



February 2005

# LM2707 Inductive-Boost Series LED Driver with Programmable Oscillator Frequency

## General Description

The LM2707 is a magnetic boost regulator specifically designed for white LED drive applications. Tightly regulated LED currents, exceptional LED brightness uniformity, and very high LED-drive power efficiency (>80%) can all be achieved by stacking the LEDs in series between the LM2707 output and the low-voltage feedback pin (0.515V).

The LM2707 requires only a few small external components. A small inductor with a low saturation current rating can safely be used because the tightly controlled current limit circuit prevents large inductor current spikes, even at start-up. The output capacitor can also be small due to the tightly controlled output over-voltage protection circuit.

The LM2707 is an excellent choice for display backlighting and other general-purpose lighting functions in battery powered applications. The 2.3V-to-7V input voltage range of the device easily accommodates single-cell Lithium-Ion batteries and battery chargers.

The LM2707 features 18V output capability, PFM regulation, and a high-current switching transistor (400mA peak). These characteristics allow the part to drive a series string of 2-to-4 LEDs with forward currents between 0 and 40mA. LED brightness can be adjusted dynamically simply by applying a PWM signal to the enable (EN) pin. The PWM signal can be as fast as 50kHz because the LM2707 has a fast turn-on time.

In addition to LED-drive applications, the LM2707 can also be used as a general purpose DC-DC voltage regulator in boost converter applications.

The LM2707 is available in a SOT23-8 surface mount package.

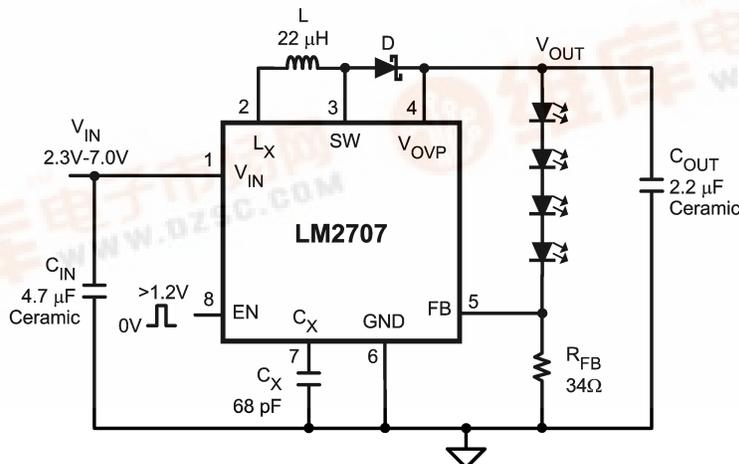
## Features

- Excellent LED Drive Capability:
  - 3 LED String: 30mA
  - 4 LED String: 20 mA
  - 6 LEDs (2 strings of 3): 15 mA
- Very High LED Drive Efficiency: > 80%
- Low Feedback Voltage: 515mV
- Low-Resistance NMOS Power Switch: 0.6Ω
- High-Speed PWM Brightness Control Capability
- Over-Voltage Protection (18V min, 19V typ, 20V max)
- Inrush and Inductor Current Limiting
- 2.3V - 7V Input Voltage Range
- Requires Only a Few External Components
- No External Compensation Needed
- Programmable Oscillator Frequency
- ON/OFF Pin
- Small SOT23-8 Package

## Applications

- White LED Drive for Display Backlights
- LED Flashlights
- General Purpose LED Lighting
- Step-up DC/DC Voltage Conversion

## Typical Application Circuit



20099225

LM2707 Inductive-Boost Series LED Driver with Programmable Oscillator Frequency





**Absolute Maximum Ratings** (Notes 1, 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

$V_{IN}$ , FB, and EN pins	-0.3V to 7.5V
SW and $V_{OVP}$ pins	-0.3V to 21V
Continuous Power Dissipation ( $T_A = 25^\circ\text{C}$ )	800mW
Switch Peak Current	400mA
Junction Temperature ( $T_{J-MAX}$ )	150°C
Storage Temperature Range	-65°C to +150°C
Maximum Lead Temperature (Soldering)	(Note 3)
ESD Rating (Note 4)	
Human Body Model:	2kV
Machine Model:	200V

**Operating Ratings** (Notes 1, 2)

Input Voltage Range	2.3V to 7.0V
Minimum $C_X$ Capacitance	10pF
Junction Temperature ( $T_J$ ) Range	-30°C to +125°C
Ambient Temperature ( $T_A$ ) Range	-30°C to +85°C
(Note 5)	

**Thermal Properties**

Junction-to-Ambient Thermal Resistance ( $\theta_{JA}$ ) (Note 6)	125°C/W
---	---------

**Electrical Characteristics** (Notes 2, 7)

Unless otherwise specified:  $V_{IN} = 3.0\text{V}$ ,  $L_X = \text{Open}$ ,  $V_{OVP} = \text{Open}$ ,  $V_{FB} = \text{GND}$ ,  $C_X = 300\text{pF}$ ,  $V_{EN} = V_{IN}$ ,  $T_A = 25^\circ\text{C}$ .

Symbol	Parameter	Condition	Min	Typ	Max	Units
<b>Oscillator Frequency Programming (<math>C_X</math> pin)</b>						
$I_{chg}$	$C_X$ Charging Current	$V_{CX} = 0.1\text{V}$ , $V_{FB} = 1\text{V}$	16	24	30	$\mu\text{A}$
$I_{dis}$	$C_X$ Discharging Current	$V_{CX} = 1.0\text{V}$ , $V_{FB} = 1\text{V}$	35	52	65	$\mu\text{A}$
$I_{dis}/I_{chg}$	Charge and Discharge Current Ratio			2.2		
$V_{CX, High}$	$C_X$ Threshold Voltage +		810	860	910	mV
$V_{CX, Low}$	$C_X$ Threshold Voltage -		260	300	340	mV
$V_{OSC}$	$C_X$ Oscillation Voltage	$(V_{CX, High}) - (V_{CX, Low})$	520	560	600	mV
<b>Current Limiting Comparator (<math>L_X</math> pin)</b>						
$I_{LIMIT}$	Inductor Current Limit	(Note 8)	220	260	300	mA
$R_{IN}$	Pin 1-2 Total Resistance	Measured between pin 1 and pin 2	380	440	500	$\text{m}\Omega$
$R_{SC}$	Internal Effective Resistance for Inductor Current Limit Sense	(Notes 9, 10)		300		$\text{m}\Omega$
<b>Output Switch Section (SW pin)</b>						
$V_{sw, DS}$	Output Transistor Drain-to-Source Voltage	$V_{CX} = 0.1\text{V}$ , $I_{SW} = 200\text{mA}$		0.12	0.22	V
$R_{DS-ON}$	Switch ON Resistance $R_{DS-ON} = V_{sw, DS} \div I_{SW}$	$V_{CX} = 0.1\text{V}$ , $I_{SW} = 200\text{mA}$		0.60	1.1	$\Omega$
$I_{sw, Off}$	Output Transistor Off Leak Current	$V_{FB} = 1\text{V}$ , $V_{SW} = 20\text{V}$		0.01	2.0	$\mu\text{A}$
<b>Feedback Comparator section (FB pin)</b>						
$V_{ref}$	Reference Voltage		0.495	0.515	0.535	V
$I_{FBin}$	FB Pin Output Current	$V_{FB} = 0.4\text{V}$	-0.2	-0.075		$\mu\text{A}$
<b>Shutdown Section (EN pin)</b>						
$V_{EN, High}$	EN Input Voltage +	ON mode	1.2		7.0	V
$V_{EN, Low}$	EN Input Voltage -	Shutdown Mode			0.3	V
$I_{ENin}$	EN pin Input Bias Current	$V_{EN} = 3.0\text{V}$		25	40	$\mu\text{A}$

## Electrical Characteristics (Notes 2, 7) (Continued)

Unless otherwise specified:  $V_{IN} = 3.0V$ ,  $L_x = \text{Open}$ ,  $V_{OVP} = \text{Open}$ ,  $V_{FB} = \text{GND}$ ,  $C_x = 300pF$ ,  $V_{EN} = V_{IN}$ ,  $T_A = 25^\circ C$ .

Symbol	Parameter	Condition	Min	Typ	Max	Units
<b>Open Circuit Protection Section (<math>V_{OVP}</math> pin)</b>						
$V_{OVP}$	Output Over-Voltage Protection (Open Circuit)	Protection Activation Threshold	17.5	18.75	20.0	V
		Protection Deactivation Threshold	17.0	18.25	19.5	V
		Hysteresis		0.5		V
$I_{OVP}$	$V_{OVP}$ Pin Input Current	$V_{OVP} = 18.5V$ , $V_{EN} = 3V$		50	100	$\mu A$
		$V_{OVP} = 18.5V$ , $V_{EN} = 0V$		0.03		$\mu A$
<b>Input Voltage Section (<math>V_{IN}</math> pin)</b>						
$V_{IN, Low}$	Undervoltage Lockout (Low Voltage Stop)	Lockout Deactivation Threshold	1.8	2.0	2.3	V
		Lockout Activation Threshold	1.7	1.9	2.2	V
		Hysteresis		0.1		V
$I_{IN, Off}$	Shutdown Supply Current	$V_{EN} = 0.3V$		0.01	1	$\mu A$
$I_{IN, On}$	Quiescent Supply Current	$V_{FB} = 1.0V$	0.2	0.5	0.8	mA

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the component may occur. Operating Ratings are conditions under which operation of the device is guaranteed. Operating Ratings do not imply guaranteed performance limits. For guaranteed performance limits and associated test conditions, see the Electrical Characteristics tables.

**Note 2:** All voltages are with respect to the potential at the GND pin.

**Note 3:** For detailed soldering specifications and information, please consult the National Semiconductor Application Note titled: "Mounting of Surface Mount Components".

**Note 4:** The Human body model is a 100pF capacitor discharged through a 1.5k $\Omega$  resistor into each pin. (MIL-STD-883 3015.7) The machine model is a 200pF capacitor discharged directly into each pin. (EAIJ)

**Note 5:** In applications where high power dissipation and/or poor package thermal resistance is present, the maximum ambient temperature may have to be derated. Maximum ambient temperature ( $T_{A-MAX}$ ) is dependent on the maximum operating junction temperature ( $T_{J-MAX-OP} = 125^\circ C$ ), the maximum power dissipation of the device in the application ( $P_{D-MAX}$ ), and the junction-to ambient thermal resistance of the part/package in the application ( $\theta_{JA}$ ), as given by the following equation:  $T_{A-MAX} = T_{J-MAX-OP} - (\theta_{JA} \times P_{D-MAX})$ .

**Note 6:** Junction-to-ambient thermal resistance ( $\theta_{JA}$ ) is highly application and board-layout dependent. The 125 $^\circ C/W$  figure provided was measured on a 4-layer test board conforming to JEDEC standards. In applications where high maximum power dissipation exists, special care must be paid to thermal dissipation issues when designing the board layout.

**Note 7:** Min and Max limits are guaranteed by design, test, or statistical analysis. Typical (Typ) numbers are not guaranteed, but do represent the most likely norm.

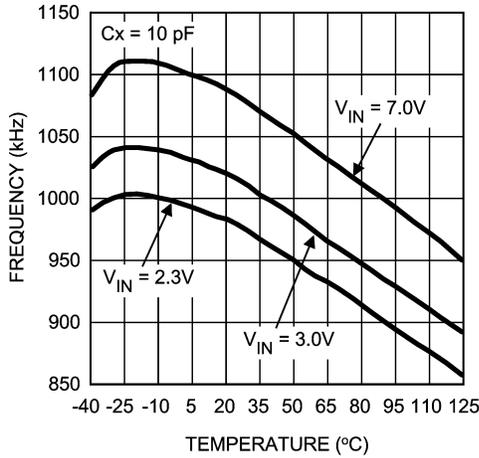
**Note 8:**  $I_{LIMIT}$ : The value of current source  $I_L$  (DC measurement) when the switching operation is stopped by the  $I_S$  comparator.

**Note 9:**  $R_{SC}$ : Guaranteed by the design equation:  $I_{LIMIT} = \{ 0.1V - [(2.3V \times V_{IN}) / 300] \} / R_{SC}$

**Note 10:** Do not connect the output circuit directly to GND:  $R_{SC}$  might be damaged. (Excessive current will pass through  $R_{SC}$ , the Schottky Diode, and the coil.)

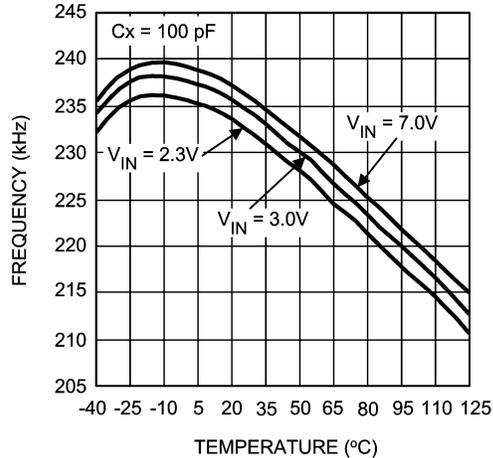
**Typical Performance Characteristics** Unless otherwise specified:  $V_{IN} = 3.0V$ ,  $V_{EN} = 3.0V$ ,  $L = 22\mu H$  (Coilcraft DT1608C-223),  $D = MBR0520L$  (Vishay),  $C_{IN} = 1.0\mu F$ ,  $C_{OUT} = 2x1\mu F$ ,  $C_x = 68pF$ ,  $T_A = 25^\circ C$ .

**Oscillator Frequency vs. Temperature**  
 $C_x = 10pF$



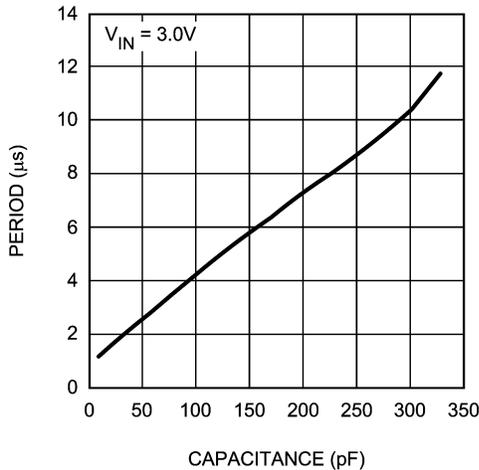
20099221

**Oscillator Frequency vs. Temperature**  
 $C_x = 100pF$



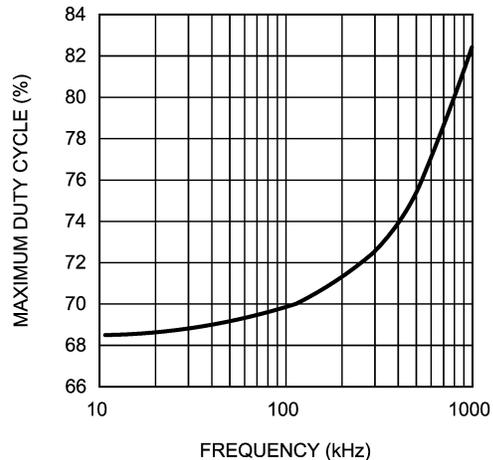
20099220

**Oscillator Period vs. Cx Capacitance**



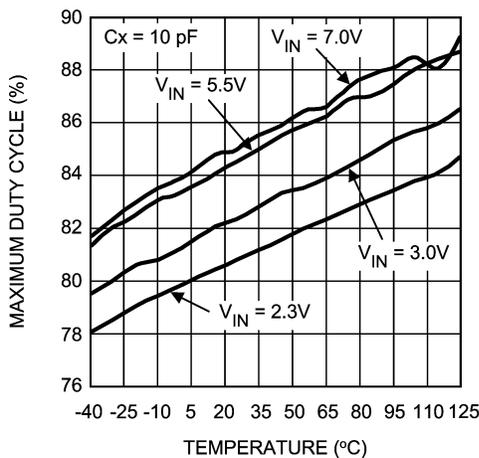
20099215

**Maximum Duty Cycle vs. Oscillator Frequency**



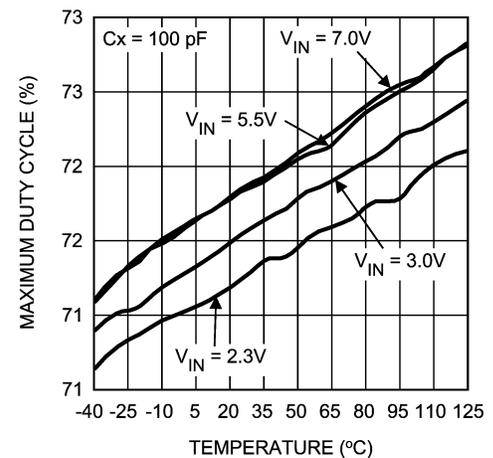
20099222

**Maximum Duty Cycle vs. Temperature**  
 $C_x = 10pF$



20099216

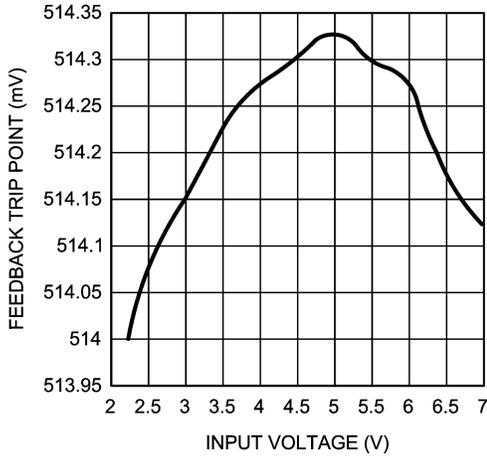
**Maximum Duty Cycle vs. Temperature**  
 $C_x = 100pF$



20099217

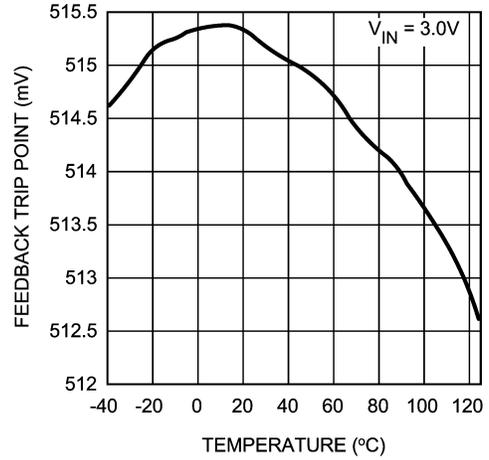
**Typical Performance Characteristics** Unless otherwise specified:  $V_{IN} = 3.0V$ ,  $V_{EN} = 3.0V$ ,  $L = 22\mu H$  (Coilcraft DT1608C-223),  $D = MBR0520L$  (Vishay),  $C_{IN} = 1.0\mu F$ ,  $C_{OUT} = 2 \times 1\mu F$ ,  $C_x = 68pF$ ,  $T_A = 25^\circ C$ . (Continued)

**Feedback Trip Point vs. Supply Voltage**



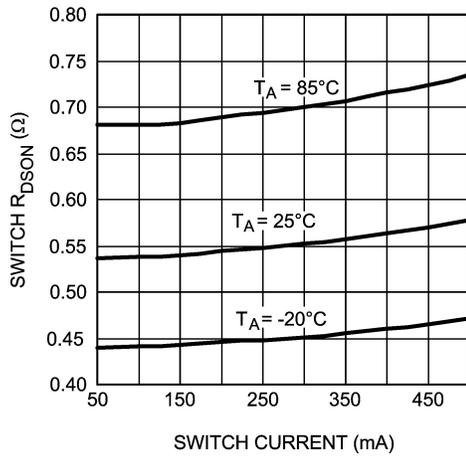
20099213

**Feedback Trip Point vs. Temperature**



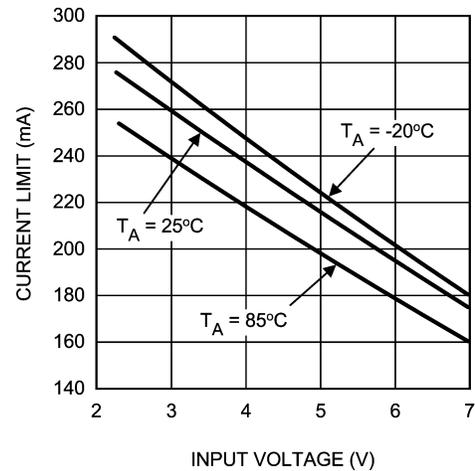
20099212

**Switch Resistance ( $R_{DS-ON}$ ) vs. Switch Current**



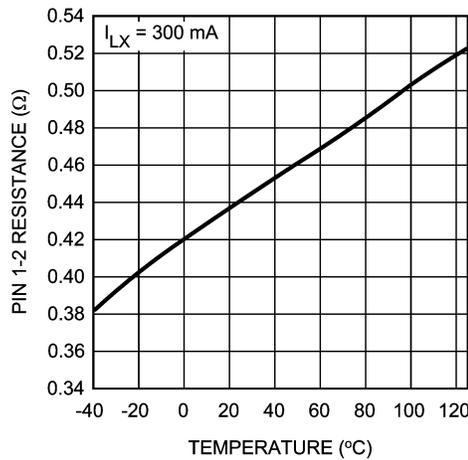
20099203

**Inductor Current Limit vs. Supply Voltage**



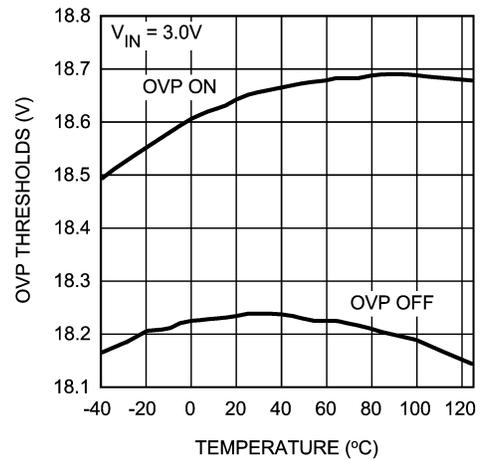
20099214

**Pin 1-2 Resistance vs. Temperature**



20099210

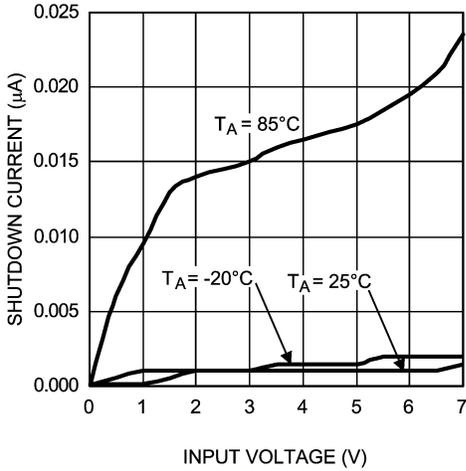
**$V_{OVP}$  Thresholds vs. Temperature**



20099211

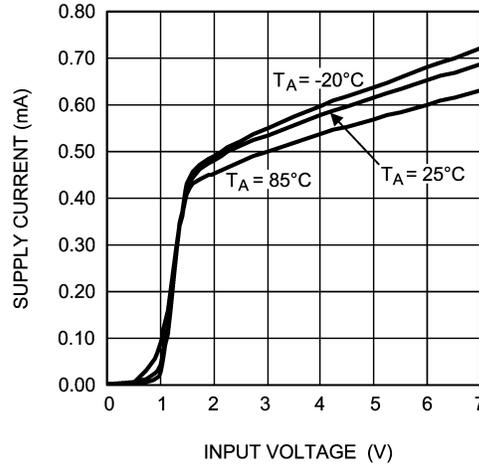
**Typical Performance Characteristics** Unless otherwise specified:  $V_{IN} = 3.0V$ ,  $V_{EN} = 3.0V$ ,  $L = 22\mu H$  (Coilcraft DT1608C-223),  $D = MBR0520L$  (Vishay),  $C_{IN} = 1.0\mu F$ ,  $C_{OUT} = 2 \times 1\mu F$ ,  $C_x = 68pF$ ,  $T_A = 25^\circ C$ . (Continued)

**Shutdown Supply Current vs. Supply Voltage**



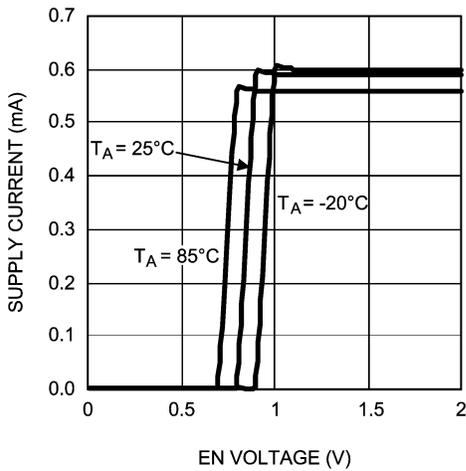
20099205

**Quiescent Supply Current vs. Supply Voltage**  
 $V_{FB} = 1V$



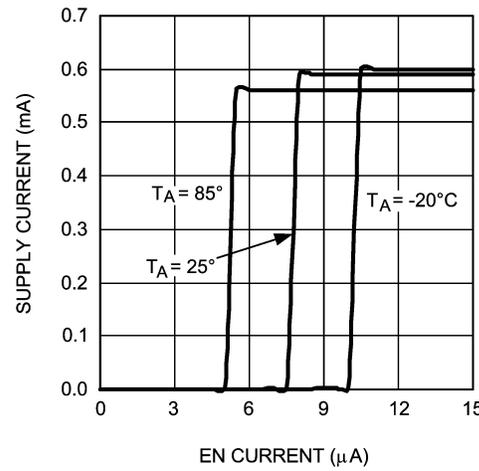
20099204

**Supply Current vs. EN Input Voltage**



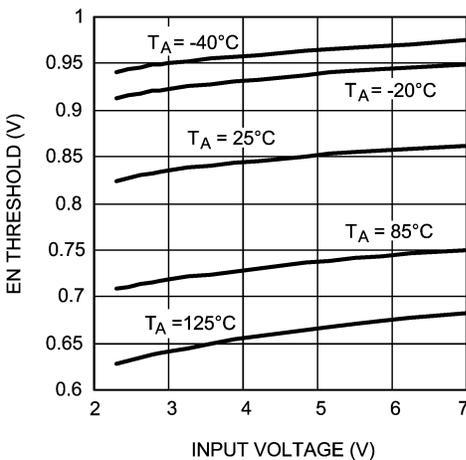
20099207

**Supply Current vs. EN Input Bias Current**



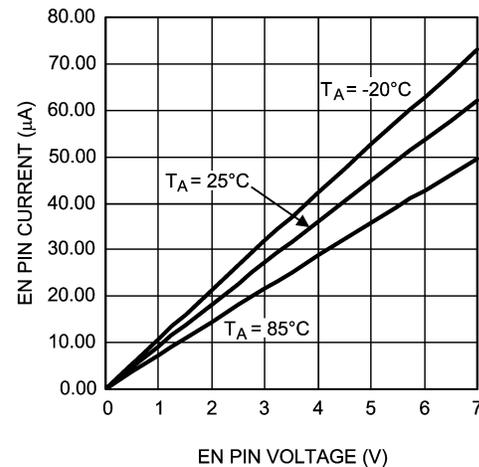
20099206

**EN Threshold vs. Supply Voltage**



20099201

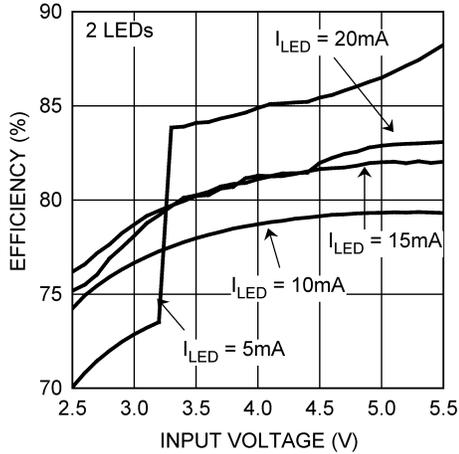
**EN Input Bias Current vs. EN Input Voltage**



20099202

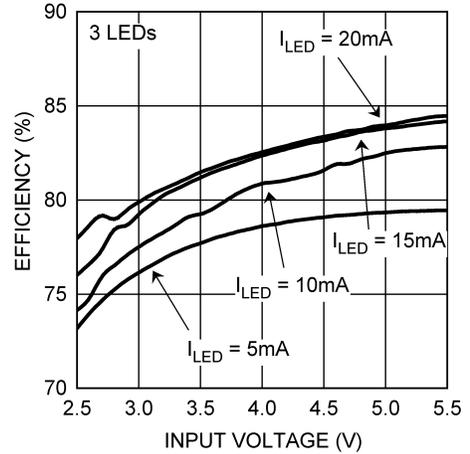
**Typical Performance Characteristics** Unless otherwise specified:  $V_{IN} = 3.0V$ ,  $V_{EN} = 3.0V$ ,  $L = 22\mu H$  (Coilcraft DT1608C-223),  $D = MBR0520L$  (Vishay),  $C_{IN} = 1.0\mu F$ ,  $C_{OUT} = 2 \times 1\mu F$ ,  $C_x = 68pF$ ,  $T_A = 25^\circ C$ . (Continued)

**LED Drive Efficiency vs. Supply Voltage**  
2 LEDs (Note 11)



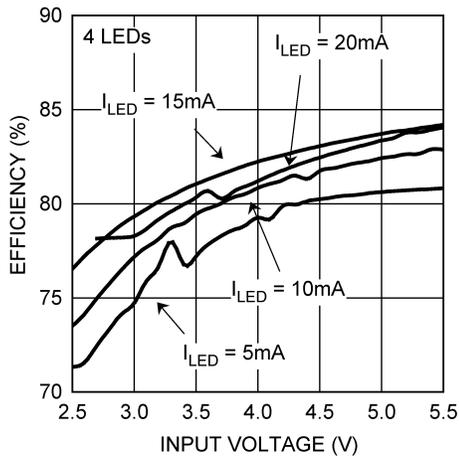
20099218

**LED Drive Efficiency vs. Supply Voltage**  
3 LEDs (Note 11)



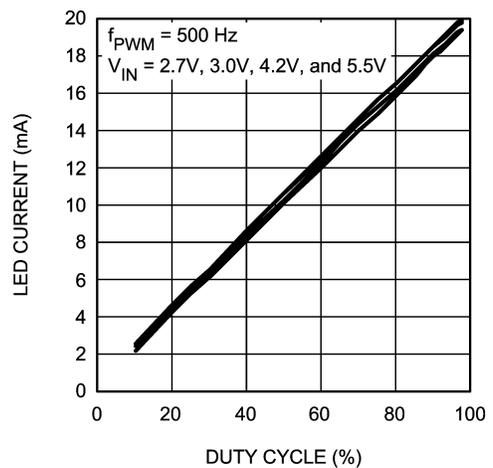
20099219

**LED Drive Efficiency vs. Supply Voltage**  
4 LEDs (Note 11)



20099253

**LED Current vs. Duty Cycle**

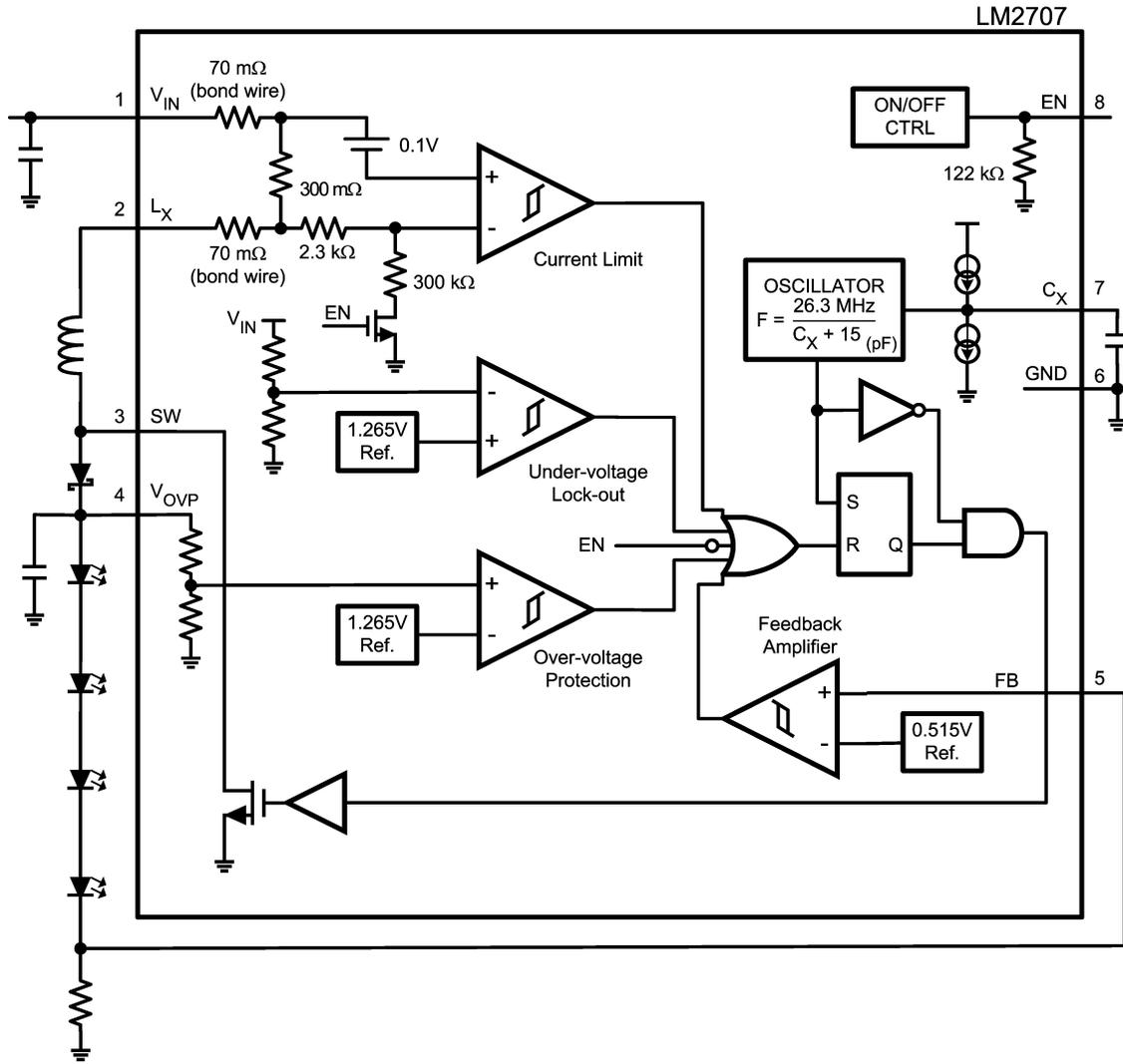


20099209

\* 20mA, 4-LED operation requires increasing the current limit.  
A  $1\Omega$  resistor was placed between the  $V_{IN}$  and  $L_x$  pins.

**Note 11:** LED drive efficiency is the ratio of the power consumed by the LEDs to the power drawn at the LM2707 input ( $E = P_{LEDs} / P_{IN}$ ). Approximate LED forward voltage characteristics of the LEDs used for the efficiency curve data:  $I_F = 5mA$ :  $V_F = 3.1V$ ;  $I_F = 10mA$ :  $V_F = 3.3V$ ;  $I_F = 15mA$ :  $V_F = 3.5V$ ;  $I_F = 20mA$ :  $V_F = 3.7V$ .

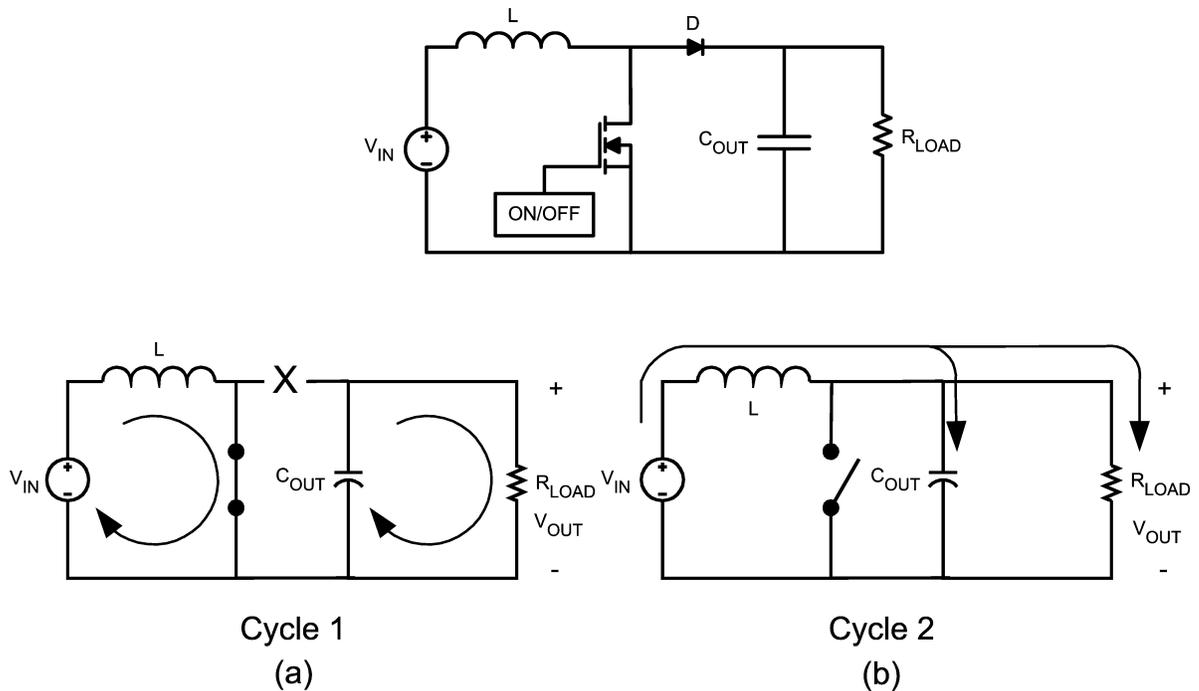
Block Diagram



20099227

FIGURE 1. LM2707 Block Diagram

## Simplified Switching Circuit



20099228

FIGURE 2. LM2707 Simplified Switching Circuit

## Product Description

### OVERVIEW

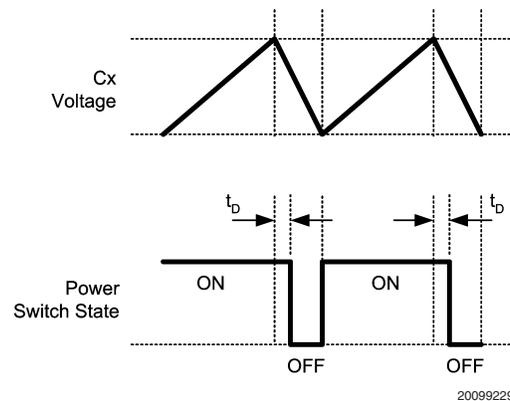
The LM2707 is a magnetic switch-mode boost converter that has been designed specifically for driving white LEDs. The device is an asynchronous boost regulator that uses a low-resistance internal NFET power transistor and an external rectifier diode. An internal high-power gate driver quickly turns the power switch ON and OFF.

Operation of the LM2707 can be best understood by referring to the block diagram of *Figure 1*, the simplified switching circuit in *Figure 2*, and the switching waveforms in *Figure 3*. The part regulates the feedback voltage with pulse-frequency-modulated (PFM) control. The key blocks in this control circuit are the R-S latch, the oscillator, and the feedback error amplifier. Several sense-and-control circuit blocks, including the oscillator and the error amplifier, are inputs to the R-S latch. The output of the R-S latch is the control signal for the power transistor gate driver. The power transistor turns ON and OFF at a frequency and duty cycle that is generated by the oscillator. The oscillator frequency can be programmed with an external capacitor ( $C_x$ ). The part switches continuously until one of the LM2707 sense circuits asserts a reset signal on the R-S latch.

The error amplifier resets the R-S latch when the output feedback voltage is above the 515mV (typ.) reference voltage. The part will idle in a low-power state until the feedback voltage falls below the reference voltage. At this point, the oscillator signal again becomes the output signal of the R-S latch, and switching resumes.

In addition to the feedback circuit, a few other internal protection and control circuits stop switching by overriding the

oscillator signal at the R-S latch. A current limit circuit brings switching to a halt when current through the power switch becomes excessive. Similar interrupts in switching are triggered by an over-voltage protection circuit on the output and an under-voltage lockout circuit on the input. An external shutdown signal can also be applied to place the LM2707 in a low-power shutdown mode.



20099229

FIGURE 3.  $C_x$  Oscillator Waveform and Power Switch Operation

### PROGRAMMABLE OSCILLATOR

The LM2707 contains an oscillator with an internally fixed duty cycle. The frequency of the oscillator is programmed externally with capacitor  $C_x$ . The oscillator frequency is:

## Product Description (Continued)

$$F_{OSC} = \frac{26.3 \text{ MHz}}{15 + C_X \text{ (pF)}}$$

An example with  $C_X = 68\text{pF}$ :

$$F_{OSC} = 26.3\text{MHz} / (15 + 68) = 317\text{kHz.}$$

The minimum recommended  $C_X$  capacitance is 10pF.

The rise time ( $t_r$ ) of the  $C_X$  signal is 2.2x longer than the fall time ( $t_f$ ). This gives an oscillator duty cycle ( $D_{OSC}$ ) of 0.69. The duty cycle of the switching converter ( $D_{SW}$ ) is actually slightly greater than the duty cycle of the oscillator because there is a delay ( $t_D$ ) of approximately 200ns in turning off the power transistor.

$$D_{OSC} = 0.69$$

$$T = \frac{1}{F_{OSC}} = t_r + t_f$$

$$t_r = 2.2 \times t_f = D_{OSC} \times T$$

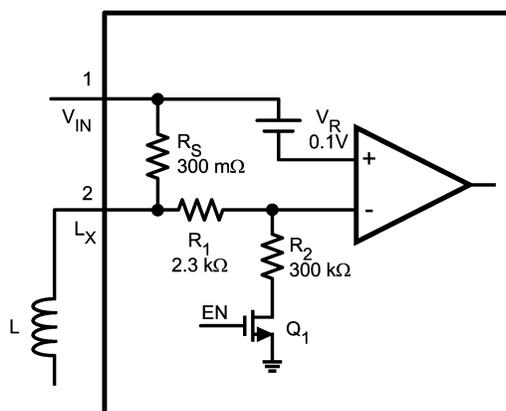
$$t_{ON} = t_r + t_D = (D_{OSC} \times T) + 200 \text{ ns}$$

$$D_{SW} = \frac{t_{ON}}{T} = D_{OSC} + (200 \text{ ns} \times F_{OSC})$$

The output of the oscillator connects to the R-S latch. When the reset signal of the latch is low, the oscillator signal becomes the ON/OFF signal for the power transistor, as described in the previous section.

### CURRENT LIMIT

The LM2707 current limit circuit senses the current through the inductor and interrupts switching when the current limit threshold is exceeded. The current limit circuit is shown in Figure 4.



20099230

FIGURE 4. LM2707 Internal Current Limit Circuit

The current limit circuit operates by comparing the voltage across sense resistor  $R_S$  to a 100mV (typ.) reference voltage  $V_R$ . Resistors  $R_1$  and  $R_2$  provide an input-voltage component to the current limit that causes the current limit to be lower at higher input voltages.

The current limit threshold can be calculated by determining when the voltages on the current limit comparator inputs are equal:

$$(V_+ - V_-) = 0 = (I_{LIMIT} \times R_S) + \left( \frac{V_{IN}}{R_2} \times R_1 \right) - 0.1V$$

$$I_{LIMIT} \approx \frac{1}{0.3\Omega} \times \left[ 0.1V - \left( \frac{2.3}{300} \times V_{IN} \right) \right]$$

$$\approx 330 \text{ mA} - (V_{IN} \times 25.5 \text{ mA/V})$$

An example: when  $V_{IN} = 4.0V$ ,  $I_{LIMIT} \approx 228\text{mA}$ .

When the current limit comparator trips, the comparator output causes the R-S latch to reset, and the power transistor is turned off. The transistor does not turn off immediately, though. There is a 200ns (typ.) delay between when the comparator trips and the power transistor turns off. Because of this delay, the peak inductor current rises above the current limit threshold. Peak inductor current is discussed and calculated in the section to follow: *Peak Inductor Current*.

The transistor Q1 in Figure 4 opens when the EN signal is low, blocking the current path from input to ground through resistors  $R_S$ ,  $R_1$ , and  $R_2$ . This keeps the input current very low during shutdown.

### PEAK INDUCTOR CURRENT

When conditions exist such that current limit is not reached during normal steady-state operation, peak inductor current is determined by the power switch ON time and can be predicted with the following equation:

$$I_{L-PK} \approx \left( \frac{V_{IN}}{L} \right) \times t_{ON}$$

$V_{IN}$ : Input voltage (Note 12)

$L$ : Inductance

$t_{ON}$ : Switch ON time. (See the *Programmable Oscillator* section)

An example --  $V_{IN} = 3.0V$ ,  $L = 22\mu\text{H}$ ,  $C_X = 38\text{pF}$ :

$$F_{SW} = \frac{26.3 \text{ MHz}}{15 + C_X \text{ (pF)}} = \frac{26.3 \text{ MHz}}{15 + 38} = 500 \text{ kHz}$$

$$t_{ON} = \frac{0.69}{500 \text{ kHz}} + 0.2 \mu\text{s} = 1.6 \mu\text{s}$$

$$I_{L-PK} = \frac{3.0V}{22 \mu\text{H}} \times 1.6 \mu\text{s} = 220 \text{ mA}$$

When the current limit is engaged before the switch is turned off by the oscillator, the peak inductor current of the circuit ( $I_{L-PK-LIMIT}$ ) is determined by the current limit value and the turn-off delay of the power switch:

$$I_{L-PK-LIMIT} \approx I_{LIMIT} + \left( \frac{V_{IN}}{L} \times t_D \right)$$

$I_{LIMIT}$ : Current Limit -- 330mA - ( $V_{IN} \times 25.5\text{mA/V}$ )

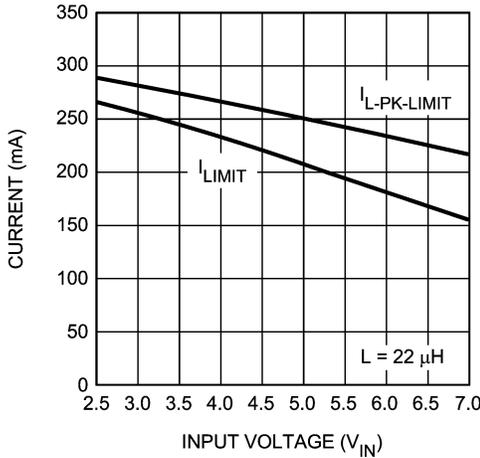
$t_D$ : Power transistor turn-off delay (200ns typ.)

An example --  $V_{IN} = 3.6V$ ,  $L = 22\mu\text{H}$ :

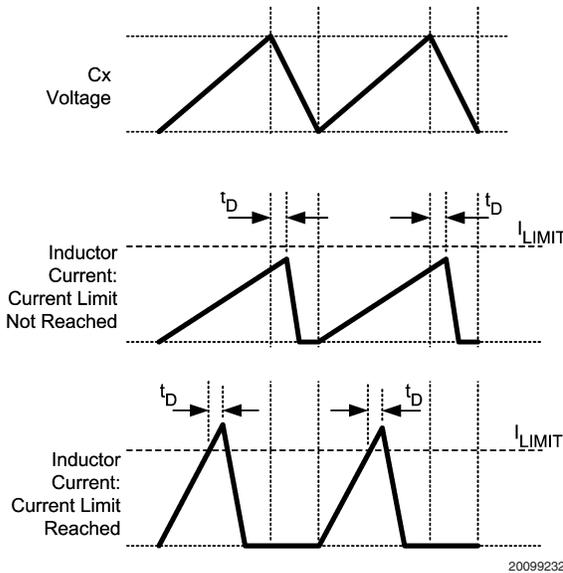
**Product Description** (Continued)

$$I_{L-PK-LIMIT} \approx 0.33A - (3.6V \times 0.025A/V) + \left( \frac{3.6V}{22 \mu H} \times 0.2 \mu s \right) \approx 238 \text{ mA}$$

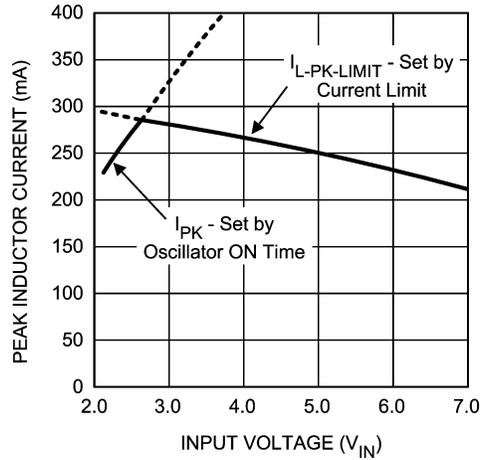
Figure 5 graphs the relationship between inductor current and current limit. Figure 6 plots ideal inductor current waveforms to illustrate inductor current behavior. Figure 7 gives peak inductor current versus input voltage and shows the two regions where the oscillator and current limit, respectively, determine peak inductor current.



**FIGURE 5. Peak Inductor Current and Current Limit vs. Input Voltage**



**FIGURE 6. Ideal Inductor Current Waveforms**

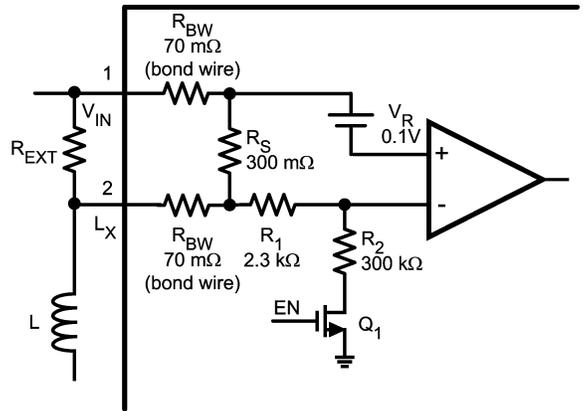


**FIGURE 7. Peak Inductor Current vs. Input Voltage.**  
L = 22μH, C<sub>x</sub> = 68pF.

**Note 12:** V<sub>IN</sub> is a good approximation of the voltage across the inductor during the charge phase. Actual voltage across the inductor will be slightly lower due to the V<sub>DS</sub> voltage of the power transistor, but this factor is minimal due to the low R<sub>DS-ON</sub> of the power transistor.

**INCREASING CURRENT LIMIT AND PEAK INDUCTOR CURRENT**

It is possible to increase the current limit by placing an external resistor between the V<sub>IN</sub> and L<sub>X</sub> pins, as shown in Figure 8. With the addition of the external resistor, only a fraction of the total inductor current passes through internal sense resistor. Thus, it takes more inductor current for the voltage across the internal sense resistor to become large enough to trip the current limit comparator.



**FIGURE 8. Increase Current Limit and Peak Inductor Current by Adding R<sub>EXT</sub>**

The addition of an external current limit resistor modifies the associated peak inductor equation to:

$$I_{L-PK} \approx \left[ \left( 1 + \frac{R_{EXT}}{R_{IN}} \right) \times I_{LIMIT} \right] + \left( \frac{V_{IN}}{L} \times t_D \right)$$

R<sub>EXT</sub>: External Current Limit Adjust Resistance

## Product Description (Continued)

$R_{IN}$ : Internal Resistance Between  $V_{IN}$  and  $L_X$  Pins.

$$R_{IN} = R_{BW} + R_S + R_{BW} \approx 440\text{m}\Omega$$

Rearranging the equation above allows for easy calculation of an external resistance to obtain a desired peak inductor current:

$$R_{EXT} = R_{IN} \times \left[ \frac{I_{L-PK} - \left( \frac{V_{IN}}{L} \times t_D \right)}{I_{LIMIT}} - 1 \right]$$

### OUTPUT OVER-VOLTAGE PROTECTION

The LM2707 contains an over-voltage protection circuit that limits the voltage at the  $V_{OVP}$  pin and prevents the LM2707 from boosting to voltages that might damage the LM2707 or external components (LEDs, capacitors, etc.). This circuit is especially important in LED-drive applications where there is the possibility that the feedback path might be broken if the LED string becomes disconnected or if an LED burns out.

The over-voltage protection circuit protects internal circuits and the NFET power transistor. The over-voltage threshold is typically centered at 18.75V, and contains approximately 500mV of hysteresis.

The output over-voltage protection feature can be disabled by connecting the  $V_{OVP}$  pin to ground.

### INPUT VOLTAGE RANGE AND UNDER-VOLTAGE LOCKOUT

The LM2707 input voltage operating range is 2.3V to 7.0V. When the input voltage becomes excessively low, the under-voltage lockout circuit interrupts switching cycles to prevent device malfunction. Lockout typically occurs when the input voltage falls to 1.9V. There is approximately 100mV of hysteresis in the under-voltage lockout threshold.

### ENABLE AND SHUTDOWN

The Enable pin (EN) is a logic input that puts the part in active mode when the voltage on the pin is high. It places the part in a low-power shutdown mode when the voltage on the pin is low. When shutdown, the LM2707 input typically consumes only a few nanoamps of current. There is a 122k $\Omega$  pull-down resistor connected internally between the EN and GND pins. This resistor pulls the LM2707 into shutdown mode when the EN pin is left floating.

## Components and Connectivity

### INDUCTOR SELECTION

Inductor selection is a vital part of LM2707 circuit design. The inductance value affects input and output ripple voltages and currents. An inductor with low series resistance will provide optimal power conversion efficiency. The saturation current rating of the inductor should be chosen so that it is above the steady-state peak inductor current of the application. (See the *Peak Inductor Current* section of the datasheet.

A few inductors recommended for use with the LM2707 are:

- TDK VLF3010A Series

- TDK VLF4012A Series
- Coilcraft DT1608C Series
- Coilcraft DO1608C Series

Many other inductors that are not on this list will also function well with the LM2707.

### DIODE SELECTION

For high efficiency and good circuit performance, a fast schottky rectifier diode with a low forward voltage is recommended for use with the LM2707. The average current rating of the diode should be higher than the peak inductor current of the application. The reverse breakdown voltage of the diode should be greater than the maximum output voltage of the circuit.

Some schottky diodes recommended for use with the LM2707 are:

- Vishay MBR0520L
- Sanyo SB07-03C
- ON Semiconductor MBR0520L

Many other diodes that are not on this list will also function well with the LM2707.

### CAPACITOR SELECTION

The LM2707 circuit requires three external capacitors for proper operation: an input capacitor ( $C_{IN}$ ), an output capacitor ( $C_{OUT}$ ), and a capacitor to program the oscillator frequency ( $C_X$ ).

The input capacitor keeps input voltage ripple, input current ripple, and input noise levels low. The ripple magnitudes will typically be inversely proportional to input capacitance: the larger the capacitance, the smaller the ripple. A 4.7 $\mu$ F capacitor is recommended for a typical LM2707 circuit. This value can be increased or decreased as desired, with the only impact being a change in input ripple and noise. The input capacitor should have a voltage rating that is at least as large as the maximum input voltage of the application.

The capacitor on the output performs a similar function: keeping ripple voltage, ripple current, and noise levels low. Like the input, the output ripple magnitudes are inversely proportional to the capacitance on the output. Due to the inherently stable ON/OFF control scheme of the LM2707, the output capacitance does not affect stability of the circuit. But an undersized capacitor may result in excessive ripple that could cause the circuit to behave erratically or even prematurely trip the over-voltage protection. A 2.2 $\mu$ F capacitor (or two 1 $\mu$ F capacitors in parallel) is sufficient for a typical LM2707 application. To accommodate the over-voltage protection circuit, a voltage rating of at least 25V is recommended for the output capacitor.

Surface-mount multi-layer ceramic capacitors are recommended for both the input and output capacitors. These capacitors are small, inexpensive and have very low equivalent series resistance ( $ESR \leq 15\text{m}\Omega$  typ.). Tantalum capacitors, OS-CON capacitors, and aluminum electrolytic capacitors generally are not recommended for use with the LM2707 due to their high ESR, as compared to ceramic capacitors. If one of these types of capacitor is used, it is recommended that small ceramic capacitors (0.1 $\mu$ F to 1 $\mu$ F) also be placed in parallel with each of the larger bypass capacitors to filter high frequency noise. These small ceramic capacitors should be placed as close to the LM2707 as possible for optimal filtering.

For most applications, ceramic capacitors with an X7R or X5R temperature characteristic should be used for  $C_{IN}$  and

## Components and Connectivity

(Continued)

$C_{OUT}$ . These capacitors have tight capacitance tolerance (as good as +/-10%) and hold their value over temperature (X7R: +/-15% over -55°C to 125°C; X5R: +/-15% over -55°C to 85°C).

Capacitors with a Y5V or Z5U temperature characteristic are generally not recommended for use with the LM2707. These types of capacitors typically have wide capacitance tolerance (+80%, -20%) and vary significantly over temperature (Y5V: +22%, -82% over -30°C to +85°C; Z5U: +22%, -56% over +10°C to +85°C). Under some conditions, a 1uF-rated Y5V or Z5U capacitor could have a capacitance as low as 0.1uF. The greatly reduced capacitance under some conditions will result in very high ripple voltages and currents.

Net capacitance of a ceramic capacitor decreases with increased DC bias. This capacitance reduction can give lower capacitance than expected on the input and/or output, resulting in higher ripple voltages and currents. Using capacitors at DC bias voltages significantly below the capacitor voltage rating will usually minimize DC bias effects. Consult capacitor manufacturers for information on capacitor DC bias characteristics.

A ceramic capacitor can also be used for the  $C_X$  capacitor. A small capacitor with a good temperature coefficient (COG, for example) should be chosen.

Below is a list of some leading ceramic capacitor manufacturers:

- TDK <[www.component.tdk.com](http://www.component.tdk.com)>
- AVX <[www.avx.com](http://www.avx.com)>
- Murata <[www.murata.com](http://www.murata.com)>
- Taiyo Yuden <[www.t-yuden.com](http://www.t-yuden.com)>
- Vishay <[www.vishay.com](http://www.vishay.com)>

### BOARD LAYOUT RECOMMENDATIONS

For optimal LM2707 circuit performance, the following board layout suggestions are recommended:

- Use short, wide traces and/or fills to connect the LM2707 and the external components. This results in low impedance connections that minimize parasitic losses and noise emissions.
- Utilize low impedance traces and an internal ground plane to connect the LM2707 GND pin to the input capacitor, output capacitor,  $C_X$  capacitor, and feedback resistor.
- Place the input capacitor as close to the LM2707  $V_{IN}$  pin as possible to minimize input noise.
- Place the inductor and rectifier diode as close as possible to the SW pin and minimize the lengths of the connections of this high-frequency switching node.

See *Figure 9* for an example of a recommended board layout of an LM2707 circuit.

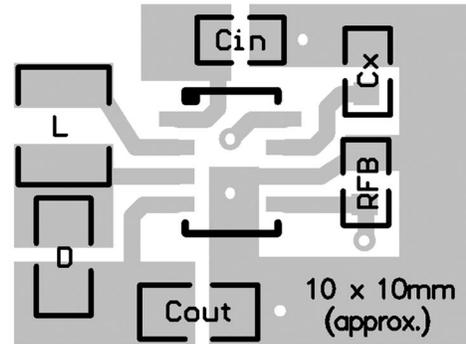


FIGURE 9. Example LM2707 LED Driver Board Layout (LEDs not shown)

## Application Information

### LED DRIVE EFFICIENCY

The LM2707 can be used to build a high efficiency LED drive circuit. The low ON resistance of the NFET power device and the sub-bandgap feedback voltage minimize the power consumption of the LED-drive circuit. A circuit that uses an inductor with a low series resistance and a diode with a low forward voltage (low- $V_F$ ) will achieve maximum LED drive efficiency.

LED drive efficiency (E) is commonly measured and calculated by taking the ratio of power consumed by the LEDs to the power consumed at the input of the LED drive circuit:

$$E = \frac{P_{LED}}{P_{IN}} = \frac{N \times V_{LED} \times I_{LED}}{V_{IN} \times I_{IN}}$$

Efficiency curves for a representative LM2707 LED drive circuits can be referenced in the *Typical Performance Characteristics* graphs.

### LED BRIGHTNESS ADJUSTMENT

There are several methods and application circuits that can be used to dynamically adjust LED brightness.

A pulse-width modulated signal applied to the enable (EN) pin can be used to strobe the LEDs and adjust the perceived LED brightness (see the schematic on page 1 of the datasheet). With this approach, the LEDs are ON and driven at the current programmed by the feedback resistor when the pulse voltage is high. The LM2707 and the LEDs are OFF when the pulse voltage is low. Brightness is proportional to the duty cycle of the pulse signal.

The LM2707 can accommodate a very wide range of PWM signal frequencies: signals between 100Hz and 50kHz are acceptable. Signals below 100Hz are not recommended because these lower frequencies are distinguishable by the human eye. The brightness vs. duty cycle characteristic of the circuit may vary slightly with different PWM frequencies. This is especially noticeable at the higher PWM frequencies. See *Table 1* for an example.

## Application Information (Continued)

**Table 1. Time-Averaged LED Current vs. PWM Frequency and Duty Cycle**

PWM Frequency	D = 10%	D = 20%	D = 30%	D = 50%	D = 90%
200 Hz	2.3	3.8	5.3	8.2	13.9
1 kHz	3.7	6.0	7.4	10.0	14.4
10 kHz	2.6	5.9	9.1	13.4	14.8
20 kHz	1.0	4.7	8.6	13.6	14.8
40 kHz	OFF	1.8	5.1	12.0	14.8
50 kHz	OFF	OFF	5.7	10.3	14.8

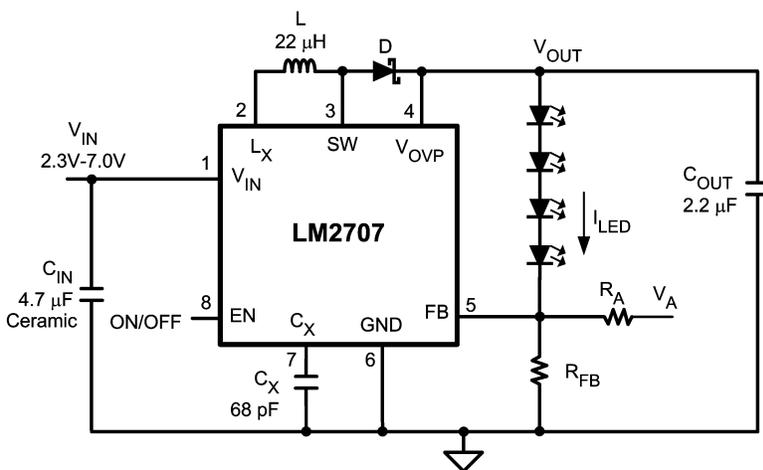
$V_{IN} = 3.6V$ , 4 LEDs,  $R_{FB} = 34\Omega$ ,  $I_{LED} = 14.9mA$  when  $V(EN)$  is HIGH.

A benefit of PWM brightness adjustment is the characteristic that LEDs are driven with the same current level (max current) at all brightness levels. Other methods that adjust brightness by changing the DC forward current of the LEDs may see a slight change in color at different brightness levels.

With the addition of an external resistor, an analog voltage can be used to adjust LED brightness, as shown in *Figure 10*. When the analog voltage is above the feedback voltage, 0.515V (typ.), the analog voltage source adds current to

feedback node. In order to keep the feedback voltage regulated, the LM2707 responds by reducing the current through the LEDs. Conversely, LED current increases when the analog voltage is below the feedback voltage.

A 4-level digital brightness adjustment, shown in *Figure 11*, can be implemented with a pair of external resistors and two digital logic signals. The workings of the circuit are similar to the analog voltage control: LED currents are set based on the current that is added to or removed from the FB node from the digital voltage supplies.



$$I_{LED} = \frac{V_{FB}}{R_{FB}} - \frac{V_A - V_{FB}}{R_A}$$

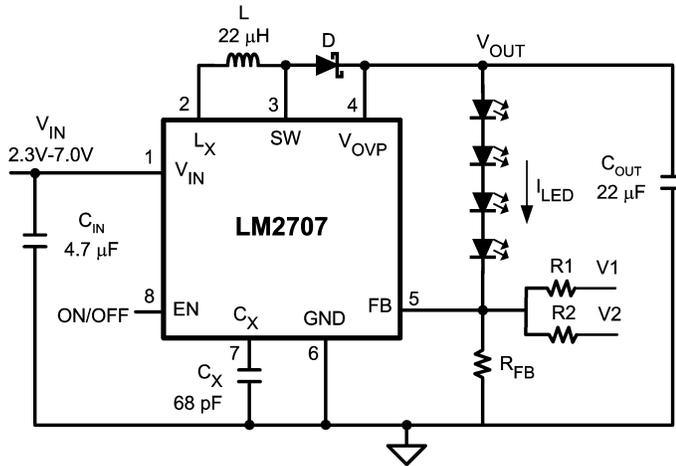
With  $R_{FB} = 40\Omega$  and  $R_A = 240\Omega$ :

$V_A$	$I_{LED}$
0V	15 mA
0.5V	13 mA
1.0V	11 mA
1.5V	9 mA
2.0V	6.5 mA
2.5V	4.5 mA
3.0V	2.5 mA
$\geq 3.5V$	OFF

20099235

**FIGURE 10. LM2707 LED-Drive Circuit with Analog Voltage Brightness Control**

### Application Information (Continued)



V1	V2	I <sub>LED</sub> EQUATION
0V	0V	$\frac{V_{FB}}{R_{FB} \parallel R1 \parallel R2}$
0V	V <sub>DIG</sub>	$\frac{V_{FB}}{R_{FB} \parallel R1} - \frac{V_{DIG} - V_{FB}}{R2}$
V <sub>DIG</sub>	0V	$\frac{V_{FB}}{R_{FB} \parallel R2} - \frac{V_{DIG} - V_{FB}}{R1}$
V <sub>DIG</sub>	V <sub>DIG</sub>	$\frac{V_{FB}}{R_{FB}} - \frac{V_{DIG} - V_{FB}}{R1 \parallel R2}$

With  
 $R_{FB} = 40\Omega$ ,  
 $R1 = 225\Omega$ , and  
 $R2 = 450\Omega$  :

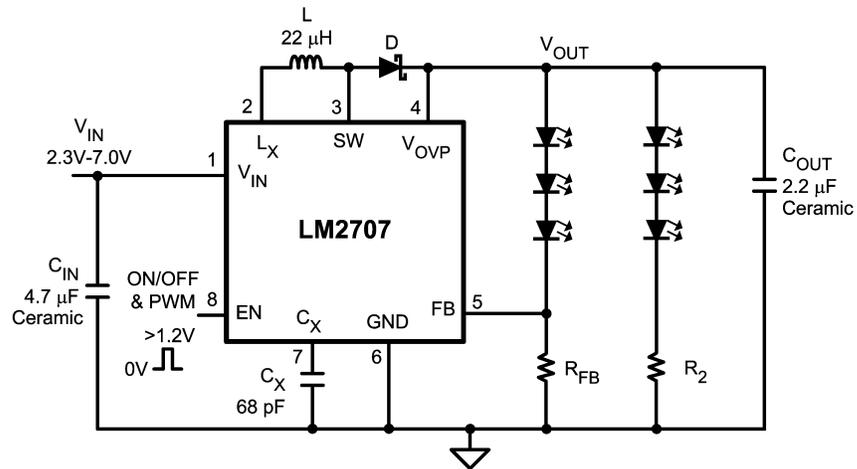
V1	V2	I <sub>LED</sub>
0V	0V	16 mA
0V	1.8V	12 mA
1.8V	0V	8 mA
1.8V	1.8V	4 mA

20099236

FIGURE 11. LM2707 LED-Drive Circuit with 2-Bit Digital Logic Brightness Control

### Application Circuits

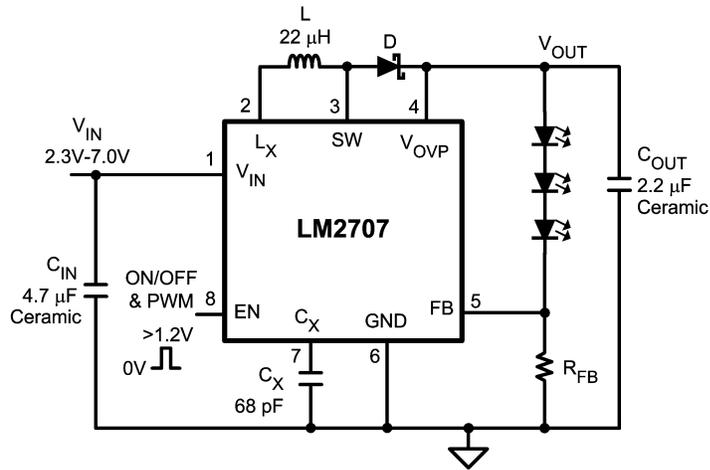
#### LM2707 DRIVING 6 LEDs



20099237

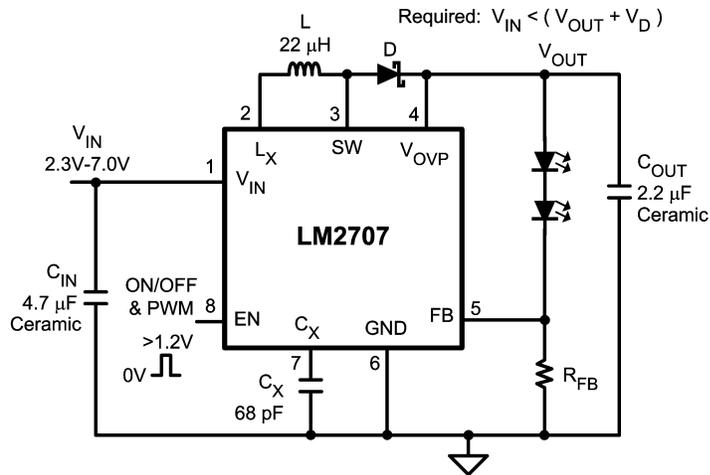
# Application Circuits (Continued)

## LM2707 DRIVING 3 LEDs



20099238

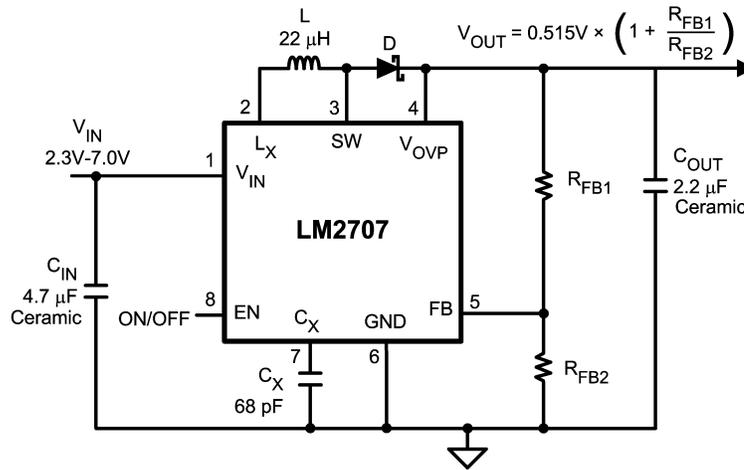
## LM2707 DRIVING 2 LEDs



20099239

# Application Circuits (Continued)

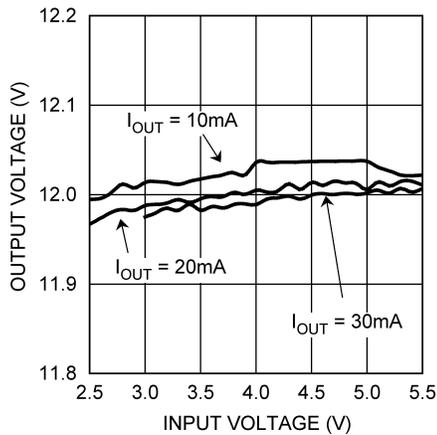
## LM2707 DC-DC VOLTAGE CONVERTER CIRCUIT



20099240

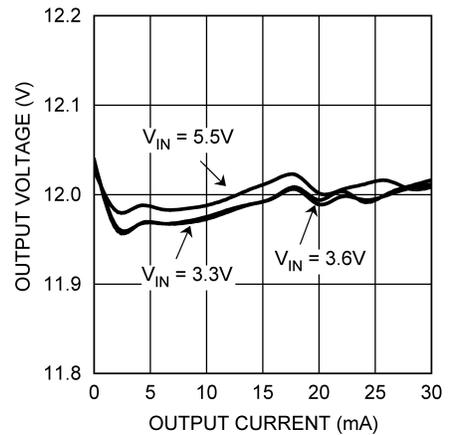
**Curves for  $V_{OUT} = 12V$ .**  $R_{FB1} = 126k\Omega$ ,  $R_{FB2} = 10k\Omega$ ,  $L = 22\mu H$  (Coilcraft DT1608C-223),  $D = MBR0520L$  (Vishay),  $C_{IN} = 1\mu F$ ,  $C_{OUT} = 2 \times 1\mu F$ ,  $C_X = 68pF$ ,  $T_A = 25^\circ C$ . A  $1\Omega$  resistor was placed between the  $V_{IN}$  and  $L_X$  pins to increase the current limit and accommodate load currents above of 15mA.

**Output Voltage vs. Input Voltage**



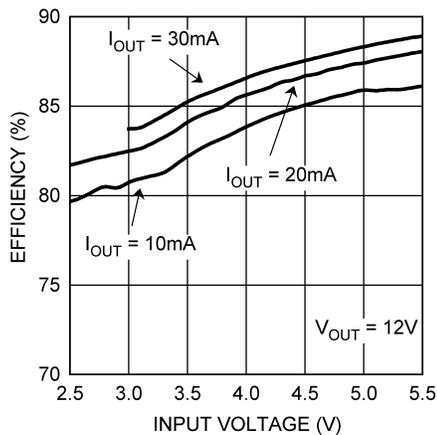
20099254

**Output Voltage vs. Output Current**



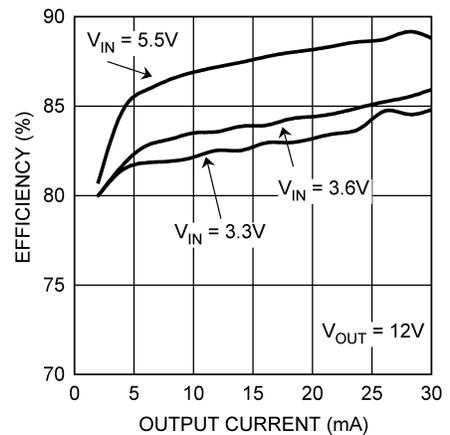
20099255

**Power Efficiency vs. Input Voltage**



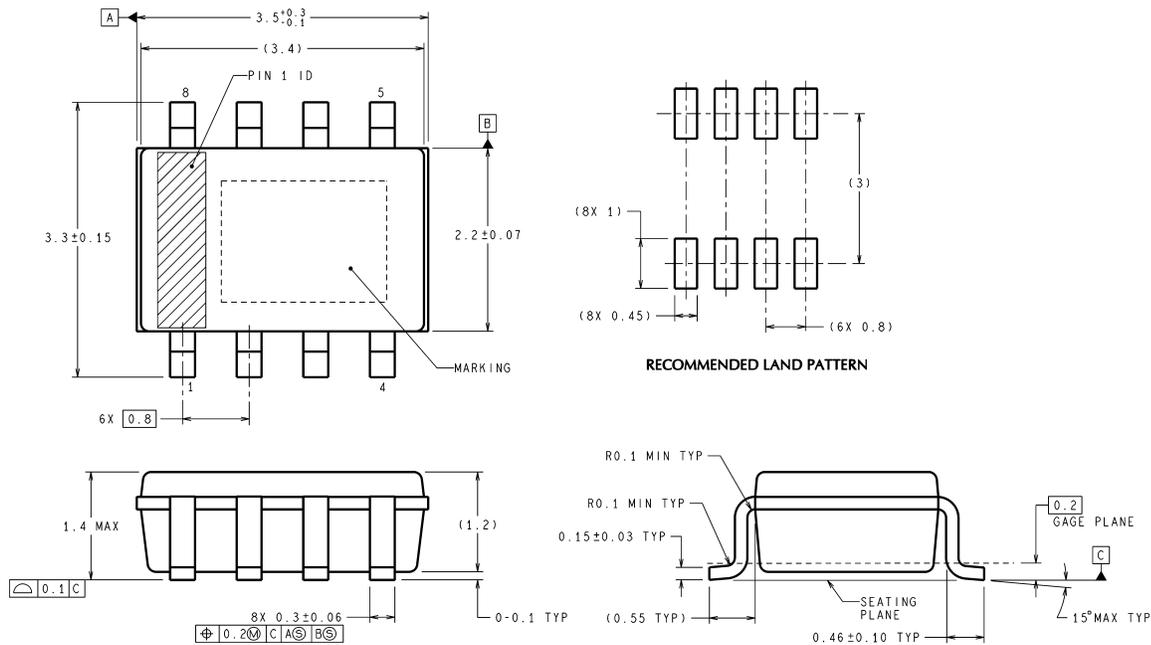
20099256

**Power Efficiency vs. Output Current**



20099257

**Physical Dimensions** inches (millimeters) unless otherwise noted



ALL DIMENSIONS ARE IN MILLIMETERS  
DIMENSIONS IN ( ) FOR REFERENCE ONLY

MF08A (Rev A)

**NS Package Number MF08A: SOT23-8**

National does not assume any responsibility for use of any circuitry described, no circuit patent licenses are implied and National reserves the right at any time without notice to change said circuitry and specifications.

For the most current product information visit us at [www.national.com](http://www.national.com).

**LIFE SUPPORT POLICY**

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

**BANNED SUBSTANCE COMPLIANCE**

National Semiconductor certifies that the products and packing materials meet the provisions of the Customer Products Stewardship Specification (CSP-9-111C2) and the Banned Substances and Materials of Interest Specification (CSP-9-111S2) and contain no "Banned Substances" as defined in CSP-9-111S2.

 **National Semiconductor**  
Americas Customer Support Center  
Email: [new.feedback@nsc.com](mailto:new.feedback@nsc.com)  
Tel: 1-800-272-9959

**National Semiconductor**  
Europe Customer Support Center  
Fax: +49 (0) 180-530 85 86  
Email: [europe.support@nsc.com](mailto:europe.support@nsc.com)  
Deutsch Tel: +49 (0) 69 9508 6208  
English Tel: +44 (0) 870 24 0 2171  
Français Tel: +33 (0) 1 41 91 8790

**National Semiconductor**  
Asia Pacific Customer Support Center  
Email: [ap.support@nsc.com](mailto:ap.support@nsc.com)

**National Semiconductor**  
Japan Customer Support Center  
Fax: 81-3-5639-7507  
Email: [jpn.feedback@nsc.com](mailto:jpn.feedback@nsc.com)  
Tel: 81-3-5639-7560