output voltage regulation is maintained when the input voltage applied is lower than the programmed output voltage.

Programming the Output Voltage

The output voltage of the TPS61070 dc/dc converter can be adjusted with an external resistor divider. The typical value of the voltage at the FB pin is 500 mV. The maximum recommended value for the output voltage is 5.5 V. The current through the resistive divider should be about 100 times greater than the current into the FB pin. The typical current into the FB pin is 0.01 µA, and the voltage across R2 is typically 500 mV. Based on those two values, the recommended value for R2 should be lower than 500 kΩ, in order to set the divider current at 1 µA or higher. Because of internal compensation circuitry, the value for this resistor should be in the range of 200 kΩ. From that, the value of resistor R1, depending on the needed output voltage (V_O), can be calculated using Equation 1:

$$R1 \;/\; R2 \times \left(\frac{V_O}{V_{FB}} + 1\right) \;/\; 180\ k\theta \times \left(\frac{V_O}{500\ mV} + 1\right) \qquad (1)$$

For example, if an output voltage of 3.3 V is needed, a 1-MΩ resistor should be chosen for R1. If for any reason the value chosen for R2 is significantly lower than 200 kΩ, additional capacitance in parallel to R1 is recommended, because the device can show unstable regulation of the output voltage. The required capacitance value can be calculated using Equation 2:

$$C_{parR1} \;/\; 3\ pF \times \left(\frac{200\ k\theta}{R2} + 1\right) \qquad (2)$$

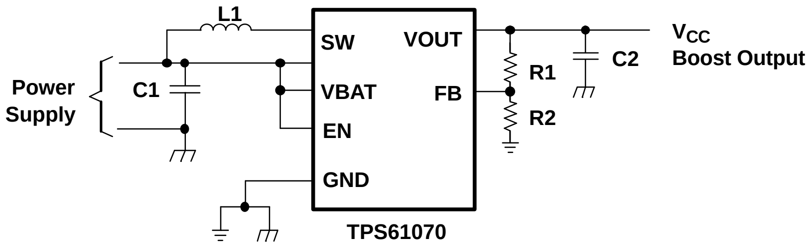


Figure 22. Typical Application Circuit for Adjustable Output Voltage Option

Inductor Selection

A boost converter normally requires two main passive components for storing energy during the conversion. A boost inductor and a storage capacitor at the output are required. To select the boost inductor, it is recommended to keep the possible peak inductor current below the current limit threshold of the power switch in the chosen configuration. For example, the current limit threshold of the TPS6107x's switch is 600 mA. The highest peak current through the inductor and the switch depends on the output load, the input (VBAT), and the output voltage (VOUT). Estimation of the maximum average inductor current is done using Equation 3:

$$I_L + I_O \times \frac{VOUT}{VBAT \times 0.8} \qquad (3)$$

For example, for an output current of 75 mA at 3.3 V, at least 340 mA of average current flows through the inductor at a minimum input voltage of 0.9 V.

The second parameter for choosing the inductor is the desired current ripple in the inductor. Normally, it is advisable to work with a ripple of less than 20% of the average inductor current. A smaller ripple reduces the magnetic hysteresis losses in the inductor, as well as output voltage ripple and EMI. But in the same way, regulation time rises at load changes. In addition, a larger inductor increases the total system costs. With these parameters, it is possible to calculate the value for the inductor by using Equation 4:

$$L \,/\, \frac{VBAT \times (VOUT \;+\; VBAT)}{\theta I_L \times f \times VOUT} \qquad (4)$$

Parameter *f* is the switching frequency and Δ I_L is the ripple current in the inductor, i.e., 40% × I_L. In this example, the desired inductor has the value of 4 µH. With this calculated value and the calculated currents, it is possible to choose a suitable inductor. In typical applications, a 4.7-µH inductance is recommended. The device has been optimized to operate with inductance values between 2.2 µH and 10 µH. Nevertheless, operation with higher inductance values may be possible in some applications. Detailed stability analysis is then recommended. Care must be taken because load transients and losses in the circuit can lead to higher currents as estimated in Equation 4. Also, the losses in the inductor caused by magnetic hysteresis losses and copper losses are a major parameter for total circuit efficiency.

The following inductor series from different suppliers have been used with the TPS6107x converters:

Table 1. List of Inductors

VENDOR	INDUCTOR SERIES
TDK	VLF3010
	VLF4012
Wurth Elektronik	744031xxx
	744042xxx
EPCOS	B82462-G4
Cooper Electronics Technologies	SD18
	SD20
Taiyo Yuden	CB2016B xxx
	CB2518B xxx

Capacitor Selection

Input Capacitor

At least a 10-µF input capacitor is recommended to improve transient behavior of the regulator and EMI behavior of the total power supply circuit. A ceramic capacitor or a tantalum capacitor with a 100-nF ceramic capacitor in parallel, placed close to the IC, is recommended.

Output Capacitor

The major parameter necessary to define the output capacitor is the maximum allowed output voltage ripple of the converter. This ripple is determined by two parameters of the capacitor, the capacitance and the ESR. It is possible to calculate the minimum capacitance needed for the defined ripple, supposing that the ESR is zero, by using Equation 5:

$$C_{min} \,/\, \frac{I_O \times \left(VOUT \;+\; VBAT\right)}{f \times \theta V \times VOUT} \qquad (5)$$

Parameter *f* is the switching frequency and ΔV is the maximum allowed ripple.

With a chosen ripple voltage of 10 mV, a minimum capacitance of 4.5 µF is needed. In this value range, ceramic capacitors are a good choice. The ESR and the additional ripple created are negligible. It is calculated using Equation 6:

$$\theta V_{ESR} + I_O \times R_{ESR} \tag{6}$$

The total ripple is the sum of the ripple caused by the capacitance and the ripple caused by the ESR of the capacitor. Additional ripple is caused by load transients. This means that the output capacitor has to completely supply the load during the charging phase of the inductor. The value of the output capacitance depends on the speed of the load transients and the load current during the load change. With the calculated minimum value of 4.5 µF and load transient considerations, the recommended output capacitance value is in a 10-µF range.

Care must be taken on capacitance loss caused by derating due to the applied dc voltage and the frequency characteristic of the capacitor. For example, larger form factor capacitors (in 1206 size) have their self resonant frequencies in the same frequency range as the TPS6107x operating frequency. So the effective capacitance of the capacitors used is significantly lower. Therefore, the recommendation is to use smaller capacitors in parallel instead of one larger capacitor.

Small Signal Stability

To analyze small signal stability in more detail, the small signal transfer function of the error amplifier and the regulator, which is given in Equation 7, can be used:

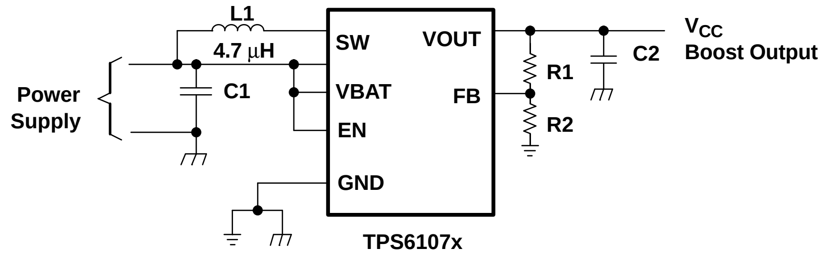
$$A_{(REG)} / \frac{d}{V_{(FB)}} / \frac{5 \times (R1 + R2)}{R2 \times (1 + i \times \omega \times 0.8\ \theta s)} \tag{7}$$

Layout Considerations

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 tracks. The input capacitor, output capacitor, and the inductor should be placed as close as possible to the IC. Use a common ground node for power ground and a different one for control ground to minimize the effects of ground noise. Connect these ground nodes at any place close to the ground pin of the IC.

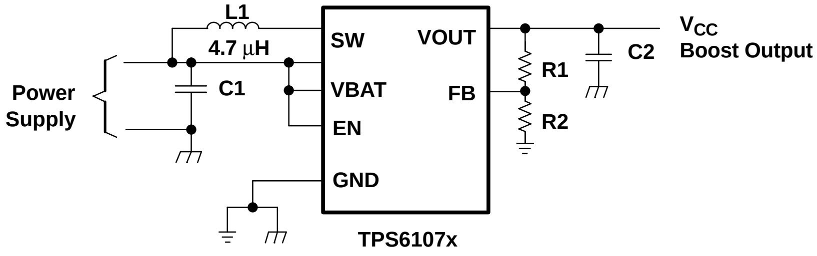
The feedback divider should be placed as close as possible to the ground pin of the IC. To lay out the control ground, it is recommended to use short traces as well, separated from the power ground traces. This avoids ground shift problems, which can occur due to superimposition of power ground current and control ground current.

APPLICATION EXAMPLES



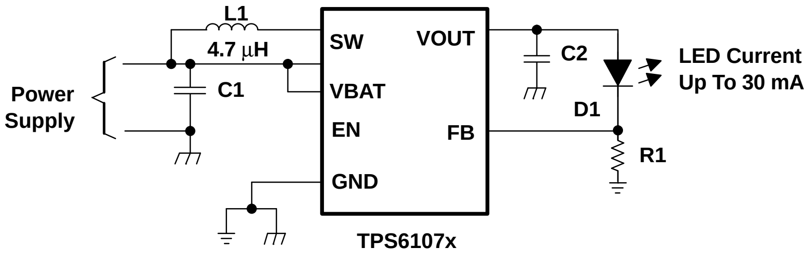
List of Components:
U1 = TPS61070DDC
L1 = Wurth Elektronik 744031004
C1 = 2 x 4.7 ΩF, 0603, X7R/X5R Ceramic
C2 = 2 x 4.7 ΩF, 0603, X7R/X5R Ceramic

Figure 23. Power Supply Solution for Maximum Output Power Operating from a Single or Dual Alkaline Cell



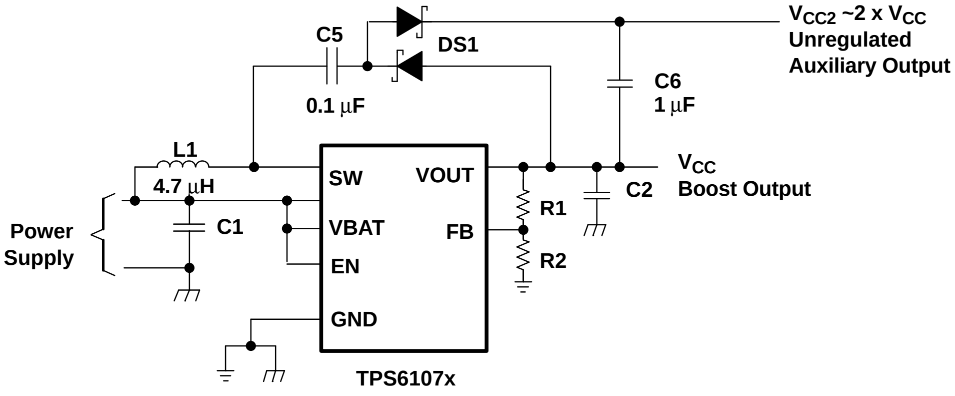
List of Components:
U1 = TPS61070DDC
L1 = Taiyo Yuden CB2016B4R7M
C1 = 1 x 4.7 ΩF, 0603, X7R/X5R Ceramic
C2 = 2 x 4.7 ΩF, 0603, X7R/X5R Ceramic

Figure 24. Power Supply Solution Having Small Total Solution Size



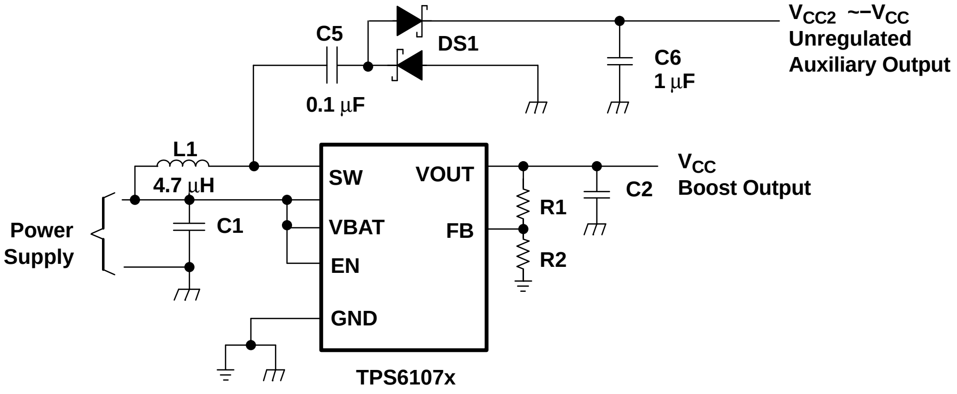
List of Components:
U1 = TPS61070DDC
L1 = Taiyo Yuden CB2016B4R7M
C1 = 1 x 4.7 ΩF, 0603, X7R/X5R Ceramic
C2 = 2 x 4.7 ΩF, 0603, X7R/X5R Ceramic

Figure 25. Power Supply Solution for Powering White LEDs in Lighting Applications



List of Components:
U1 = TPS61070DDC
L1 = Wurth Elektronik 744031004
C1 = 2 x 4.7 ΩF, 0603, X7R/X5R Ceramic
C2 = 2 x 4.7 ΩF, 0603, X7R/X5R Ceramic

Figure 26. Power Supply Solution With Auxiliary Positive Output Voltage



List of Components:
U1 = TPS61070DDC
L1 = Wurth Elektronik 744031004
C1 = 2 x 4.7 ΩF, 0603, X7R/X5R Ceramic
C2 = 2 x 4.7 ΩF, 0603, X7R/X5R Ceramic

Figure 27. Power Supply Solution With Auxiliary Negative Output Voltage

THERMAL INFORMATION

Implementation of integrated circuits in low-profile and fine-pitch surface-mount packages typically requires special attention to power dissipation. Many system-dependent issues such as thermal coupling, airflow, added heat sinks and convection surfaces, and the presence of other heat-generating components affect the power-dissipation limits of a given component.

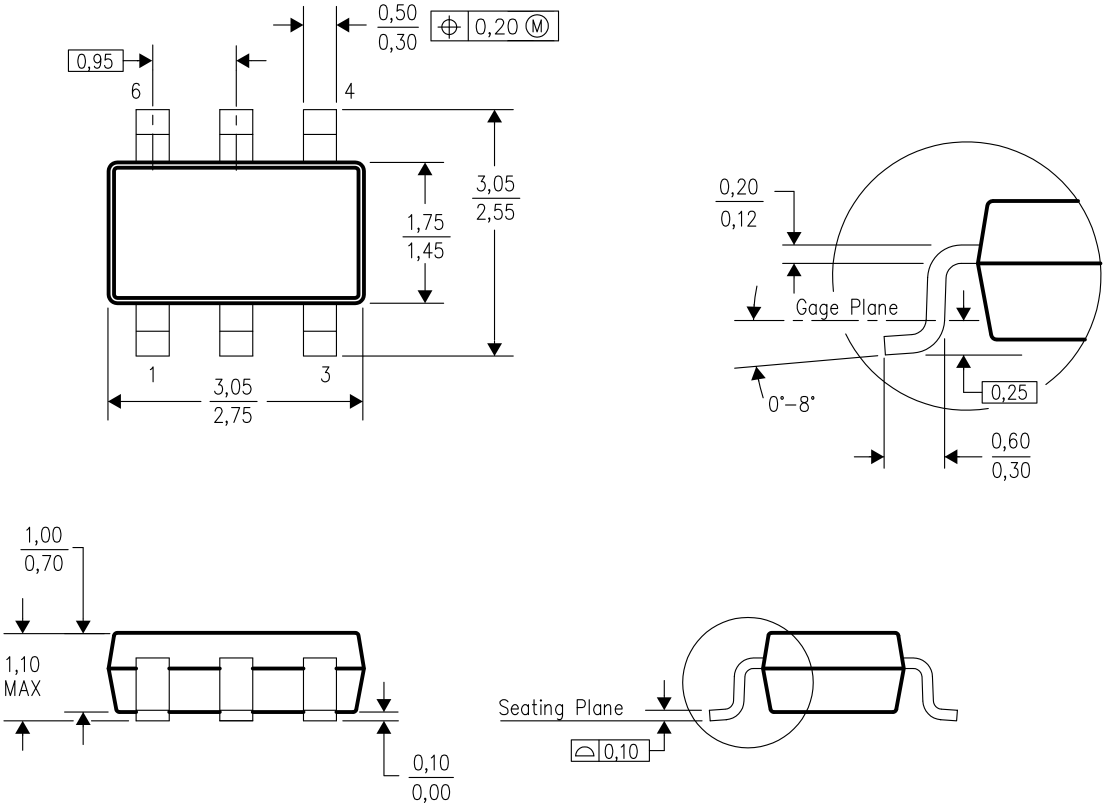
Three basic approaches for enhancing thermal performance follow.

- Improving the power dissipation capability of the PCB design
- Improving the thermal coupling of the component to the PCB
- Introducing airflow in the system

The maximum recommended junction temperature (T_J) of the TPS6107x devices is 125°C. The thermal resistance of the 6-pin thin SOT package (DDC) is $R_{\Theta JA}$ = 76°C/W. Specified regulator operation is assured to a maximum ambient temperature T_A of 85°C. Therefore, the maximum power dissipation is about 520 mW. More power can be dissipated if the maximum ambient temperature of the application is lower.

$$P_{D(MAX)} + \frac{T_{J(MAX)} \times T_A}{R_{\theta JA}} + \frac{125°C \times 85°C}{76\ °C/W} + 520\ \text{mW} \tag{8}$$

DDC (R–PDSO–G6) PLASTIC SMALL–OUTLINE



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NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion.
- D. Falls within JEDEC MO–193 variation AA (6 pin).

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