

# 2.4MHz White LED Step-Up Converter with Built-In Schottky in ThinSOT™

August 2003

## FEATURES

- Inherently Matched LED Current
- Drives Up to Six LEDs from a 3.6V Supply
- No External Schottky Diode Required
- Open LED Protection
- High Efficiency: 79% Typical
- Requires Only 0.22μF Output Capacitor
- Switching Frequency Above AM Broadcast Band
- Low Profile (<1mm) SOT-23 Packaging

## APPLICATIONS

- Cellular Phones
- PDAs, Handheld Computers
- Digital Cameras
- MP3 Players
- GPS Receivers

## DESCRIPTION

The LT®3465A is a step-up DC/DC converter designed to drive up to six LEDs in series from a Li-Ion cell. Series connection of the LEDs provides identical LED currents and eliminates the need for ballast resistors. This device integrates the Schottky diode required externally on competing devices. Additional features include output voltage limiting when LEDs are disconnected, one-pin shutdown and dimming control.

The LT3465A switches at 2.4MHz, allowing the use of tiny external components. Constant frequency switching results in low input noise and a small output capacitor. Just 0.22μF is required for 3-, 4- or 5-LED applications.

The LT3465A is available in a low profile (<1mm) 6-lead SOT-23 package.

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## TYPICAL APPLICATION

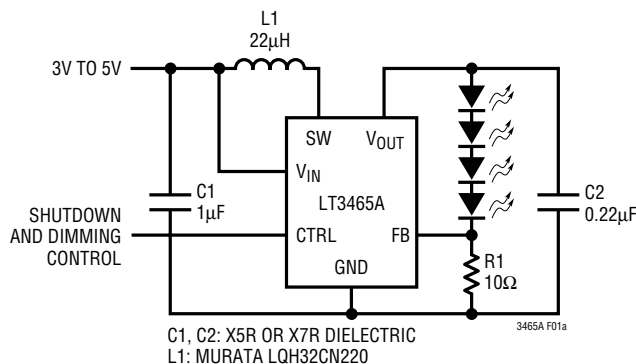
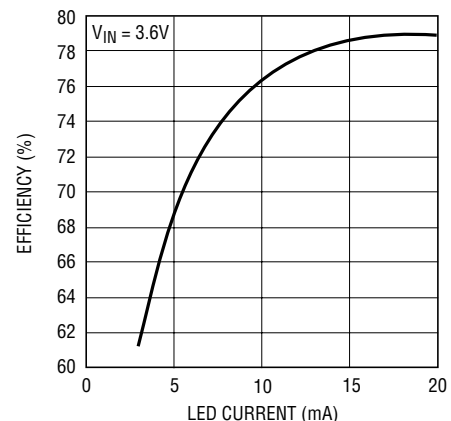


Figure 1. Li-Ion Powered Driver for Four White LEDs

### Conversion Efficiency



3465A F01b

## ABSOLUTE MAXIMUM RATINGS

(Note 1)

Input Voltage ( $V_{IN}$ ) .....	16V
SW Voltage .....	36V
FB Voltage .....	2V
CTRL Voltage .....	10V
Operating Temperature Range (Note 2) ..	-40°C to 85°C
Maximum Junction Temperature .....	125°C
Storage Temperature Range .....	-65°C to 150°C
Lead Temperature (Soldering, 10 sec) .....	300°C

## PACKAGE/ORDER INFORMATION

	ORDER PART NUMBER
	LT3465AES6
	S6 PART MARKING
	LTAFT

Consult LTC Marketing for parts specified with wider operating temperature ranges.

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{IN} = 3\text{V}$ ,  $V_{CTRL} = 3\text{V}$ , unless otherwise noted.

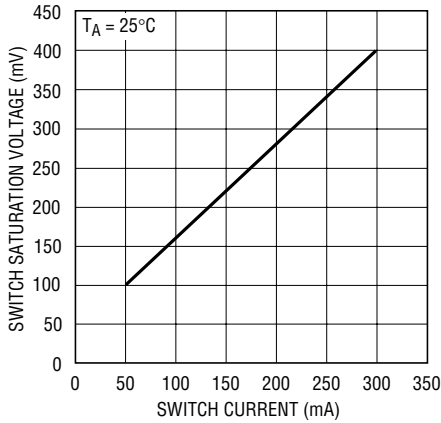
PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Minimum Operating Voltage		2.7			V
Maximum Operating Voltage				16	V
Feedback Voltage	$0^\circ\text{C} \leq T_A \leq 85^\circ\text{C}$	188	200	212	mV
FB Pin Bias Current		10	35	100	nA
Supply Current	Not Switching $CTRL = 0\text{V}$	1.9 2.0	2.6 3.2	3.3 5.0	mA $\mu\text{A}$
Switching Frequency		1.8	2.4	2.8	MHz
Maximum Duty Cycle		● 90	93		%
Switch Current Limit		● 225	340		mA
Switch $V_{CESAT}$	$I_{SW} = 250\text{mA}$		300		mV
Switch Leakage Current	$V_{SW} = 5\text{V}$		0.01	5	$\mu\text{A}$
$V_{CTRL}$ for Full LED Current		1.8			V
$V_{CTRL}$ to Shut Down Device				50	mV
CTRL Pin Bias Current	$T_A = 85^\circ\text{C}$ $T_A = -40^\circ\text{C}$	48 40 60	60 50 75	72 60 90	$\mu\text{A}$ $\mu\text{A}$ $\mu\text{A}$
Schottky Forward Drop	$I_D = 150\text{mA}$		0.7		V
Schottky Leakage Current	$V_R = 30\text{V}$			4	$\mu\text{A}$

**Note 1:** Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

**Note 2:** The LT3465AE is guaranteed to meet performance specifications from  $0^\circ\text{C}$  to  $70^\circ\text{C}$ . Specifications over the  $-40^\circ\text{C}$  to  $85^\circ\text{C}$  operating temperature range are assured by design, characterization and correlation with statistical process controls.

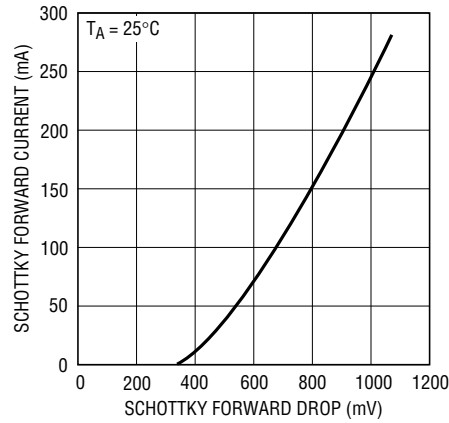
# TYPICAL PERFORMANCE CHARACTERISTICS

**Switch Saturation Voltage ( $V_{CESAT}$ )**



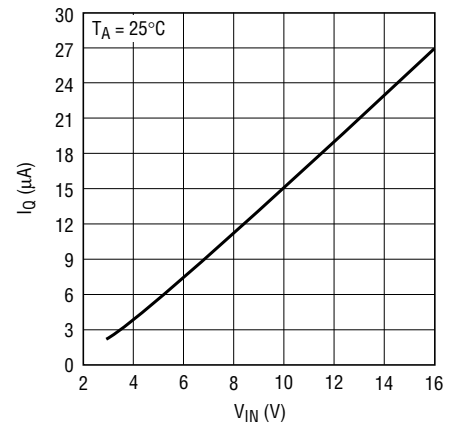
3465 G01

**Schottky Forward Voltage Drop**



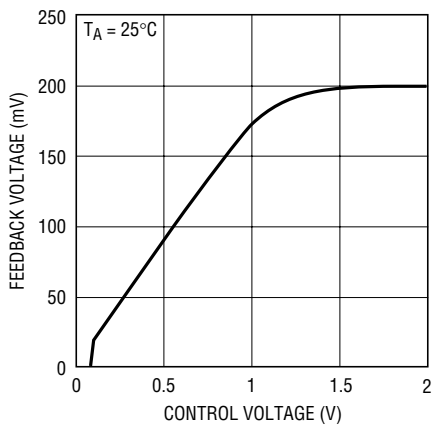
3465 G02

**Shutdown Quiescent Current ( $I_Q$ ) ( $CTRL = 0V$ )**



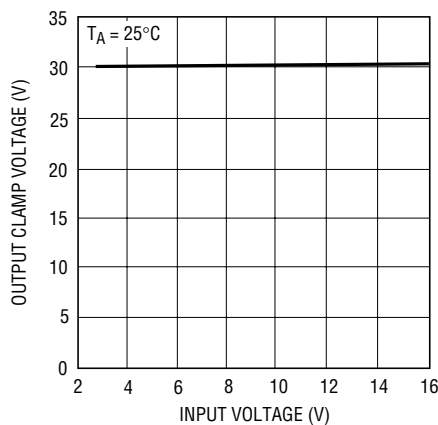
3465 G03

**$V_{FB}$  vs  $V_{CTRL}$**



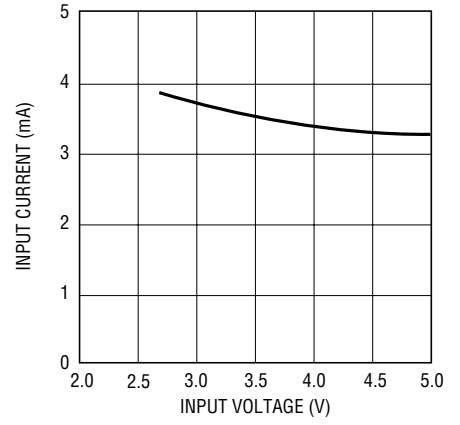
3465 G04

**Open-Circuit Output Clamp Voltage**



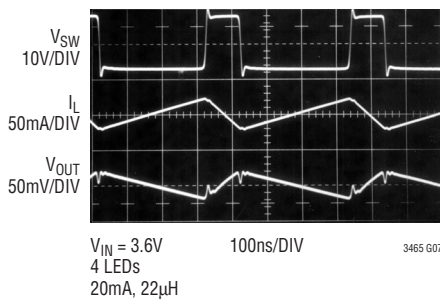
3465 G05

**Input Current in Output Open Circuit**



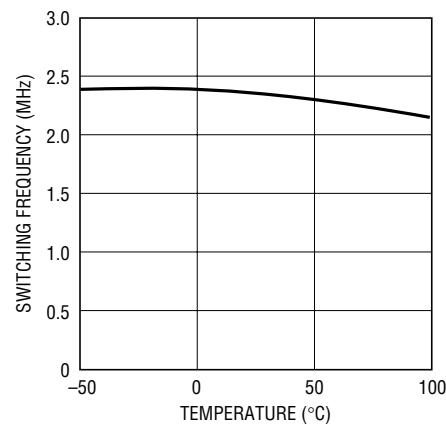
3465 G06

**Switching Waveforms**



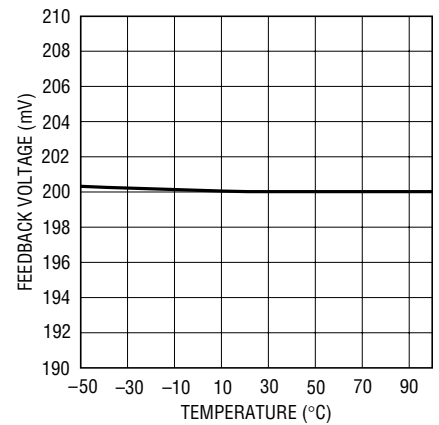
3465 G07

**Switching Frequency**



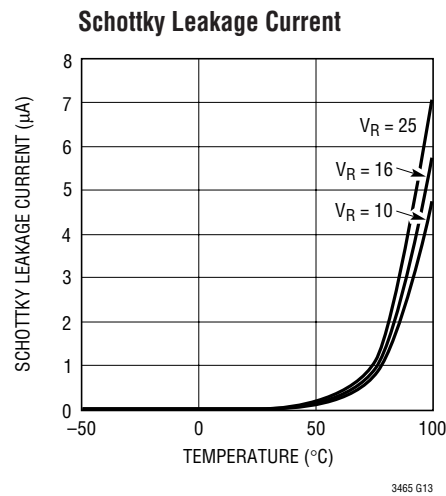
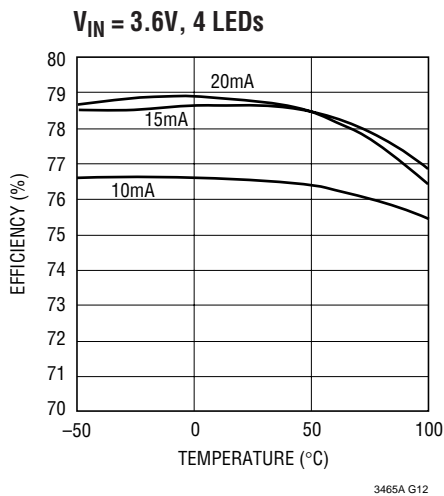
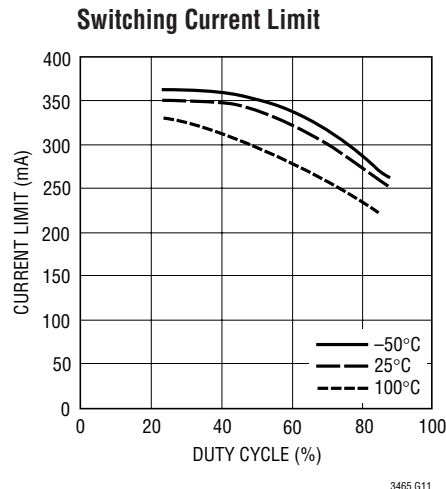
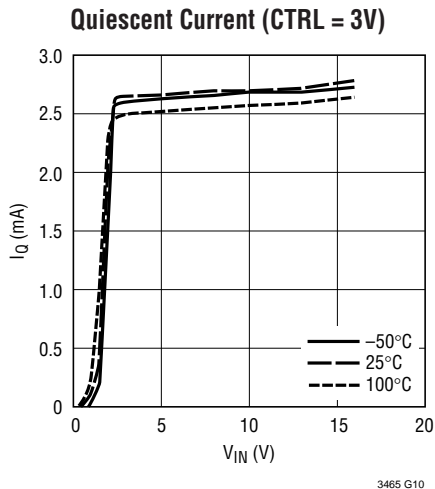
3465 G08

**Feedback Voltage**



3465 G09

## TYPICAL PERFORMANCE CHARACTERISTICS



## PIN FUNCTIONS

**V<sub>OUT</sub> (Pin 1):** Output Pin. Connect to output capacitor and LEDs. Minimize trace between this pin and output capacitor to reduce EMI.

**GND (Pin 2):** Ground Pin. Connect directly to local ground plane.

**FB (Pin 3):** Feedback Pin. Reference voltage is 200mV. Connect LEDs and a resistor at this pin. LED current is determined by the resistance and CTRL pin voltage:

$$I_{LED} \approx \frac{200mV}{R_{FB}} \text{ When } V_{CTRL} > 1.8V$$

$$I_{LED} \approx \frac{V_{CTRL}}{5 \cdot R_{FB}} \text{ When } V_{CTRL} < 1V$$

(1)

**CTRL (Pin 4):** Dimming Control and Shutdown Pin. Ground this pin to shut down the device. When V<sub>CTRL</sub> is greater than about 1.8V, full-scale LED current is generated. When V<sub>CTRL</sub> is less than 1V, LED current is reduced.

**V<sub>IN</sub> (Pin 5):** Input Supply Pin. Must be locally bypassed with a 1µF X5R or X7R type ceramic capacitor.

**SW (Pin 6):** Switch Pin. Connect inductor here.

## BLOCK DIAGRAM

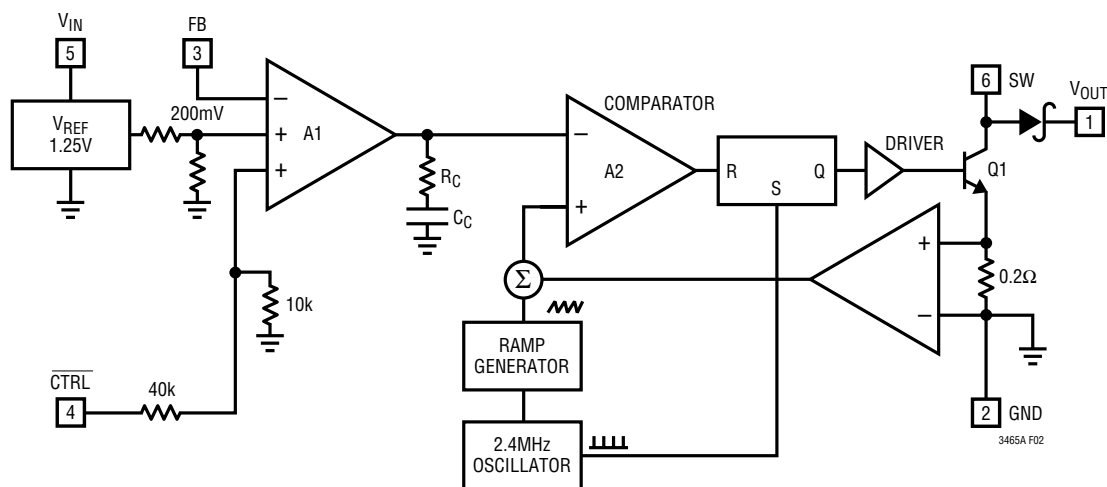


Figure 2. LT3465A Block Diagram

## APPLICATIONS INFORMATION

### Operation

The LT3465A uses a constant frequency, current mode control scheme to provide excellent line and load regulation. Operation can be best understood by referring to the block diagram in Figure 2. At the start of each oscillator cycle, the SR latch is set, which turns on the power switch Q1. A voltage proportional to the switch current is added to a stabilizing ramp and the resulting sum is fed into the positive terminal of the PWM comparator A2. When this voltage exceeds the level at the negative input of A2, the SR latch is reset turning off the power switch. The level at the negative input of A2 is set by the error amplifier A1, and is simply an amplified version of the difference between the feedback voltage and the reference voltage of 200mV. In this manner, the error amplifier sets the correct peak current level to keep the output in regulation. If the error amplifier's output increases, more current is delivered to the output; if it decreases, less current is delivered. The CTRL pin voltage is used to adjust the reference voltage.

### Minimum Output Current

The LT3465A can drive a 3-LED string at 0.2mA LED current without pulse skipping. As current is further reduced, the device may begin skipping pulses. This will

result in some low frequency ripple, although the LED current remains regulated on an average basis down to zero. The photo in Figure 3 details circuit operation driving three white LEDs at a 0.2mA load. Peak inductor current is less than 30mA and the regulator operates in discontinuous mode, meaning the inductor current reaches zero during the discharge phase. After the inductor current reaches zero, the SW pin exhibits ringing due to the LC tank circuit formed by the inductor in combination with switch and diode capacitance. This ringing is not harmful; far less spectral energy is contained in the ringing than in the switch transitions. The ringing can be damped by application of a 300Ω resistor across the inductor, although this will degrade efficiency.

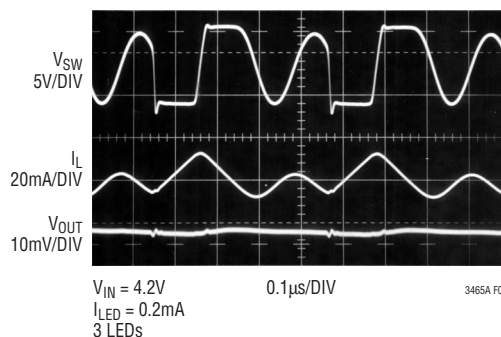


Figure 3. Switching Waveforms

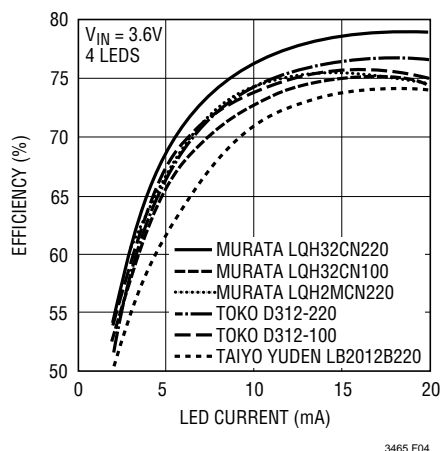
## APPLICATIONS INFORMATION

### Inductor Selection

A 22μH or 10μH inductor is recommended for most LT3465A applications. Although small size and high efficiency are major concerns, the inductor should have low core losses at 1.2MHz and low DCR (copper wire resistance). Some inductors in this category with small size are listed in Table 1. The efficiency comparison of different inductors is shown in Figure 4.

**Table 1. Recommended Inductors**

PART NUMBER	DCR (Ω)	CURRENT RATING (mA)	MANUFACTURER
LQH32CN220	0.71	250	Murata 814-237-1431 www.murata.com
ELJPC220KF	4.0	160	Panasonic 714-373-7334 www.panasonic.com
CDRH3D16-220	0.53	350	Sumida 847-956-0666 www.sumida.com
LB2012B220M	1.7	75	Taiyo Yuden 408-573-4150 www.t-yuden.com
LEM2520-220	5.5	125	Taiyo Yuden 408-573-4150 www.t-yuden.com



**Figure 4. Efficiency Comparison of Different Inductors**

### Capacitor Selection

The small size of ceramic capacitors makes them ideal for LT3465A applications. X5R and X7R types are recommended because they retain their capacitance over wider voltage and temperature ranges than other types such as Y5V or Z5U. A 1μF input capacitor and a 0.22μF output capacitor are sufficient for most LT3465A applications.

**Table 2. Recommended Ceramic Capacitor Manufacturers**

MANUFACTURER	PHONE	URL
Taiyo Yuden	408-573-4150	www.t-yuden.com
Murata	814-237-1431	www.murata.com
Kemet	408-986-0424	www.kemet.com

### Inrush Current

The LT3465A has a built-in Schottky diode. When supply voltage is applied to the  $V_{IN}$  pin, the voltage difference between  $V_{IN}$  and  $V_{OUT}$  generates inrush current flowing from input through the inductor and the Schottky diode to charge the output capacitor to  $V_{IN}$ . The maximum current the Schottky diode in the LT3465A can sustain is 1A. The selection of inductor and capacitor value should ensure the peak of the inrush current to be below 1A. The peak inrush current can be calculated as follows:

$$I_P = \frac{V_{IN} - 0.6}{L \cdot \omega} \cdot \exp\left[-\frac{\alpha}{\omega} \cdot a \tan\left(\frac{\omega}{\alpha}\right)\right] \cdot \sin\left[a \tan\left(\frac{\omega}{\alpha}\right)\right]$$

$$\alpha = \frac{r + 1.5}{2 \cdot L}$$

$$\omega = \sqrt{\frac{1}{L \cdot C} - \frac{(r + 1.5)^2}{4 \cdot L^2}}$$

where  $L$  is the inductance,  $r$  is the resistance of the inductor and  $C$  is the output capacitance. For low DCR inductors, which is usually the case for this application, the peak inrush current can be simplified as follows:

$$I_P = \frac{V_{IN} - 0.6}{L \cdot \omega} \cdot \exp\left(-\frac{\alpha}{\omega} \cdot \frac{\pi}{2}\right)$$

## APPLICATIONS INFORMATION

Table 3 gives inrush peak currents for some component selections.

**Table 3. Inrush Peak Current**

V <sub>IN</sub> (V)	r (Ω)	L (μH)	C (μF)	I <sub>P</sub> (A)
5	0.5	22	0.22	0.38
5	0.5	22	1	0.70
3.6	0.5	22	0.22	0.26
5	0.5	33	1	0.60

### LED Current and Dimming Control

The LED current is controlled by the feedback resistor (R1 in Figure 1) and the feedback reference voltage.

$$I_{LED} = V_{FB}/R_{FB}$$

The CTRL pin sets the feedback reference voltage as shown in the Typical Performance Characteristics. When CTRL is at 1.8V or more, the feedback reference is 200mV, which results in full-scale LED current. The CTRL pin can be used as a dimming control when its voltage is between 200mV to 1.5V. To maintain LED current accuracy, a 1% or better resistor for R1 is recommended. The formula and table for R<sub>FB</sub> selection are shown below:

$$R_{FB} = 200mV/I_{LEDF}$$

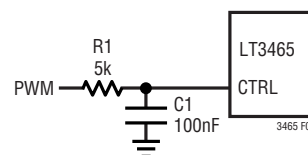
where I<sub>LEDF</sub> is full-scale LED current

**Table 4. R<sub>FB</sub> Resistor Value Selection**

I <sub>LED</sub> (mA)	R1 (Ω)
5	40.2
10	20.0
15	13.3
20	10.0

### Dimming Using Filtered PWM

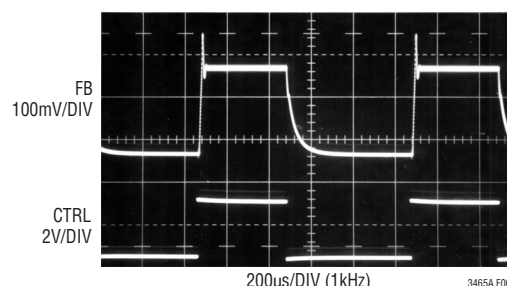
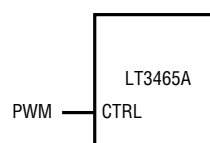
Dimming can be realized by using an RC filter in front of the CTRL pin to filter a PWM signal, as depicted in Figure 5. The filtered PWM signal is equivalent to a constant voltage. The time constant R1 • C1 should be much lower than the frequency of the PWM signal. Additionally, R1 should be small compared to the 50kΩ impedance of the CTRL pin. Suggested values are shown in Figure 5.



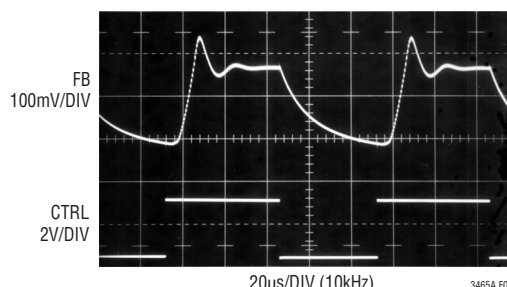
**Figure 5. Dimming Control Using a Filtered PWM Signal**

### Dimming Using Direct PWM

Unlike the LT3465, the LT3465A does not have internal soft-start. Although the input current is higher during start-up, the absence of soft-start allows the CTRL pin to be directly driven with a PWM signal for dimming. A zero percent duty cycle sets the LED current to zero, while 100% duty cycle sets it to full current. Average LED current increases proportionally with the duty cycle of the PWM signal. PWM frequency should be between 1kHz and 10kHz for best performance. The PWM signal should be at least 1.8V in magnitude; lower voltage will lower the feedback voltage as shown in Equation 1. Waveforms are shown for a 1kHz PWM and 10kHz PWM signal in Figures 6a and 6b respectively.



**Figure 6a.**



**Figure 6b.**

## APPLICATIONS INFORMATION

### Open Circuit Protection

The LT3465A has an internal open-circuit protection circuit. When the LEDs are disconnected from the circuit or fail open,  $V_{OUT}$  is clamped at 30V. The LT3465A will then switch at a low frequency, minimizing input current.  $V_{OUT}$  and input current during open circuit are shown in the Typical Performance Characteristics.

### Board Layout Consideration

As with all switching regulators, careful attention must be paid to the PCB board layout and component placement. To maximize efficiency, switch rise and fall times are made as short as possible. To prevent electromagnetic interference (EMI) problems, proper layout of the high frequency

switching path is essential. Place  $C_{OUT}$  next to the  $V_{OUT}$  pin. Always use a ground plane under the switching regulator to minimize interplane coupling. In addition, the ground connection for the feedback resistor  $R_1$  should be tied directly to the GND pin and not shared with any other component, ensuring a clean, noise-free connection. Recommended component placement is shown in Figure 7.

### Start-Up Input Current

As previously mentioned, the LT3465A does not have an internal soft-start circuit. Inrush current can therefore rise to approximately 400mA as shown in Figure 8 when driving 4 LEDs. The LT3465 has an internal soft-start circuit and is recommended if inrush current must be minimized.

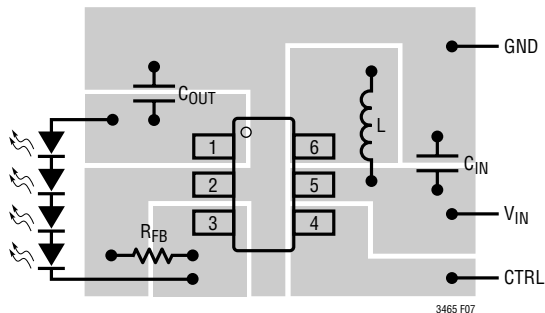


Figure 7. Recommended Component Placement

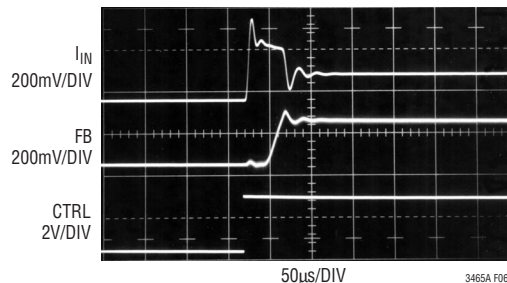
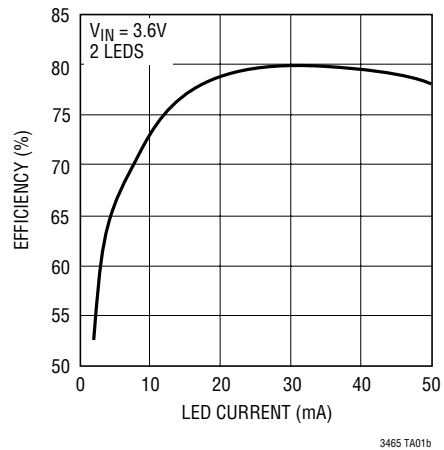
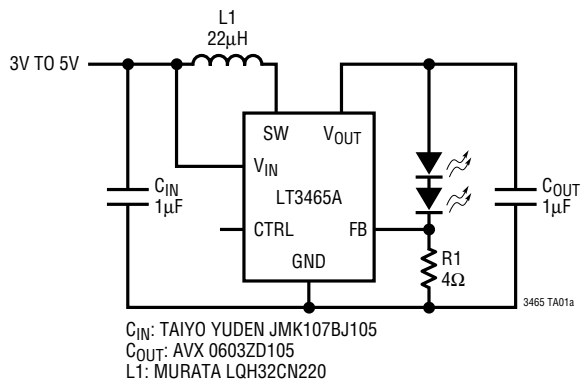


Figure 8.

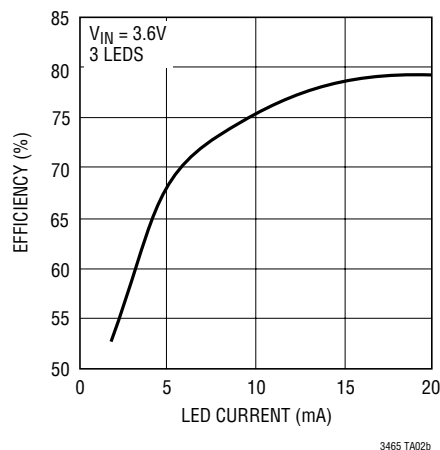
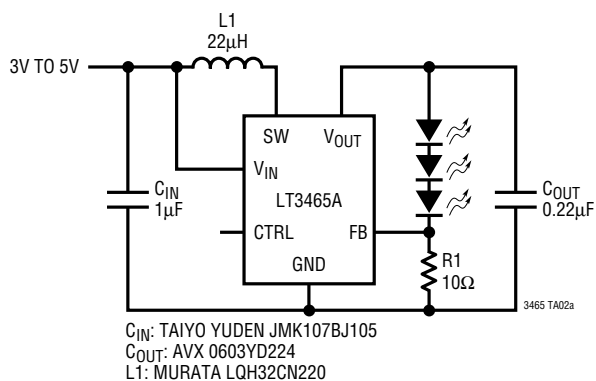


# TYPICAL APPLICATIONS

## Li-Ion to Two White LEDs

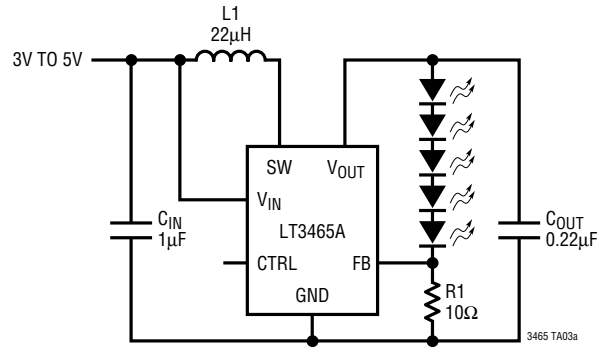


## Li-Ion to Three White LEDs

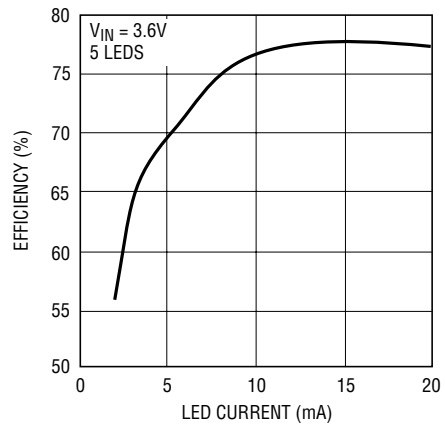


## TYPICAL APPLICATIONS

Li-Ion to Five White LEDs



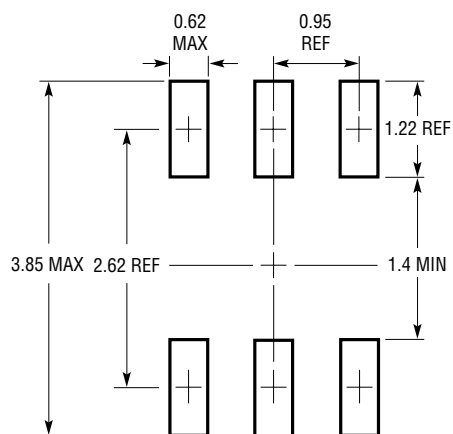
$C_{IN}$ : TAIYO YUDEN JMK107BJ105  
 $C_{OUT}$ : TAIYO YUDEN GMK212BJ224  
 $L1$ : MURATA LQH32CN220



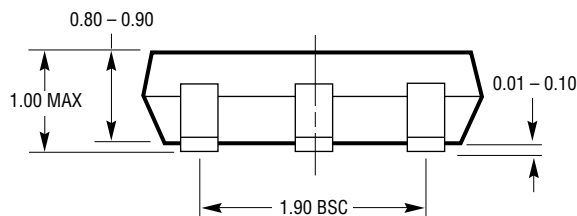
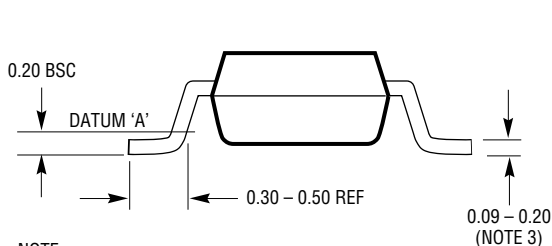
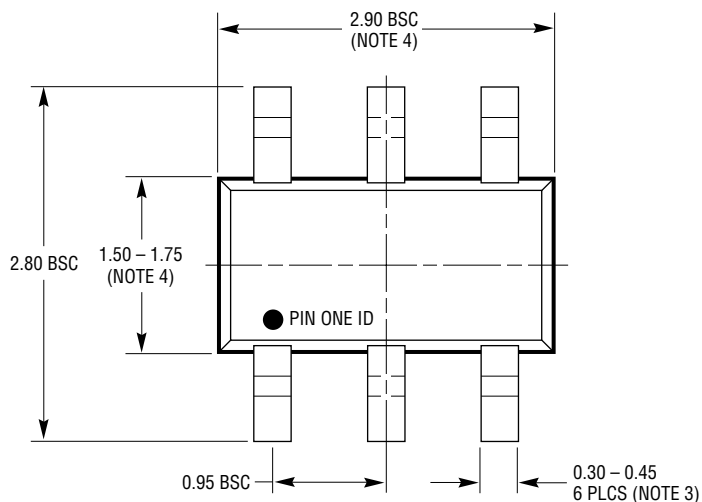
3465 TA03b

# PACKAGE DESCRIPTION

## S6 Package 6-Lead Plastic TSOT-23 (Reference LTC DWG # 05-08-1636)



RECOMMENDED SOLDER PAD LAYOUT  
PER IPC CALCULATOR

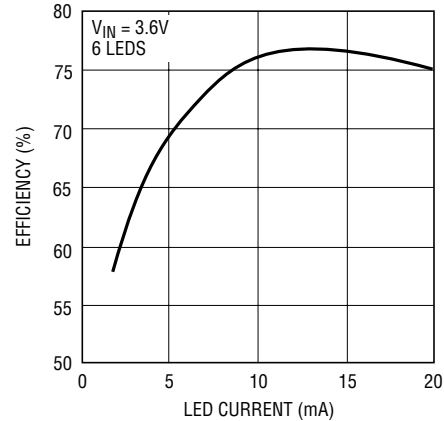
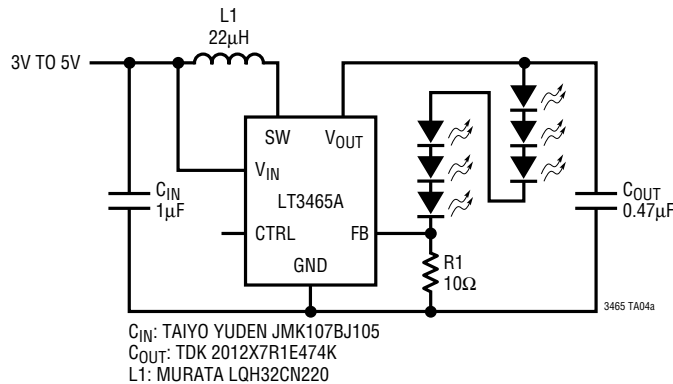


S6 TSOT-23 0302

- NOTE:
1. DIMENSIONS ARE IN MILLIMETERS
  2. DRAWING NOT TO SCALE
  3. DIMENSIONS ARE INCLUSIVE OF PLATING
  4. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
  5. MOLD FLASH SHALL NOT EXCEED 0.254mm
  6. JEDEC PACKAGE REFERENCE IS MO-193

## TYPICAL APPLICATION

### Li-Ion to Six White LEDs



3465 TA04b

## RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1618	Constant Current, Constant Voltage, 1.4MHz, High Efficiency Boost Regulator	Up to 16 White LEDs, $V_{IN}$ : 1.6V to 18V, $V_{OUT(MAX)}$ : 34V, $I_Q$ : 1.8mA, $I_{SD}$ : <1µA, 10-Lead MS Package
LT1932	Constant Current, 1.2MHz, High Efficiency White LED Boost Regulator	Up to 8 White LEDs, $V_{IN}$ : 1V to 10V, $V_{OUT(MAX)}$ : 34V, $I_Q$ : 1.2mA, $I_{SD}$ : <1µA, ThinSOT Package
LT1937	Constant Current, 1.2MHz, High Efficiency White LED Boost Regulator	Up to 4 White LEDs, $V_{IN}$ : 2.5V to 10V, $V_{OUT(MAX)}$ : 34V, $I_Q$ : 1.9mA, $I_{SD}$ : <1µA, ThinSOT, SC70 Packages
LTC®3200-5	Low Noise, 2MHz, Regulated Charge Pump White LED Driver	Up to 6 White LEDs, $V_{IN}$ : 2.7V to 4.5V, $I_Q$ : 8mA, $I_{SD}$ : <1µA, ThinSOT Package
LTC3200	Low Noise, 2MHz, Regulated Charge Pump White LED Driver	Up to 6 White LEDs, $V_{IN}$ : 2.7V to 4.5V, $I_Q$ : 8mA, $I_{SD}$ : <1µA, 10-Lead MS Package
LTC3201	Low Noise, 1.7MHz, Regulated Charge Pump White LED Driver	Up to 6 White LEDs, $V_{IN}$ : 2.7V to 4.5V, $I_Q$ : 6.5mA, $I_{SD}$ : <1µA, 10-Lead MS Package
LTC3202	Low Noise, 1.5MHz, Regulated Charge Pump White LED Driver	Up to 8 White LEDs, $V_{IN}$ : 2.7V to 4.5V, $I_Q$ : 5mA, $I_{SD}$ : <1µA, 10-Lead MS Package
LTC3404	600mA ( $I_{OUT}$ ), 1.4MHz Synchronous Step-Down DC/DC Converter	95% Efficiency, $V_{IN}$ : 2.7V to 6V, $V_{OUT(MIN)}$ : 0.8V, $I_Q$ : 10µA, $I_{SD}$ : <1µA, MS8 Package
LTC3405 LTC3405A	300mA ( $I_{OUT}$ ), 1.5MHz Synchronous Step-Down DC/DC Converters	95% Efficiency, $V_{IN}$ : 2.7V to 6V, $V_{OUT(MIN)}$ : 0.8V, $I_Q$ : 20µA, $I_{SD}$ : <1µA, ThinSOT Package
LTC3406 LTC3406B	600mA ( $I_{OUT}$ ), 1.5MHz Synchronous Step-Down DC/DC Converters	95% Efficiency, $V_{IN}$ : 2.5V to 5.5V, $V_{OUT(MIN)}$ : 0.6V, $I_Q$ : 20µA, $I_{SD}$ : <1µA, ThinSOT Package
LT3407	Dual 600mA ( $I_{OUT}$ ), 1.5MHz Synchronous Step-Down DC/DC Converter	96% Efficiency, $V_{IN}$ : 2.5V to 5.5V, $V_{OUT(MIN)}$ : 0.6V, $I_Q$ : 40µA, $I_{SD}$ : <1µA, MS Package
LTC3412	2.5A ( $I_{OUT}$ ), 4MHz Synchronous Step-Down DC/DC Converter	95% Efficiency, $V_{IN}$ : 2.5V to 5.5V, $V_{OUT(MIN)}$ : 0.8V, $I_Q$ : 60µA, $I_{SD}$ : <1µA, TSSOP16E Package
LTC3440	600mA ( $I_{OUT}$ ), 2MHz Synchronous Buck-Boost DC/DC Converter	95% Efficiency, $V_{IN}$ : 2.5V to 5.5V, $V_{OUT(MIN)}$ : 2.5V, $I_Q$ : 25µA, $I_{SD}$ : <1µA, 10-Lead MS Package
LTC3465	Constant Current, 1.2MHz, High Efficiency White LED Boost Regulator	Up to 5 White LEDs, $V_{IN}$ : 2.7V to 16V, $I_Q$ : 1.9A, $I_{SD}$ : <1µA, ThinSOT Package

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