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

**Check for Samples: LM2707**

## 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 SOT-23-8 Package**

## APPLICATIONS

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

## DESCRIPTION

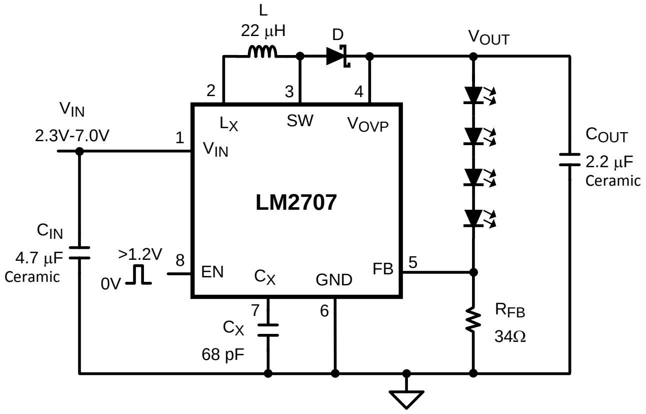
The LM2707 is a magnetic boost regulator specifically designed for white LED drive applications. Tightly regulated LED currents, exceptional LED brightness uniformity, and very high LED-drive power efficiency (>80%) can all be achieved by stacking the LEDs in series between the LM2707 output and the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

## Typical Application Circuit

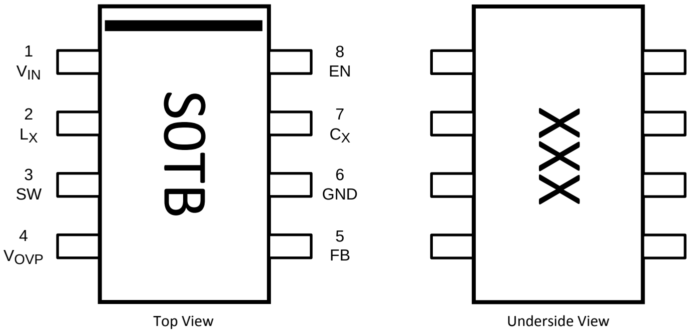


## DESCRIPTION (CONTINUED)

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 SOT-23-8 surface mount package.

### Connection Diagram



The actual physical placement of the package marking will vary from part to part. The package marking "XXX" is an internal code for die traceability. "S0TB" identifies the LM2707 device.

**Figure 1. 8-Pin SOT-23 Package**

### PIN DESCRIPTIONS

| Pin # | Name | Description |
|---|---|---|
| 1 | $V_{IN}$ | Input Voltage Connection. Input Voltage Range: 2.3V to 7.0V |
| 2 | $L_X$ | Inductor Input Connection |
| 3 | SW | Switching Node |
| 4 | $V_{OVP}$ | Output Sense Pin for Over-Voltage Protection Circuit |
| 5 | FB | Output Voltage Feedback. Reference Voltage is 0.515V (typ.) |
| 6 | GND | Ground |
| 7 | $C_X$ | Oscillator Frequency Adjustment |
| 8 | EN | Active-High Enable Pin<br>LM2707 is ON when V(EN) is above 1.2V<br>LM2707 is Shutdown when V(EN) is below 0.3V |

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.

## ABSOLUTE MAXIMUM RATINGS(1)(2)(3)

| | |
|---|---|
| $V_{IN}$, FB, and EN pins | -0.3V to 7.5V |
| SW and $V_{OVP}$ pins | -0.3V to 21V |
| Continuous Power Dissipation ($T_A$ = 25ºC) | 800mW |
| Switch Peak Current | 400mA |
| Junction Temperature ($T_{J-MAX}$) | 150ºC |
| Storage Temperature Range | -65ºC to +150º C |
| Maximum Lead Temperature (Soldering) | (4) |
| ESD Rating (5)<br>Human Body Model:<br>Machine Model: | <br>2kV<br>200V |

(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 specified. Operating Ratings do not imply ensured performance limits. For ensured performance limits and associated test conditions, see the Electrical Characteristics tables.

(2) All voltages are with respect to the potential at the GND pin.

(3) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/Distributors for availability and specifications.

(4) For detailed soldering specifications and information, please consult the Application Note titled: *Mounting of Surface Mount Components* (literature number SNOA040).

(5) The Human body model is a 100pF capacitor discharged through a 1.5kΩ resistor into each pin. (MIL-STD-883 3015.7) The machine model is a 200pF capacitor discharged directly into each pin. (EAIJ)

## OPERATING RATINGS(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 (3) | -30°C to +85°C |

(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 specified. Operating Ratings do not imply ensured performance limits. For ensured performance limits and associated test conditions, see the Electrical Characteristics tables.

(2) All voltages are with respect to the potential at the GND pin.

(3) 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 ($T_{JMAX-OP}$ = 125ºC), 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: $T_{A-MAX} = T_{J-MAX-OP} - (\theta_{JA} \times P_{D-MAX})$.

## THERMAL PROPERTIES

| | |
|---|---|
| Junction-to-Ambient Thermal Resistance ($\theta_{JA}$) (1) | 125ºC/W |

(1) Junction-to-ambient thermal resistance ($\theta_{JA}$) is highly application and board-layout dependent. The 125ºC/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.

## ELECTRICAL CHARACTERISTICS

(1)(2)

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

| Symbol | Parameter | Condition | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| **Oscillator Frequency Programming ($C_x$ pin)** | | | | | | |
| $I_{chg}$ | $C_x$ Charging Current | $V_{Cx}$ = 0.1V, $V_{FB}$ = 1V | 16 | 24 | 30 | µA |
| $I_{dis}$ | $C_x$ Discharging Current | $V_{Cx}$ = 1.0V, $V_{FB}$ = 1V | 35 | 52 | 65 | µA |
| $I_{dis}/I_{chg}$ | 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 |
| **Current Limiting Comparator ($L_x$ pin)** | | | | | | |
| $I_{LIMIT}$ | Inductor Current Limit | (3) | 220 | 260 | 300 | mA |
| $R_{IN}$ | Pin 1-2 Total Resistance | Measured between pin 1 and pin 2 | 380 | 440 | 500 | mΩ |
| $R_{SC}$ | Internal Effective Resistance for Inductor Current Limit Sence | | | (4)(5)300 | | mΩ |
| **Output Switch Section (SW pin)** | | | | | | |
| $V_{sw,\ DS}$ | Output Transistor Drain-to-Source Voltage | $V_{Cx}$ = 0.1V, $I_{SW}$ = 200mA | | 0.12 | 0.22 | V |
| $R_{DS\text{-}ON}$ | Switch ON Resistance<br>$R_{DS\text{-}ON} = V_{sw,DS} \div I_{SW}$ | $V_{Cx}$ = 0.1V, $I_{SW}$ = 200mA | | 0.60 | 1.1 | Ω |
| $I_{sw,Off}$ | Output Transistor Off Leak Current | $V_{FB}$ = 1V, $V_{SW}$ = 20V | | 0.01 | 2.0 | µA |
| **Feedback Comparator section (FB pin)** | | | | | | |
| $V_{ref}$ | Reference Voltage | | 0.495 | 0.515 | 0.535 | V |
| $I_{FBin}$ | FB Pin Output Current | $V_{FB}$ = 0.4V | -0.2 | -0.075 | | µA |
| **Shutdown Section (EN pin)** | | | | | | |
| $V_{EN,\ High}$ | 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 | $V_{EN}$ = 3.0V | | 25 | 40 | µA |
| **Open Circuit Protection Section ($V_{OVP}$ pin)** | | | | | | |
| $V_{OVP}$ | 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 | µA |
| | | $V_{OVP}$ = 18.5V, $V_{EN}$ = 0V | | 0.03 | | µA |
| **Input Voltage Section ($V_{IN}$ pin)** | | | | | | |
| $V_{IN,\ Low}$ | 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 | µA |
| $I_{IN,\ On}$ | Quiescent Supply Current | $V_{FB}$ = 1.0V | 0.2 | 0.5 | 0.8 | mA |

(1) All voltages are with respect to the potential at the GND pin.
(2) Min and Max limits are specified by design, test, or statistical analysis. Typical (Typ) numbers are not specified, but do represent the most likely norm.
(3) $I_{LIMIT}$: The value of current source $I_L$ (DC measurement) when the switching operation is stopped by the $I_S$ comparator.
(4) $R_{SC}$: Specified by the design equation: $I_{LIMIT}$ = { 0.1V - [(2.3V × $V_{IN}$) / 300] } / $R_{SC}$
(5) 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 = 22µH (Coilcraft DT1608C-223), D = MBR0520L (Vishay), $C_{IN}$ = 1.0µF, $C_{OUT}$ = 2x1µF, $C_x$ = 68pF, $T_A$ = 25ºC.

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

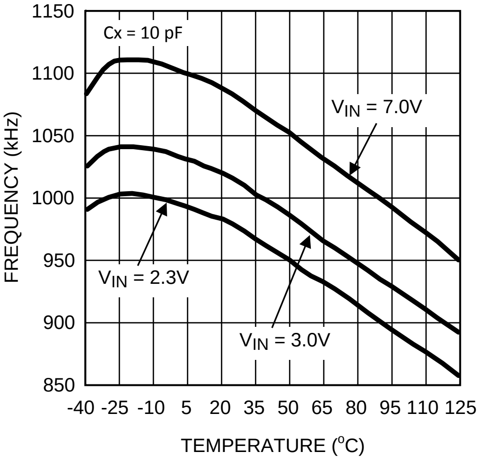


Figure 2.

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

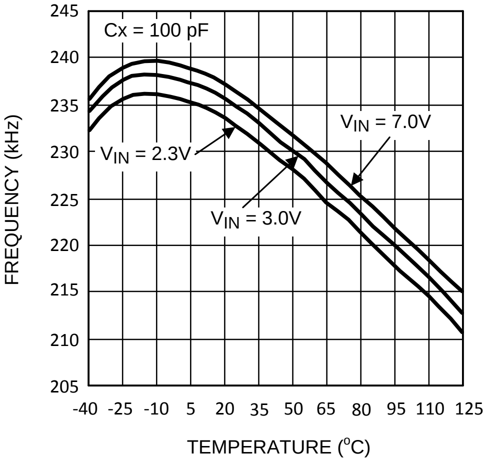


Figure 3.

**Oscillator Period vs. Cx Capacitance**

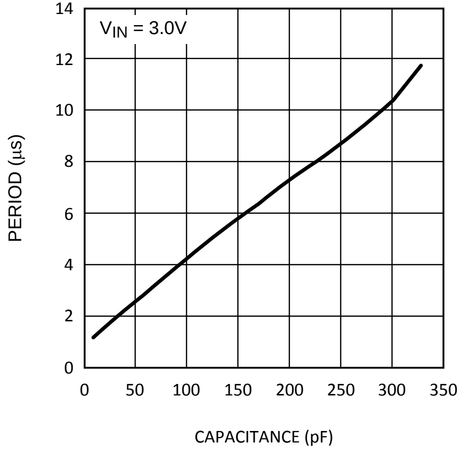


Figure 4.

**Maximum Duty Cycle vs. Oscillator Frequency**

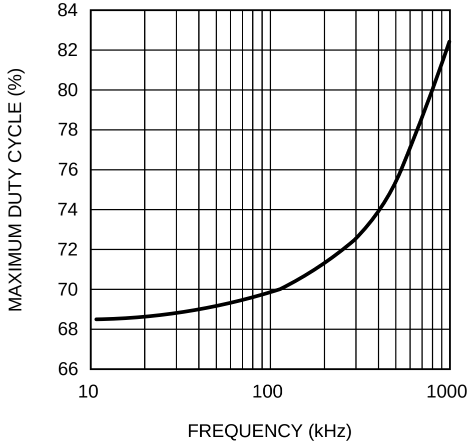


Figure 5.

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

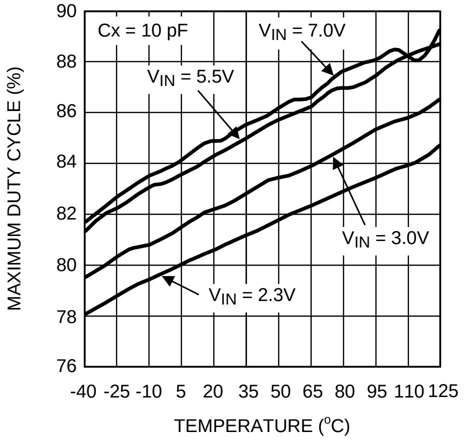


Figure 6.

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

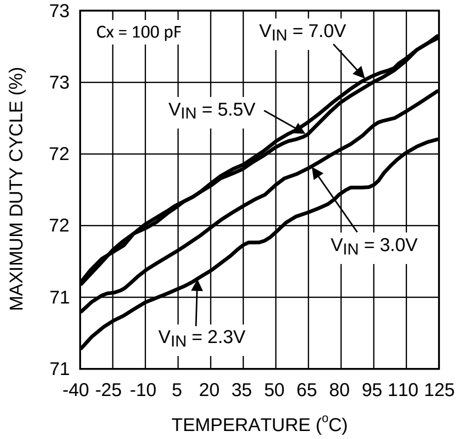


Figure 7.

## TYPICAL PERFORMANCE CHARACTERISTICS (continued)

Unless otherwise specified: $V_{IN}$ = 3.0V, $V_{EN}$ = 3.0V, L = 22µH (Coilcraft DT1608C-223), D = MBR0520L (Vishay), $C_{IN}$ = 1.0µF, $C_{OUT}$ = 2x1µF, $C_x$ = 68pF, $T_A$ = 25ºC.

Feedback Trip Point vs. Supply Voltage

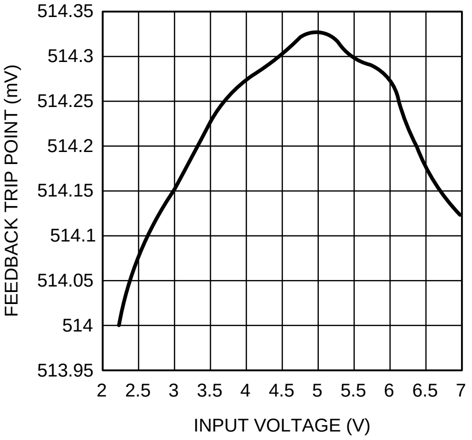


**Figure 8.**

Feedback Trip Point vs. Temperature

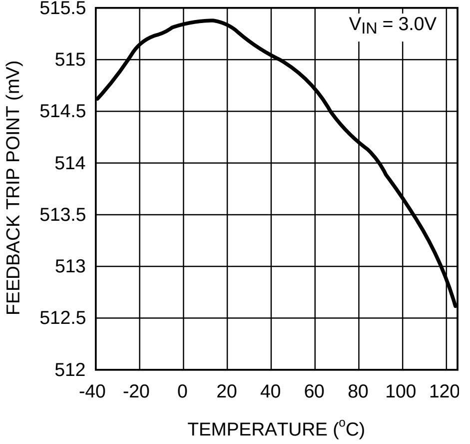


**Figure 9.**

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

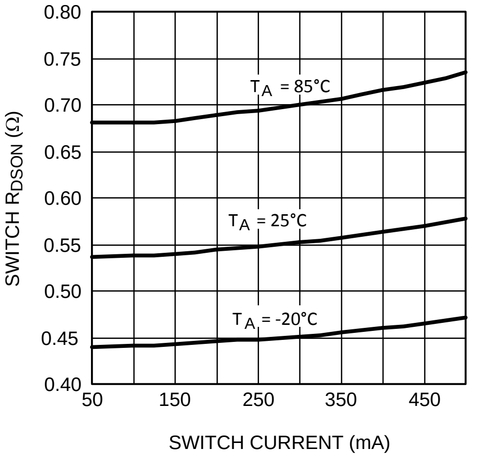


**Figure 10.**

Inductor Current Limit vs. Supply Voltage

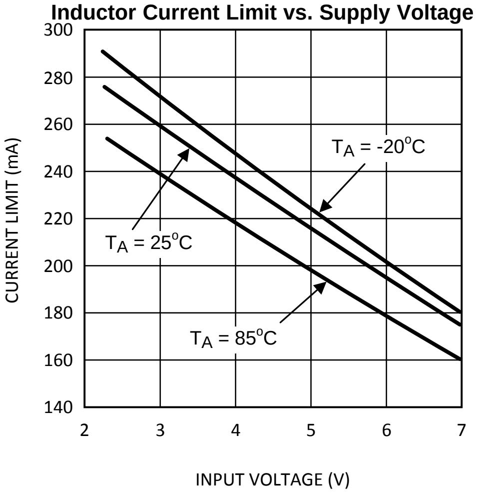


**Figure 11.**

Pin 1-2 Resistance vs. Temperature

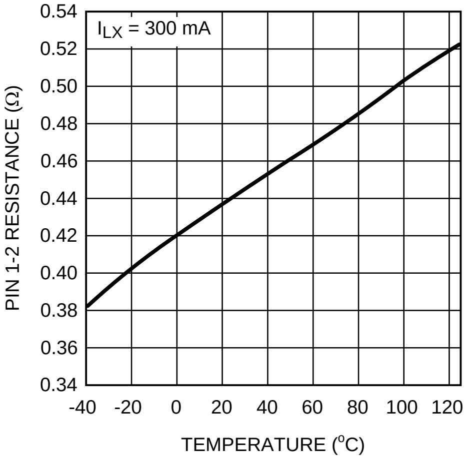


**Figure 12.**

$V_{OVP}$ Thresholds vs. Temperature

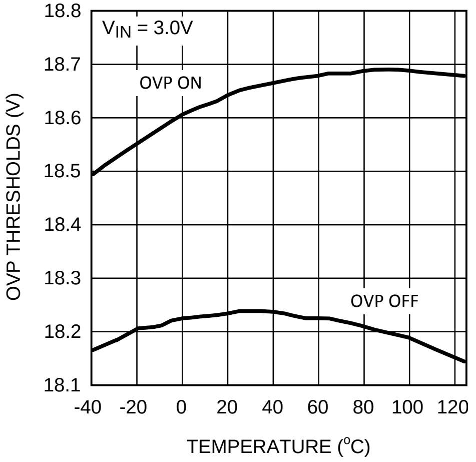


**Figure 13.**

## TYPICAL PERFORMANCE CHARACTERISTICS (continued)

Unless otherwise specified: $V_{IN}$ = 3.0V, $V_{EN}$ = 3.0V, L = 22µH (Coilcraft DT1608C-223), D = MBR0520L (Vishay), $C_{IN}$ = 1.0µF, $C_{OUT}$ = 2x1µF, $C_x$ = 68pF, $T_A$ = 25ºC.

**Shutdown Supply Current vs. Supply Voltage**

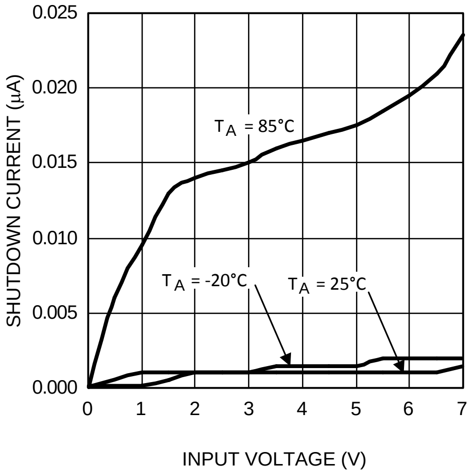


Figure 14.

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

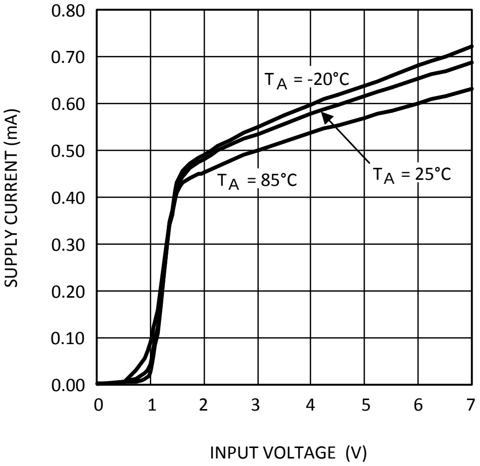


Figure 15.

**Supply Current vs. EN Input Voltage**

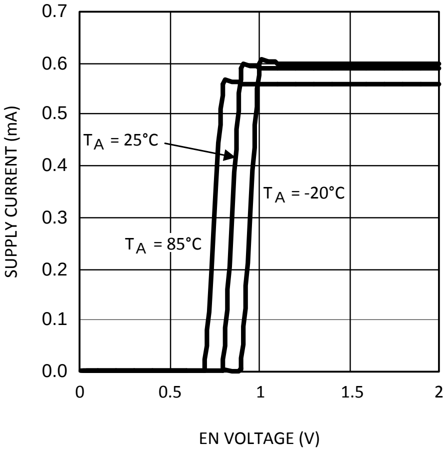


Figure 16.

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

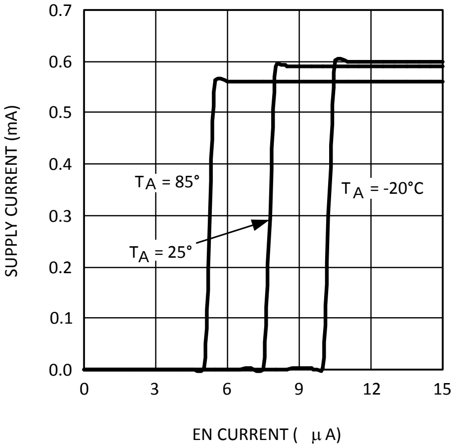


Figure 17.

**EN Threshold vs. Supply Voltage**

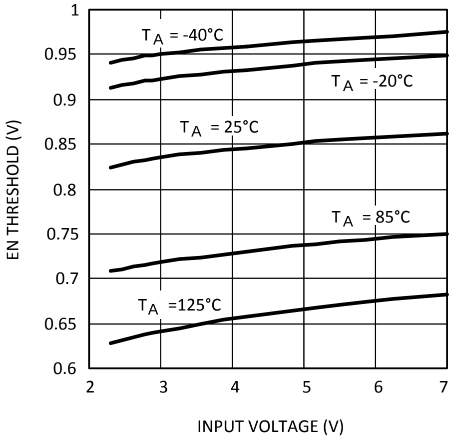


Figure 18.

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

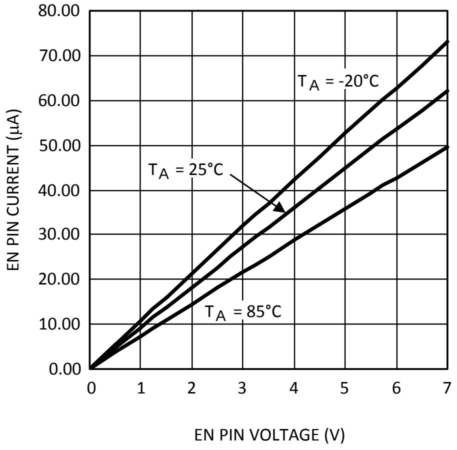


Figure 19.

## TYPICAL PERFORMANCE CHARACTERISTICS (continued)

Unless otherwise specified: $V_{IN}$ = 3.0V, $V_{EN}$ = 3.0V, L = 22µH (Coilcraft DT1608C-223), D = MBR0520L (Vishay), $C_{IN}$ = 1.0µF, $C_{OUT}$ = 2x1µF, $C_x$ = 68pF, $T_A$ = 25ºC.

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

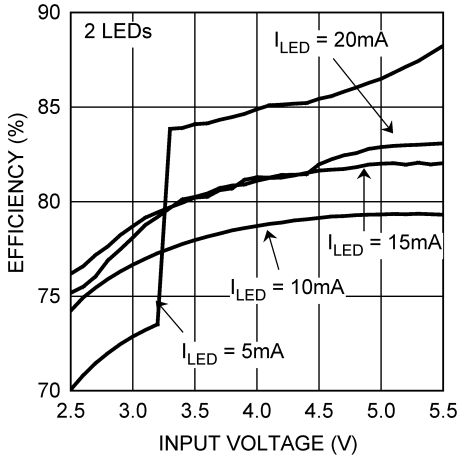


**Figure 20.**

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

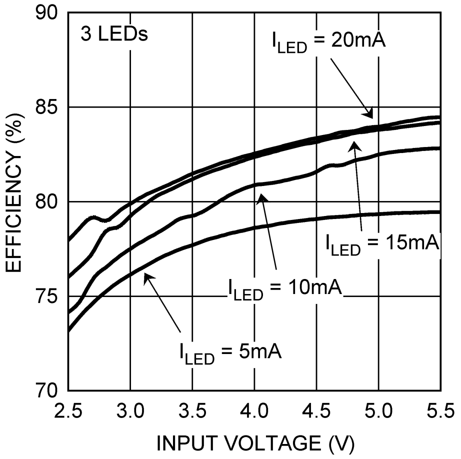


**Figure 21.**

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

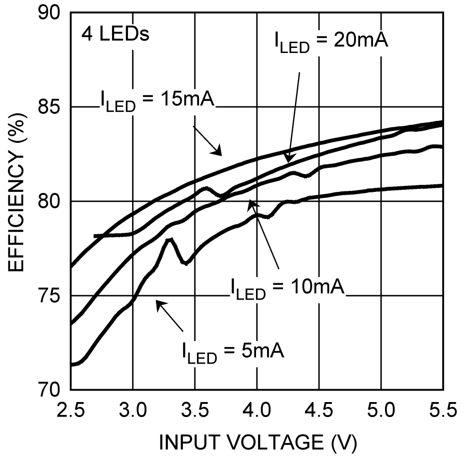


**Figure 22.**

**LED Current vs. Duty Cycle**

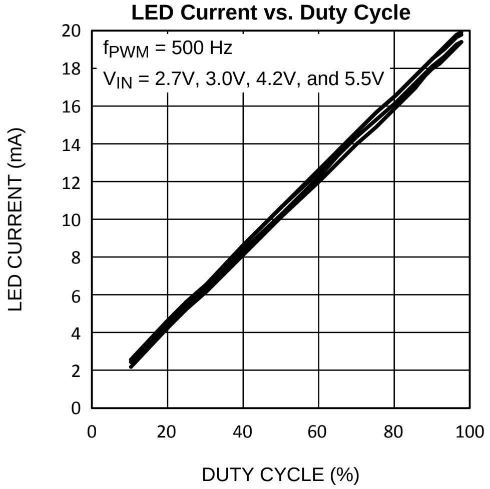


**Figure 23.**

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(1) * 20mA, 4-LED operation requires increasing the current limit.
A 1Ω resistor was placed between the $V_{IN}$ and $L_X$ pins.

(2) 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

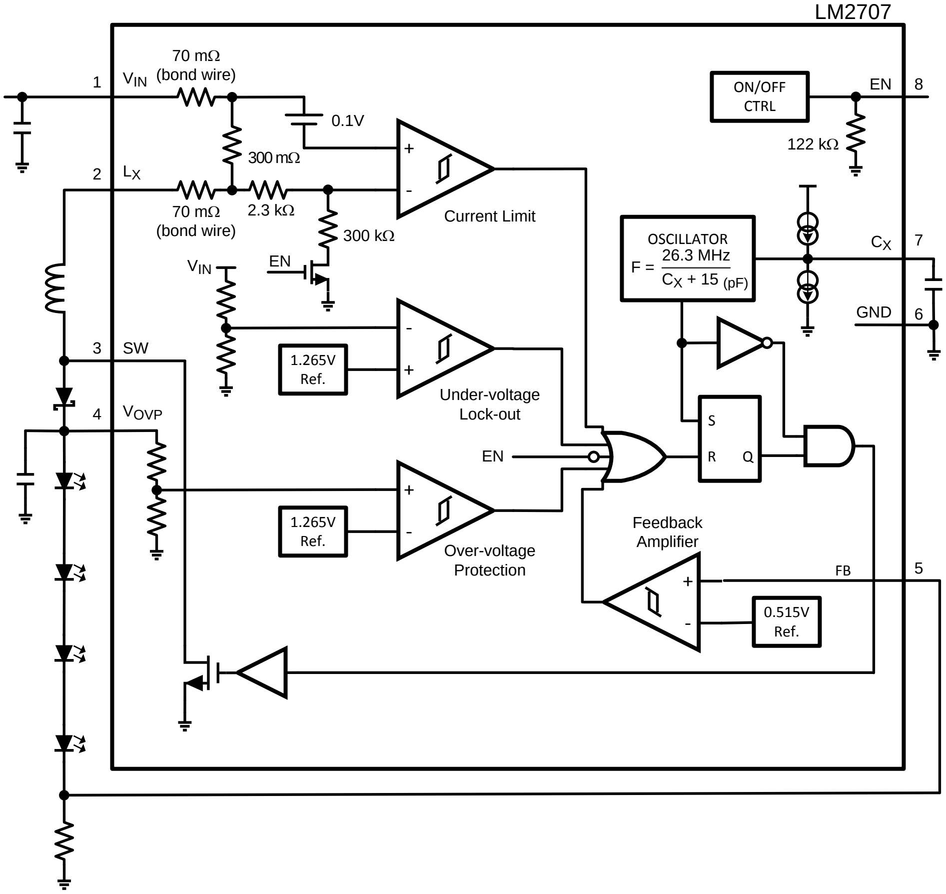
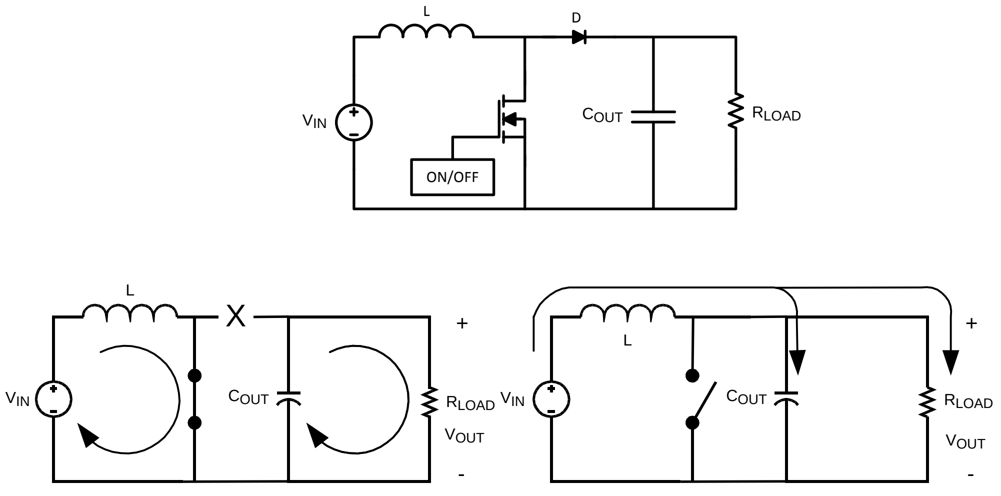


Figure 24. LM2707 Block Diagram

## Simplified Switching Circuit



Cycle 1
(a)

Cycle 2
(b)

**Figure 25. 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 24, the simplified switching circuit in Figure 25, and the switching waveforms in Figure 26. 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.

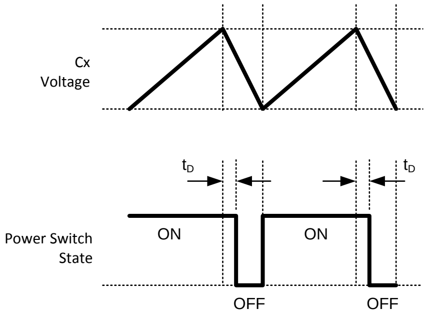


**Figure 26. $C_X$ Oscillator Waveform and Power Switch Operation**

## 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:

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

An example with $C_X$ = 68pF:

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

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 27.

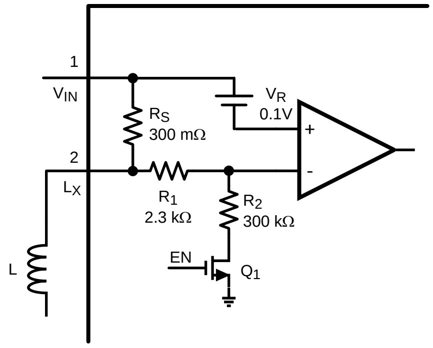


**Figure 27. LM2707 Internal Current Limit Circuit**

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 $V_{IN} = 4.0V$, $I_{LIMIT} \cong 228mA$.

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 27 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:

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

where

- $V_{IN}$: Input voltage
- L: Inductance
- $t_{ON}$: Switch ON time. (See the Programmable Oscillator section)

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

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

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

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

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:

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

where

- $I_{LIMIT}$: Current Limit -- 330mA - ($V_{IN}$ × 25.5mA/V)
- $t_D$: Power transistor turn-off delay (200ns typ.)
- An example -- $V_{IN} = 3.6V$, $L = 22\mu H$:

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

$$\approx 238\text{ mA}$$

Figure 28 graphs the relationship between inductor current and current limit. Figure 29 plots ideal inductor current waveforms to illustrate inductor current behavior. Figure 30 gives peak inductor current versus input voltage and shows the two regions where the oscillator and current limit, respectively, determine peak inductor current.

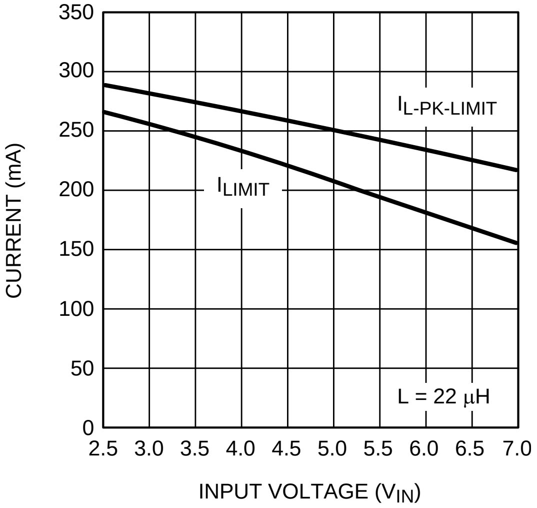


**Figure 28. Peak Inductor Current and Current Limit vs. Input Voltage**

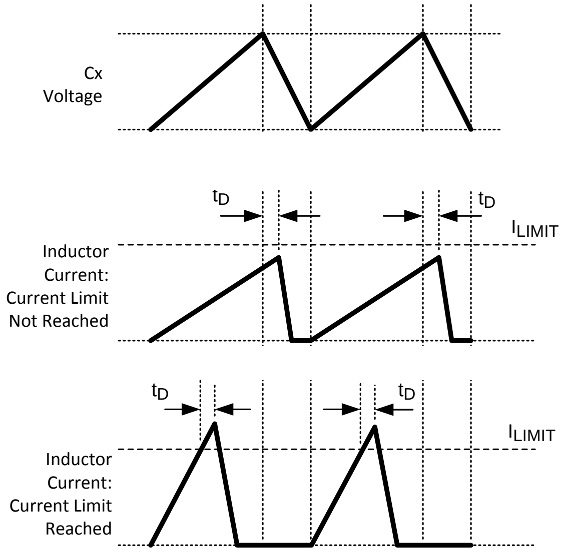


**Figure 29. Ideal Inductor Current Waveforms**

$V_{IN}$ 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 $V_{DS}$ voltage of the power transistor, but this factor is minimal due to the low $R_{DS\text{-}ON}$ of the power transistor.

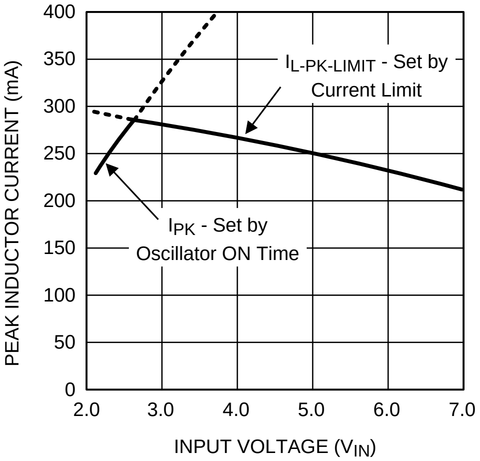


**Figure 30. Peak Inductor Current vs. Input Voltage. L = 22µH, $C_X$ = 68pF.**

## INCREASING CURRENT LIMIT AND PEAK INDUCTOR CURRENT

It is possible to increase the current limit by placing an external resistor between the $V_{IN}$ and $L_X$ pins, as shown in Figure 31. 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.

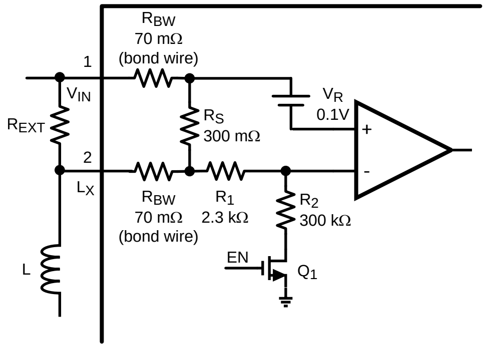


**Figure 31. Increase Current Limit and Peak Inductor Current by Adding $R_{EXT}$**

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

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

where

- $R_{EXT}$: External Current Limit Adjust Resistance
- $R_{IN}$: Internal Resistance Betwen $V_{IN}$ and $L_X$ Pins

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

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

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

## 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 122kΩ 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 4.7µF 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 2.2µF capacitor (or two 1µF 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 ≤ 15mΩ 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 (0.1µF to 1µF) 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 $C_{OUT}$. 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 |
| AVX | www.avx.com |
| Murata | www.murata.com |
| Taiyo Yuden | www.t-yuden.com |
| Vishay | 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 32 for an example of a recommended board layout of an LM2707 circuit.

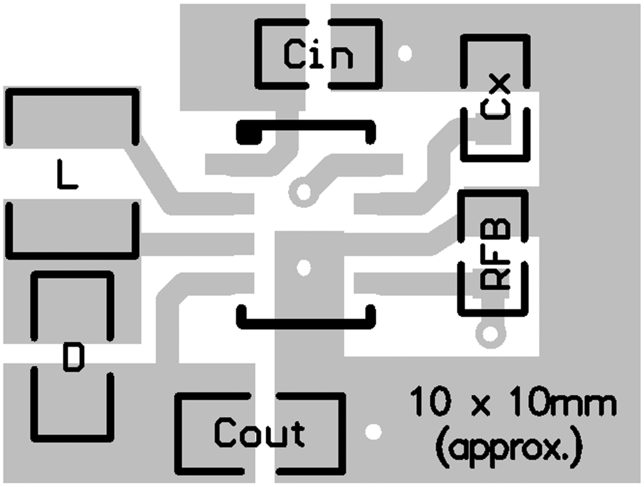


Figure 32. Example LM2707 LED Driver Board Layout (LEDs not shown)

## 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 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 noticable at the higher PWM frequencies. See Table 1 for an example.

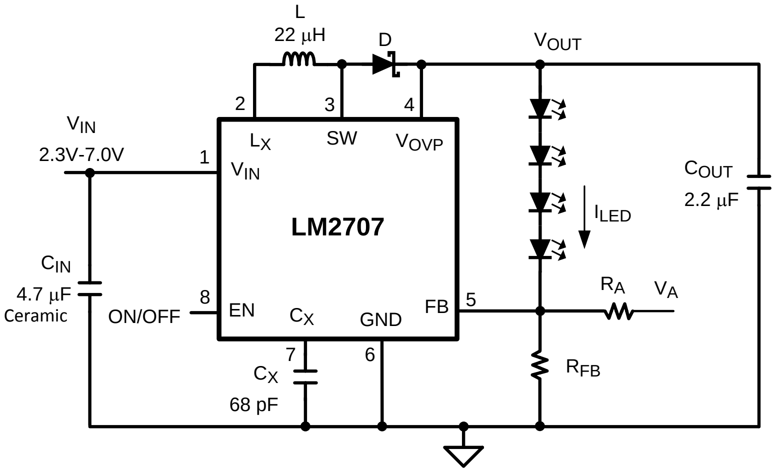
**Table 1. Time-Averaged LED Current vs. PWM Frequency and Duty Cycle**

| 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 |

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 33. 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 34, 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.

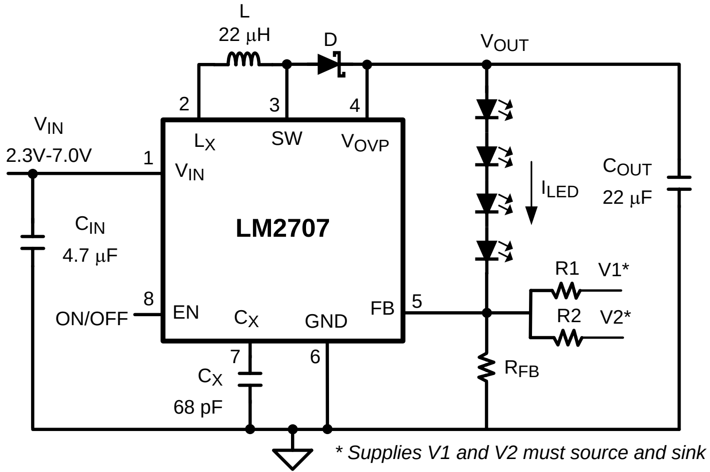


$$I_{LED} = \frac{V_{FB}}{R_{FB}} - \frac{V_A - V_{FB}}{R_A}$$

*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 |
| ≥ 3.5V | OFF |

**Figure 33. LM2707 LED-Drive Circuit with Analog Voltage Brightness Control**



** Supplies V1 and V2 must source and sink currents on the order of a few milli-Amps*

| V1 | V2 | $I_{LED}$ EQUATION |
|---|---|---|
| 0V | 0V | $\frac{V_{FB}}{R_{FB} \| R1 \| R2}$ |
| 0V | $V_{DIG}$ | $\frac{V_{FB}}{R_{FB} \| R1} - \frac{V_{DIG} - V_{FB}}{R2}$ |
| $V_{DIG}$ | 0V | $\frac{V_{FB}}{R_{FB} \| R2} - \frac{V_{DIG} - V_{FB}}{R1}$ |
| $V_{DIG}$ | $V_{DIG}$ | $\frac{V_{FB}}{R_{FB}} - \frac{V_{DIG} - V_{FB}}{R1 \| R2}$ |

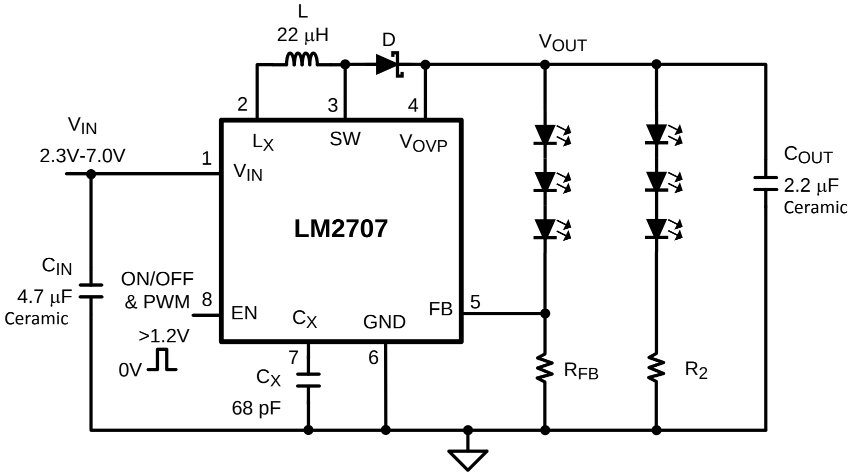
*With $R_{FB} = 40\Omega$, $R1 = 225\Omega$, and $R2 = 450\Omega$ :*

| V1 | V2 | $I_{LED}$ |
|---|---|---|
| 0V | 0V | 16 mA |
| 0V | 1.8V | 12 mA |
| 1.8V | 0V | 8 mA |
| 1.8V | 1.8V | 4 mA |

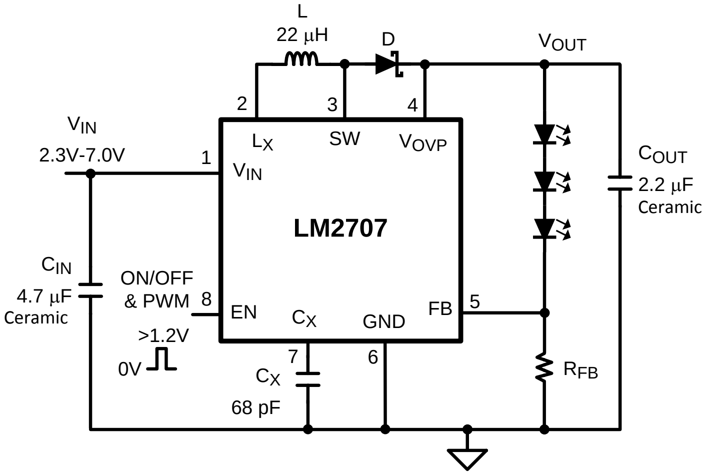
**Figure 34. LM2707 LED-Drive Circuit with 2-Bit Digital Logic Brightness Control**

## Application Circuits

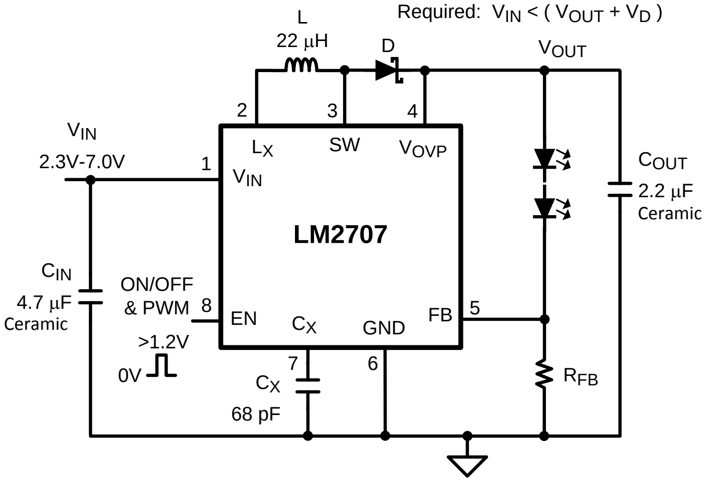
### LM2707 DRIVING 6 LEDs



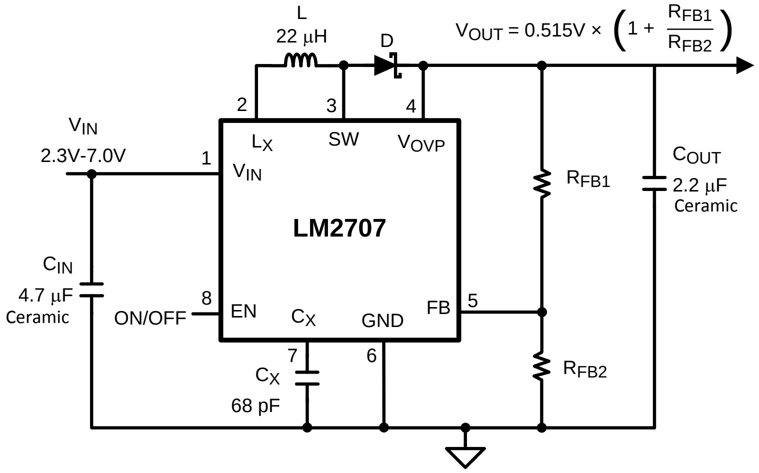
### LM2707 DRIVING 3 LEDs



### LM2707 DRIVING 2 LEDs



## LM2707 DC-DC VOLTAGE CONVERTER CIRCUIT



**Curves for $V_{OUT}$ = 12V.** $R_{FB1}$ = 126kΩ, $R_{FB2}$ = 10kΩ, L = 22µH (Coilcraft DT1608C-223), D = MBR0520L (Vishay), $C_{IN}$ = 1µF, $C_{OUT}$ = 2x1µF, $C_X$ = 68pF, $T_A$ = 25ºC. A 1Ω resistor was placed between the $V_{IN}$ and $L_X$ pins to increase the current limit and accommodate load currents above of 15mA.

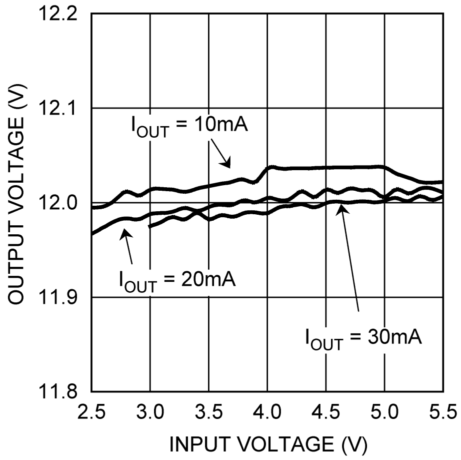


Figure 35. Output Voltage vs. Input Voltage

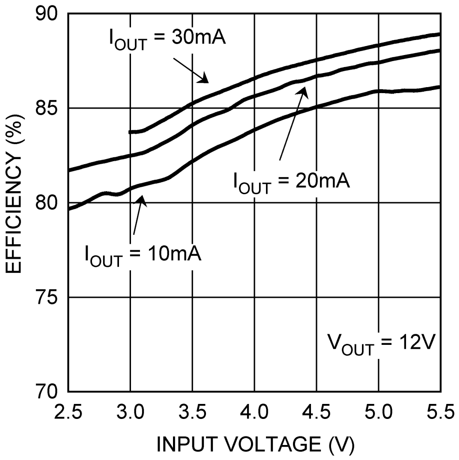


Figure 36. Power Efficiency vs. Input Voltage

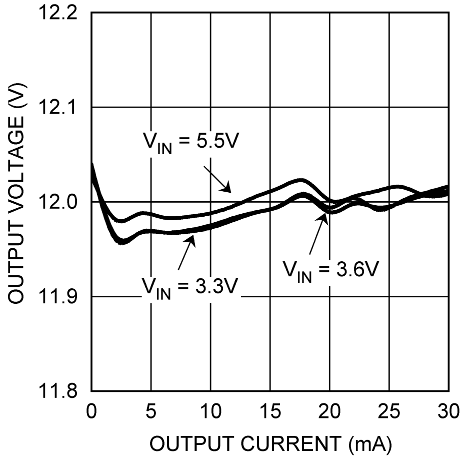


Figure 37. Output Voltage vs. Output Current

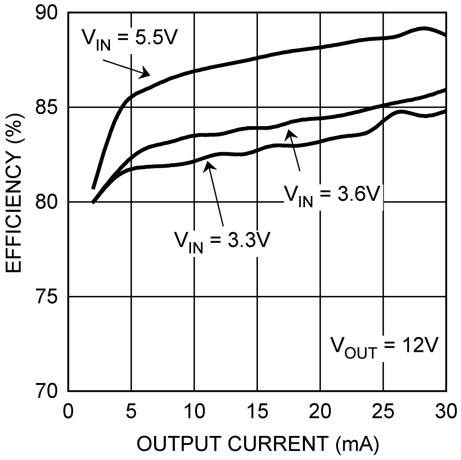


Figure 38. Power Efficiency vs. Output Current

## REVISION HISTORY

| Changes from Revision A (April 2013) to Revision B | Page |
|---|---|
| • Changed layout of National Data Sheet to TI format | 20 |

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