CAT3644

4-Channel Ultra High Efficiency Quad-Mode® LED Driver

Description

The CAT3644 is a high efficiency Quad−Mode® fractional charge pump that can drive up to four LEDs programmable by a one wire digital interface. The inclusion of a 1.33x fractional charge pump mode increases device efficiency by up to 10% over traditional 1.5x charge pumps with no added external capacitors.

Low noise input ripple is achieved by operating at a constant switching frequency which allows the use of small external ceramic capacitors. The multi−fractional charge pump supports a wide range of input voltages from 2.5 V to 5.5 V.

The EN/DIM logic input functions as a chip enable and a digital dimming interface for current setting of all LEDs. Six different current ratios are available via the interface.

The device is available in the tiny 16−pad TQFN 3 mm x 3 mm package with a max height of 0.8 mm.

ON Semiconductor's Quad−Mode® 1.33x charge pump switching architecture is patented.

Features

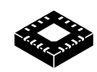
- High Efficiency 1.33x Charge Pump
- Quad−mode Charge Pump: 1x, 1.33x, 1.5x, 2x
- Drives up to 4 LEDs at 25 mA Each
- 1−wire EZDim LED Current Programming
- Power Efficiency up to 92%
- Low Noise Input Ripple in All Modes
- "Zero" Current Shutdown Mode
- Soft Start and Current Limiting
- Short Circuit Protection
- Thermal Shutdown Protection
- 3 mm x 3 mm, 16−pad TQFN Package
- These Devices are Pb−Free, Halogen Free/BFR Free and are RoHS Compliant

Applications

- LCD Display Backlight
- Cellular Phones
- Digital Still Cameras
- Handheld Devices

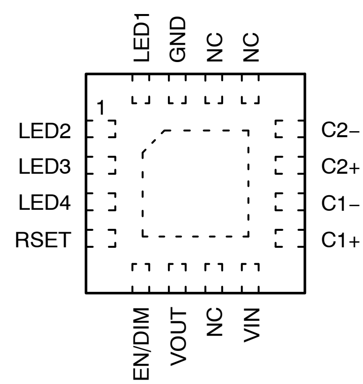
ON Semiconductor®

http://onsemi.com



TQFN−16
HV3 SUFFIX
CASE 510AD

PIN CONNECTIONS



(Top View)

MARKING DIAGRAMS

JAAG AXXX YWW	JAAH AXXX YWW

JAAG = CAT3644HV3−T2
JAAH = CAT3644HV3−GT2
A = Assembly Location
XXX = Last Three Digits of Assembly Lot Number
Y = Production Year (Last Digit)
WW = Production Week (Two Digits)

ORDERING INFORMATION

Device	Package	Shipping†
CAT3644HV3−T2 (Note 1)	TQFN−16 (Pb−Free)	2,000/ Tape & Reel
CAT3644HV3−GT2 (Note 2)	TQFN−16 (Pb−Free)	

1. Matte−Tin Plated Finish (RoHS−compliant).
2. NiPdAu Plated Finish (RoHS−compliant).

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specification Brochure, BRD8011/D.

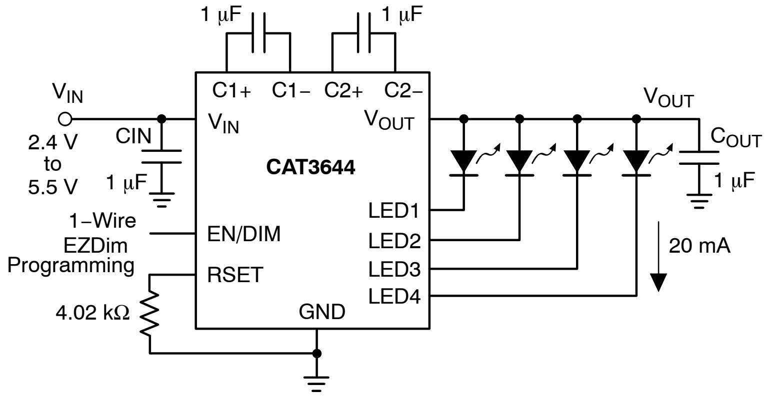


Figure 1. Typical Application Circuit

Table 1. ABSOLUTE MAXIMUM RATINGS

Parameter	Rating	Unit
V_{IN}, LEDx, C1±, C2±, EN/DIM voltage	6	V
V_{OUT} voltage	7	V
Storage Temperature Range	−65 to +160	°C
Junction Temperature Range	−40 to +150	°C

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

Table 2. RECOMMENDED OPERATING CONDITIONS

Parameter	Rating	Unit
V_{IN}	2.5 to 5.5	V
Ambient Temperature Range	−40 to +85	°C
I_{LED} per LED pin	up to 30	mA
LED Forward Voltage Range	1.3 to 4.3	V

NOTE: Typical application circuit with external components is shown above.

Table 3. ELECTRICAL OPERATING CHARACTERISTICS
(over recommended operating conditions unless specified otherwise) V_{IN} = 3.6 V, EN = High, T_{AMB} = 25°C.

Symbol	Name	Conditions	Min	Typ	Max	Units
I_Q	Quiescent Current	1x mode, no load 1.33x mode, no load 1.5x mode, no load 2x mode, no load		1.0 1.7 2.2 2.4		mA
I_{QSHDN}	Shutdown Current	V_{EN} = 0 V			1	μA
$I_{LED-ACC}$	LED Current Accuracy	(I_{LEDAVG} – $I_{NOMINAL}$) / $I_{NOMINAL}$ RSET = 5 kΩ		±2		%
$I_{LED-DEV}$	LED Channel Matching	(I_{LED} – I_{LEDAVG}) / I_{LEDAVG}		±1.5		%
V_{RSET}	RSET Regulated Voltage		0.58	0.6	0.62	V
R_{OUT}	Output Resistance (open loop)	1x mode 1.33x mode, V_{IN} = 3 V 1.5x mode, V_{IN} = 2.7 V 2x mode, V_{IN} = 2.4 V		0.8 5 5 10		Ω
F_{OSC}	Charge Pump Frequency	1.33x and 2x mode 1.5x mode	0.8 1	1 1.3	1.3 1.6	MHz
I_{SC_MAX}	Output short circuit Current Limit	V_{OUT} < 0.5 V		50		mA
I_{IN_MAX}	Input Current Limit	V_{OUT} > 1 V		250		mA
LED_{TH}	1x to 1.33x or 1.33x to 1.5x or 1.5x to 2x Transition Thresholds at any LED pin			130		mV
V_{HYS}	1x Mode Transition Hysteresis			400		mV
T_{DF}	Transition Filter Delay			500		μs
 $R_{EN/DIM}$ V_{HI} V_{LO}	EN/DIM Pin – Internal Pull–down Resistor – Logic High Level – Logic Low Level		 1.3 	 100 	 0.4	 kΩ V V
T_{SD}	Thermal Shutdown			150		°C
T_{HYS}	Thermal Hysteresis			20		°C
V_{UVLO}	Undervoltage lockout (UVLO) threshold		1.6	1.8	2.0	V

Table 4. RECOMMENDED EN/DIM TIMING
(For 2.4 V ≤ V_{IN} ≤ 5.5 V, over full ambient temperature range −40°C to +85°C.)

Symbol	Name	Conditions	Min	Typ	Max	Units
T_{SETUP}	EN/DIM setup from shutdown		10			μs
T_{LO}	EN/DIM program low time		0.2		100	μs
T_{HI}	EN/DIM program high time		0.2			μs
T_{PWRDWN}	EN/DIM low time to shutdown		1.5			ms
T_{LED}	LED current settling time			40		μs

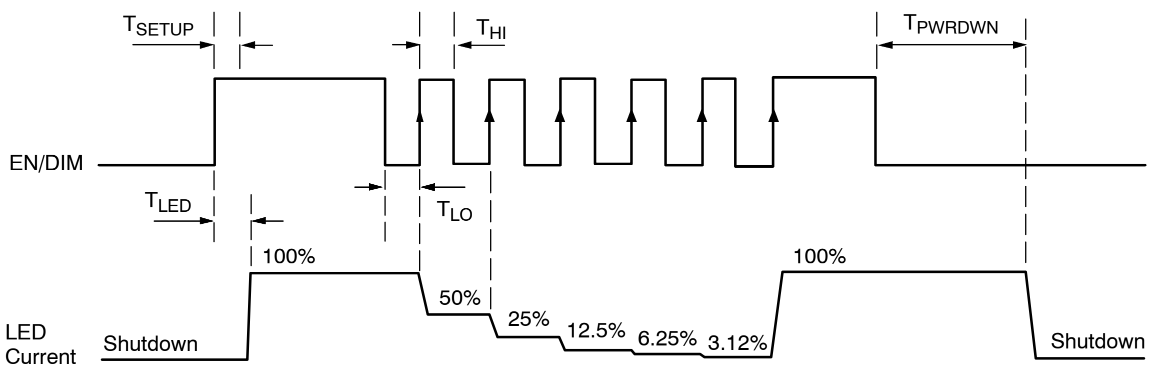


Figure 2. EN/DIM Digital Dimming Timing Diagram

LED Current Setting

The nominal LED current is set by the external resistor connected between the RSET pin and ground. Table 5 lists standard resistor values for several LED current settings.

Table 5. RESISTOR RSET AND LED CURRENT

LED Current (mA)	RSET (kΩ)
2	40.0
5	15.8
10	7.87
15	5.23
20	4.02
25	3.16
30	2.67

TYPICAL PERFORMANCE CHARACTERISTICS

(V_{IN} = 3.6 V, I_{OUT} = 80 mA (4 LEDs at 20 mA), C_{IN} = C_{OUT} = C_1 = C_2 = 1 μF, T_{AMB} = 25°C unless otherwise specified.)

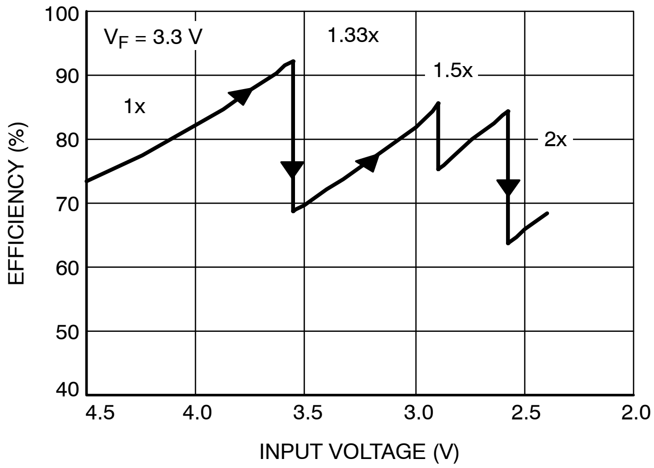


Figure 3. Efficiency vs. Input Voltage

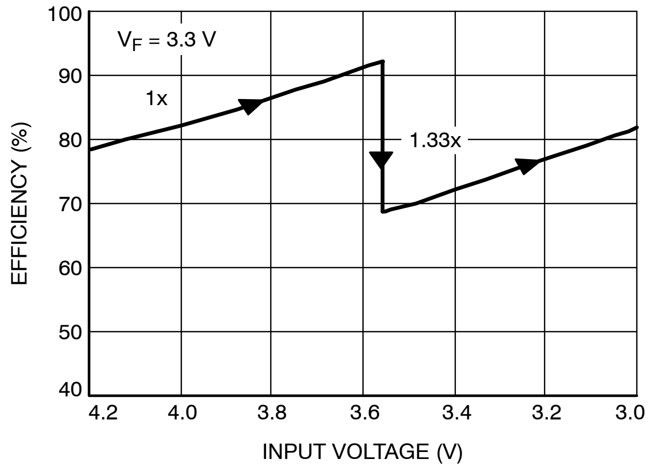


Figure 4. Efficiency vs. Li−Ion Voltage

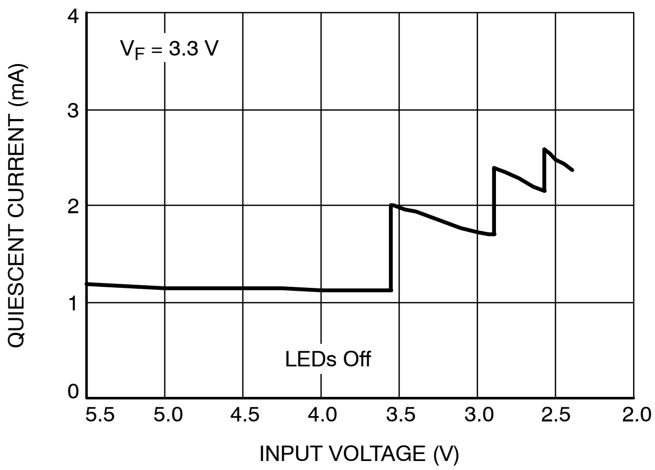


Figure 5. Quiescent Current vs. Input Voltage

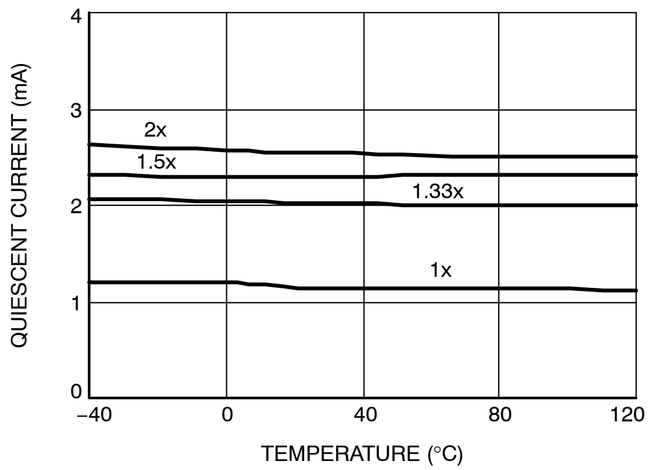


Figure 6. Quiescent Current vs. Temperature

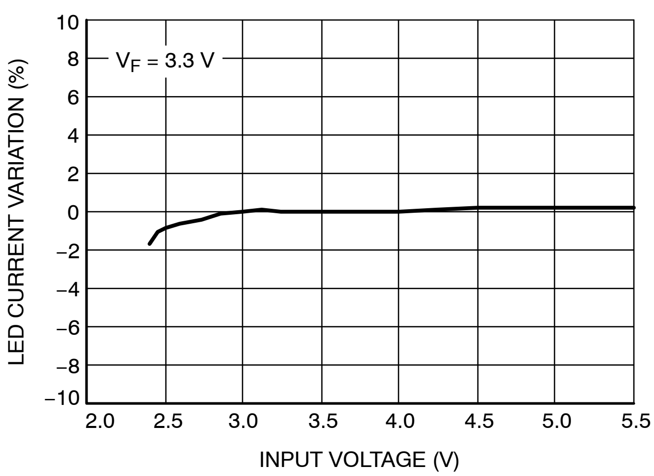


Figure 7. LED Current Change vs. Input Voltage

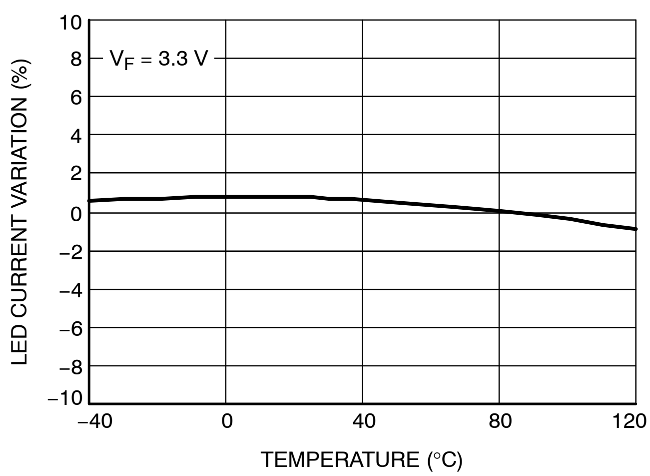


Figure 8. LED Current Change vs. Temperature

TYPICAL PERFORMANCE CHARACTERISTICS

(V_{IN} = 3.6 V, I_{OUT} = 80 mA (4 LEDs at 20 mA), C_{IN} = C_{OUT} = C_1 = C_2 = 1 µF, T_{AMB} = 25°C unless otherwise specified.)

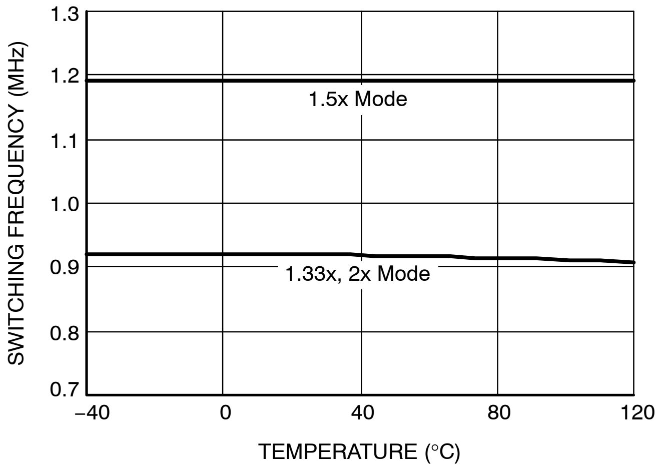


Figure 9. Switching Frequency vs. Temperature

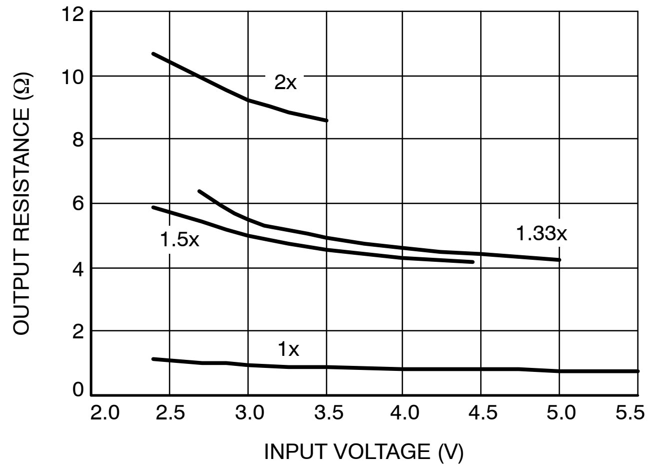


Figure 10. Output Resistance vs. Input Voltage

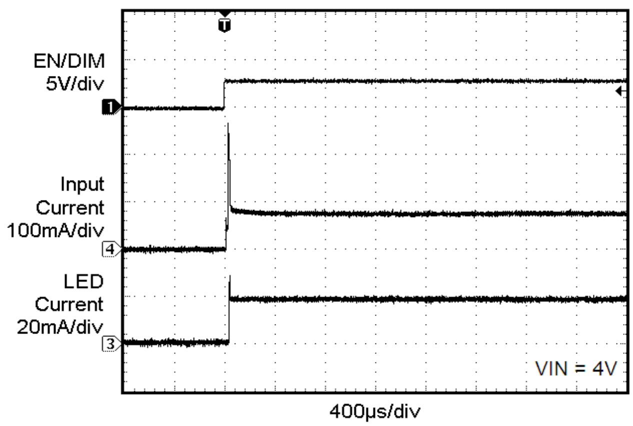


Figure 11. Power Up in 1x Mode

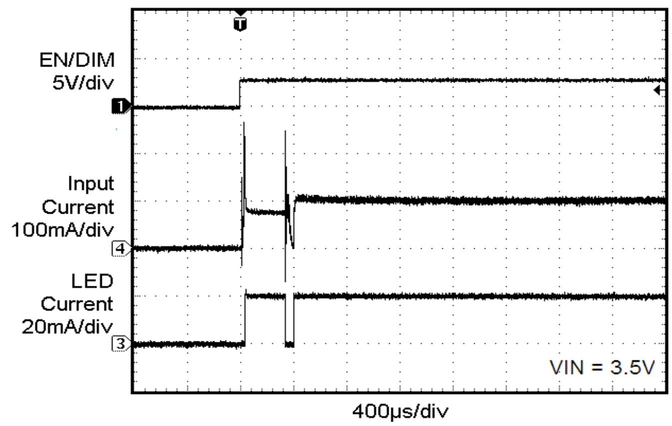


Figure 12. Power Up in 1.33x Mode

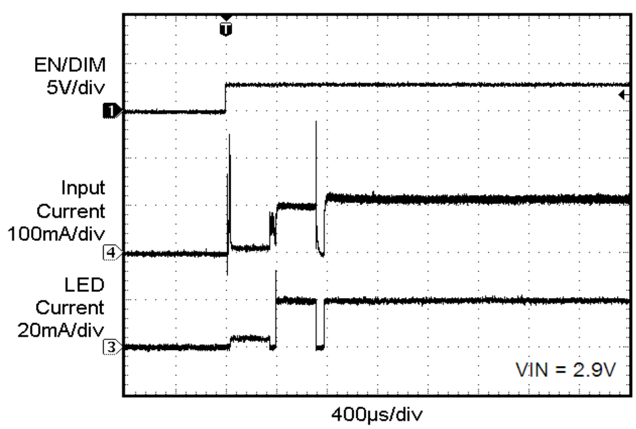


Figure 13. Power Up in 1.5x Mode

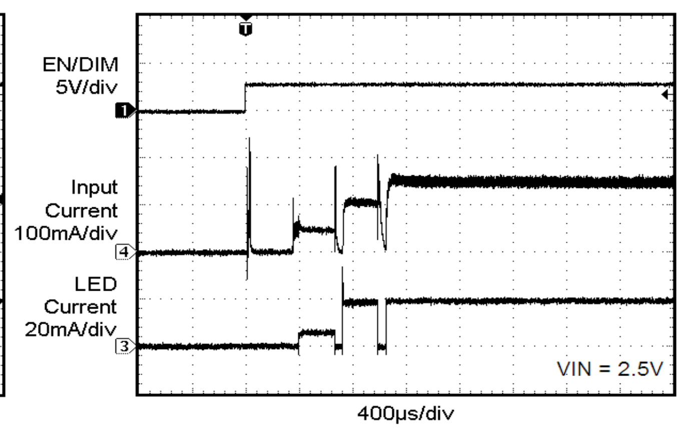


Figure 14. Power Up in 2x Mode

TYPICAL PERFORMANCE CHARACTERISTICS

(V_{IN} = 3.6 V, I_{OUT} = 80 mA (4 LEDs at 20 mA), C_{IN} = C_{OUT} = C_1 = C_2 = 1 μF, T_{AMB} = 25°C unless otherwise specified.)

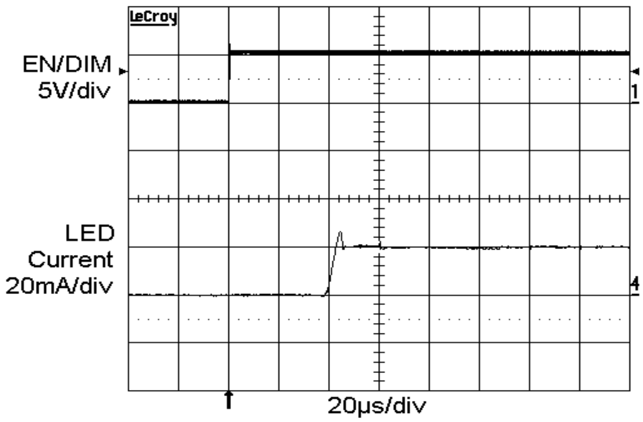


Figure 15. Power Up Delay (1x Mode)

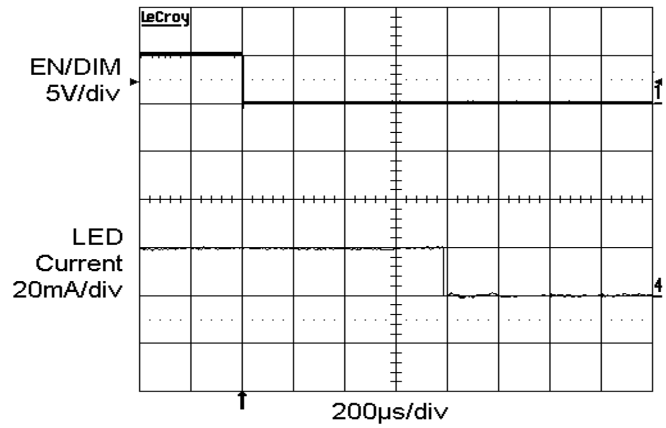


Figure 16. Power Down Delay (1x Mode)

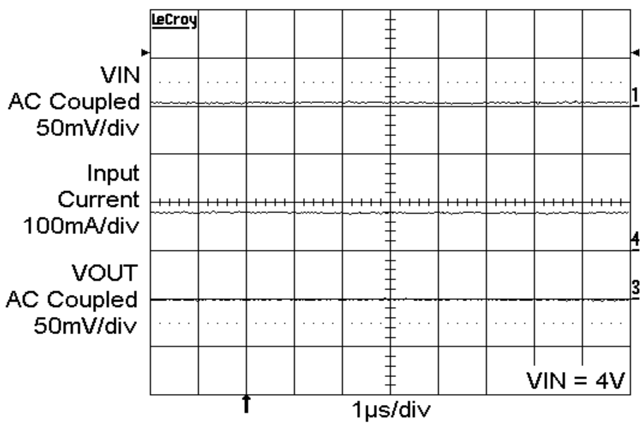


Figure 17. Operating Waveforms in 1x Mode

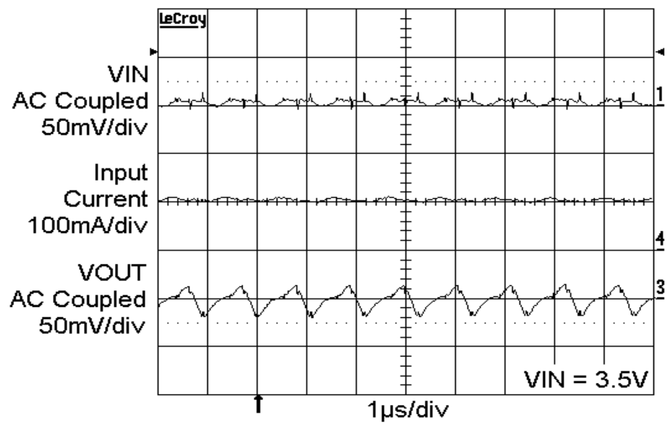


Figure 18. Switching Waveforms in 1.33x Mode

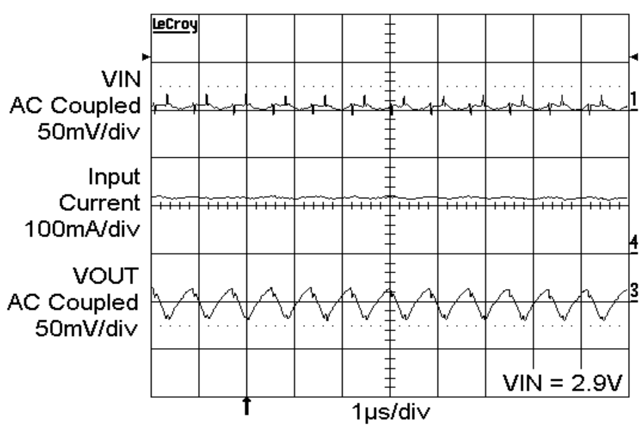


Figure 19. Switching Waveforms in 1.5x Mode

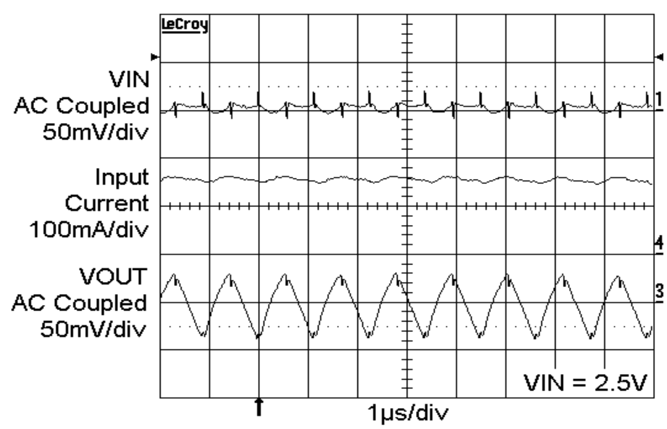


Figure 20. Switching Waveforms in 2x Mode

TYPICAL PERFORMANCE CHARACTERISTICS

(V_{IN} = 3.6 V, I_{OUT} = 80 mA (4 LEDs at 20 mA), $C_{IN} = C_{OUT} = C_1 = C_2$ = 1 μF, T_{AMB} = 25°C unless otherwise specified.)

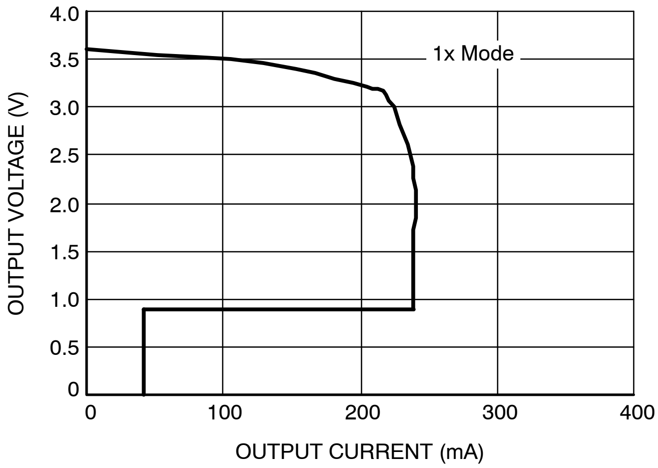


Figure 21. Foldback Current Limit

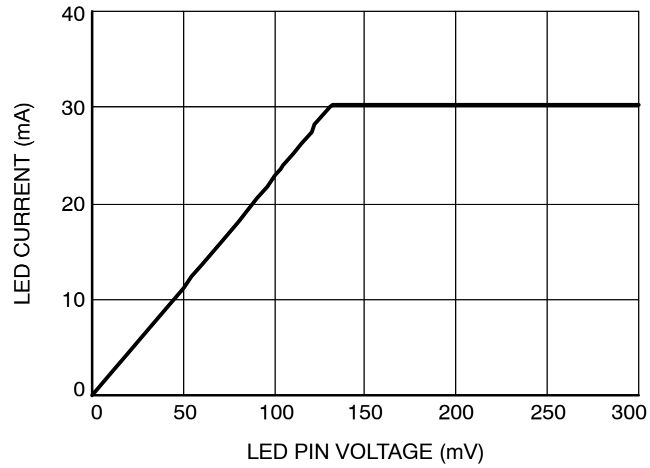


Figure 22. LED Current vs. LED Pin Voltage

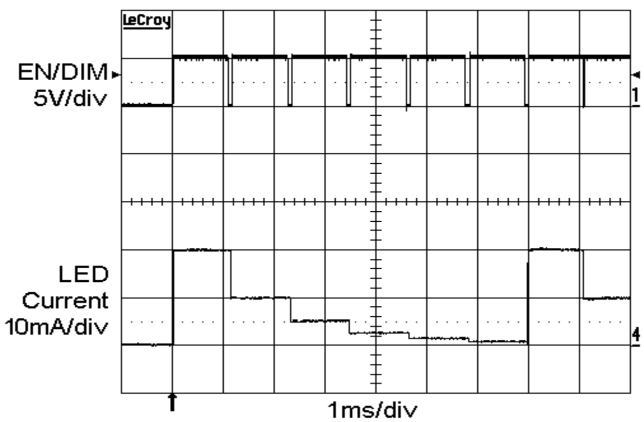


Figure 23. Dimming Waveform

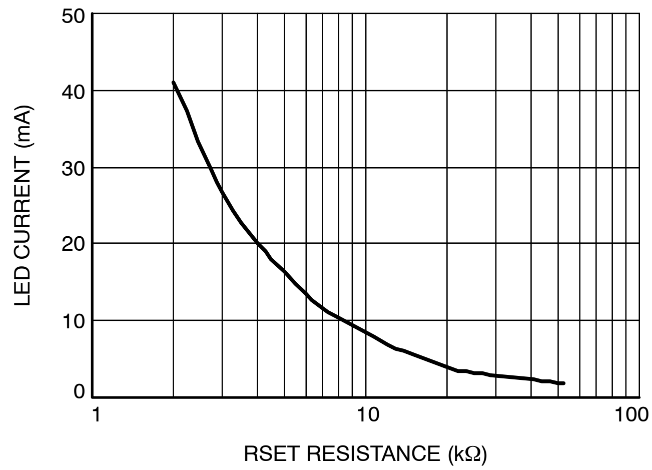


Figure 24. LED Current vs. RSET

Table 6. PIN DESCRIPTION

Pin #	Name	Function
1	LED2	LED2 cathode terminal.
2	LED3	LED3 cathode terminal.
3	LED4	LED4 cathode terminal.
4	RSET	Connect resistor RSET to set the LED current.
5	EN/DIM	Device enable (active high) and Dimming Control.
6	VOUT	Charge pump output connected to the LED anodes.
7	NC	Not connected inside the package.
8	VIN	Charge pump input, connect to battery or supply.
9	C1+	Bucket capacitor 1 Positive terminal
10	C1−	Bucket capacitor 1 Negative terminal
11	C2+	Bucket capacitor 2 Positive terminal
12	C2−	Bucket capacitor 2 Negative terminal
13	NC	Not connected inside the package.
14	NC	Not connected inside the package.
15	GND	Ground Reference
16	LED1	LED1 cathode terminal.
TAB	GND	Connect to GND on the PCB.

Pin Function

VIN is the supply pin for the charge pump. A small 1 μF ceramic bypass capacitor is required between the VIN pin and ground near the device. The operating input voltage range is from 2.5 V to 5.5 V. Whenever the input supply falls below the under−voltage threshold (1.8 V), all the LED channels are disabled and the device enters shutdown mode.

EN/DIM is the enable and one wire dimming input for all LED channels. Levels of logic high and logic low are set at 1.3 V and 0.4 V respectively. When EN/DIM is initially taken high, the device becomes enabled and all LED currents are set to the full scale according to the resistor R_{SET}. To place the device into "zero current" shutdown mode, the EN/DIM pin must be held low for at least 1.5 ms.

VOUT is the charge pump output that is connected to the LED anodes. A small 1 μF ceramic bypass capacitor is required between the V_{OUT} pin and ground near the device.

GND is the ground reference for the charge pump. The pin must be connected to the ground plane on the PCB.

C1+, C1− are connected to each side of the ceramic bucket capacitor C_1.

C2+, C2− are connected to each side of the ceramic bucket capacitor C_2.

LED1 to LED4 provide the internal regulated current source for each of the LED cathodes. These pins enter high−impedance zero current state whenever the device is placed in shutdown mode.

TAB is the exposed pad underneath the package. For best thermal performance, the tab should be soldered to the PCB and connected to the ground plane.

RSET is connected to the resistor (R_{SET}) to set the full scale current for the LEDs. The voltage at this pin regulated to 0.6 V. The ground side of the external resistor should be star connected back to the GND of the PCB. In shutdown mode, RSET becomes high impedance.

Block Diagram

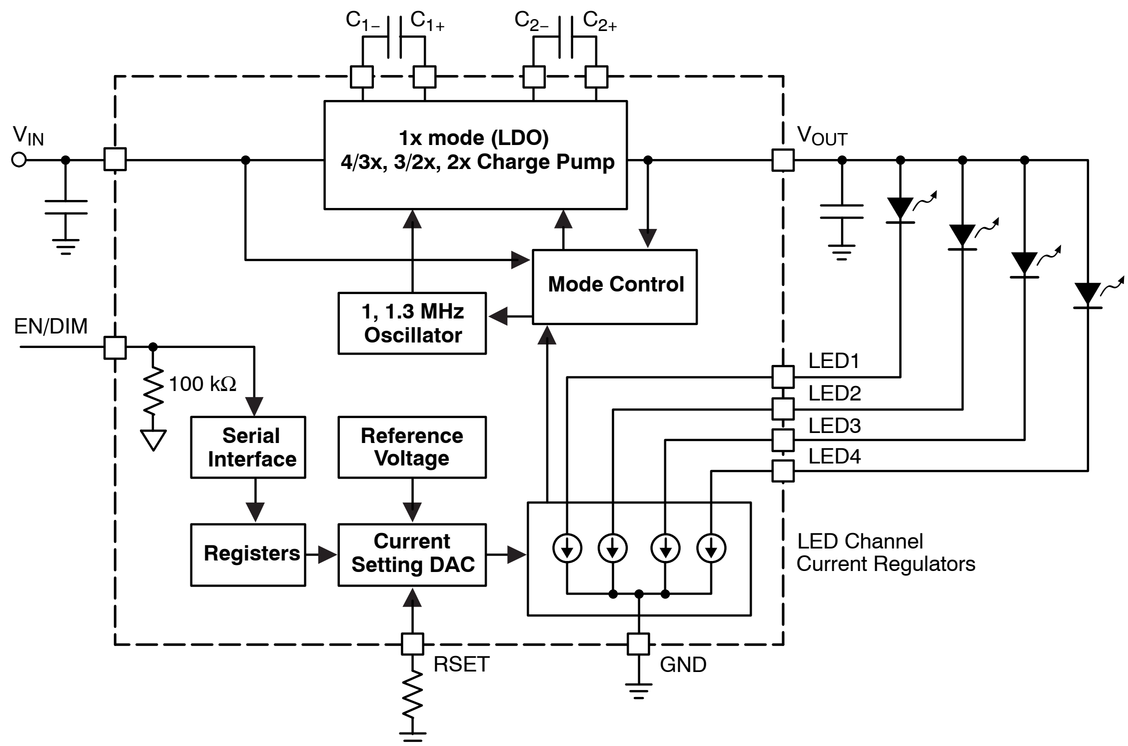


Figure 25. CAT3644 Functional Block Diagram

Basic Operation

At power−up, the CAT3644 starts operating in 1x mode where the output will be approximately equal to the input supply voltage (less any internal voltage losses). If the output voltage is sufficient to regulate all LED currents, the device remains in 1x operating mode.

If the input voltage is insufficient or falls to a level where the regulated currents cannot be maintained, the device automatically switches into 1.33x mode (after a fixed delay time of about 400 μs). In 1.33x mode, the output voltage is approximately equal to 1.33 times the input supply voltage (less any internal voltage losses).

This sequence repeats in the 1.33x and 1.5x mode until the driver enters the 2x mode. In 1.5x mode, the output voltage is approximately equal to 1.5 times the input supply voltage. While in 2x mode, the output is approximately equal to 2 times the input supply voltage.

If the device detects a sufficient input voltage is present to drive all LED currents in 1x mode, it will change automatically back to 1x mode. This only applies for changing back to the 1x mode. The difference between the input voltage when exiting 1x mode and returning to 1x mode is called the 1x mode transition hysteresis (V_{HYS}) and is about 500 mV.

LED Current Selection

At power−up, the initial LED current is set to full scale (100% brightness) by the external resistor R_{SET} as follows:

$$\text{LED current} = 132 \times \frac{0.6\ \text{V}}{R_{SET}}$$

The EN/DIM pin has two primary functions. One function enables and disables the device. The other function is LED current dimming with six different levels by pulsing the input signal, as shown on Figure 26. On each consecutive pulse rising edge, the LED current is divided by half to 50%, then 25%, 12.5%, 6.25% and 3.125% dimming levels. Pulses faster than the minimum T_{LO} may be ignored and filtered by the device. Pulses longer than the maximum T_{LO} may shutdown the device.

The LED driver enters a “zero current” shutdown mode if EN/DIM is held low for 1.5 ms or more.

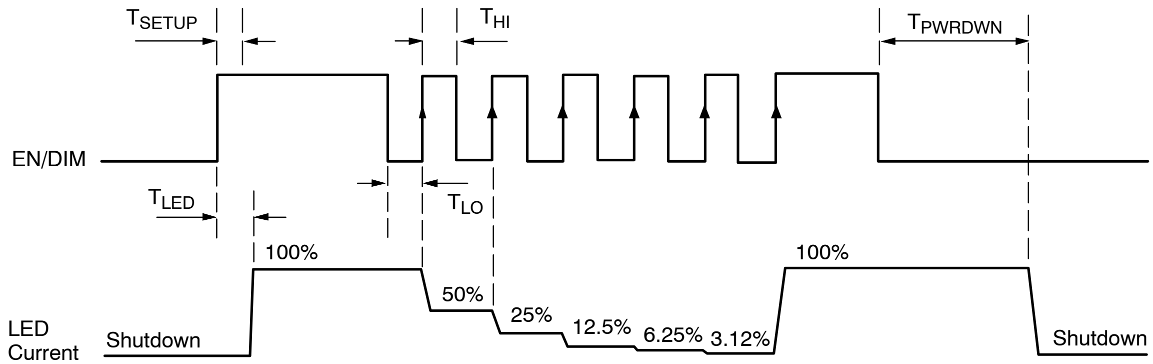


Figure 26. EN/DIM Digital Dimming Timing Diagram

Table 7. LED CURRENT DIMMING LEVELS

EN/DIM # of Pulses *	R_{SET} Gain	LED Current
EN = High	132	132 x 0.6 V / R_{SET}
1st	66	66 x 0.6 V / R_{SET}
2nd	33	33 x 0.6 V / R_{SET}
3rd	16.5	16.5 x 0.6 V / R_{SET}
4th	8.25	8.25 x 0.6 V / R_{SET}
5th	4.125	4.125 x 0.6 V / R_{SET}
6th	132	132 x 0.6 V / R_{SET}
xth	Device cycling through gain selection	GAIN x 0.6 V / R_{SET}

* The gain is changed on the rising edges of the EN/DIM input.

Unused LED Channels

For applications not requiring all the channels, it is recommended the unused LED pins be tied directly to V_{OUT} (see Figure 27).

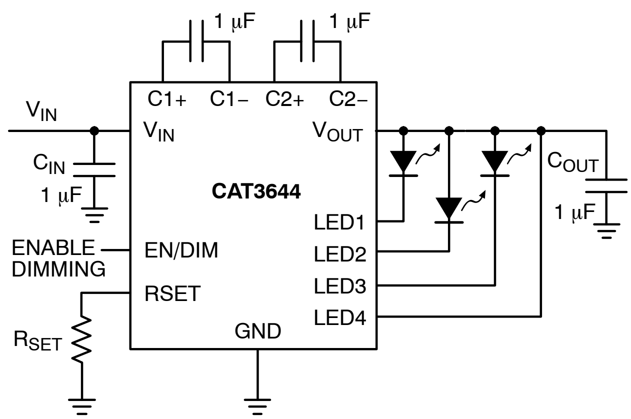


Figure 27. Application with 3 LEDs

Protection Mode

If an LED is disconnected, the driver senses that and automatically ignores that channel. When all LEDs are disconnected, the driver goes to 1x mode where the output is equal to the input voltage.

As soon as the output exceeds about 6 V, the driver resets itself and reevaluate the mode.

If the die temperature exceeds +150°C, the driver will enter a thermal protection shutdown mode. When the device temperature drops by about 20°C, the device will resume normal operation.

LED Selection

LEDs with forward voltages (V_F) ranging from 1.3 V to 4.3 V may be used. Selecting LEDs with lower V_F is recommended in order to improve the efficiency by keeping the driver in 1x mode longer as the battery voltage decreases.

For example, if a white LED with a V_F of 3.3 V is selected over one with V_F of 3.5 V, the driver will stay in 1x mode for lower supply voltage of 0.2 V. This helps improve the efficiency and extends battery life.

External Components

The driver requires four external 1 μF ceramic capacitors for decoupling input, output, and for the charge pump. Both capacitors type X5R and X7R are recommended for the LED driver application. In all charge pump modes, the input current ripple is kept very low by design and an input bypass capacitor of 1 μF is sufficient.

In 1x mode, the device operates in linear mode and does not introduce switching noise back onto the supply.

Recommended Layout

In charge pump mode, the driver switches internally at a high frequency. It is recommended to minimize trace length to all four capacitors. A ground plane should cover the area under the driver IC as well as the bypass capacitors. Short connection to ground on capacitors C_{IN} and C_{OUT} can be implemented with the use of multiple via. A copper area matching the TQFN exposed pad (TAB) must be connected to the ground plane underneath. The use of multiple via improves the package heat dissipation.

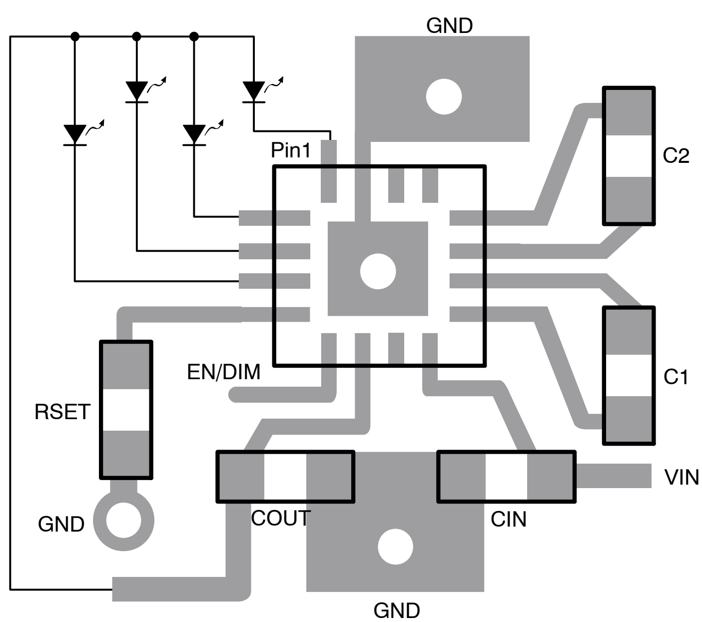
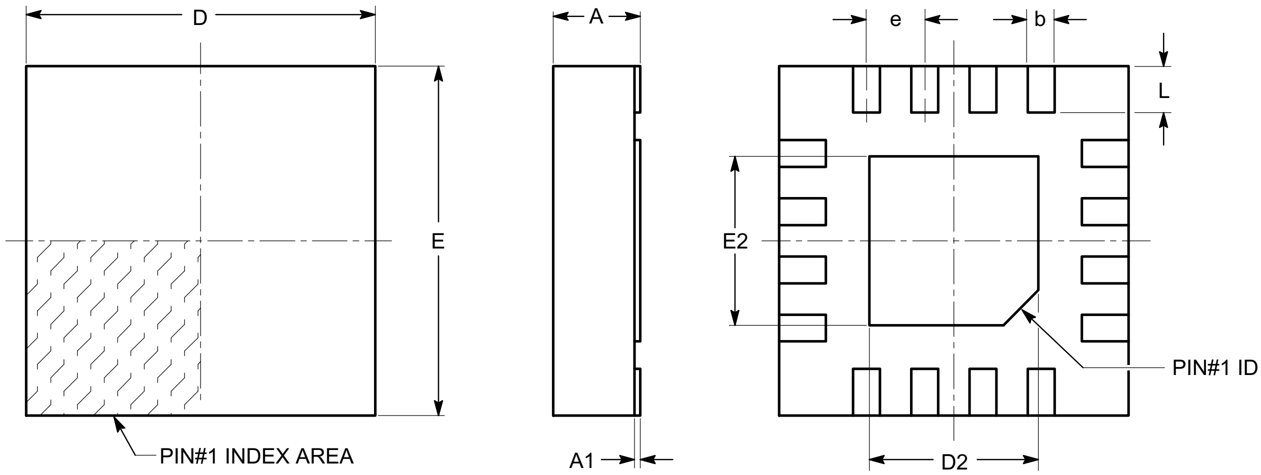


Figure 28. Recommended Layout

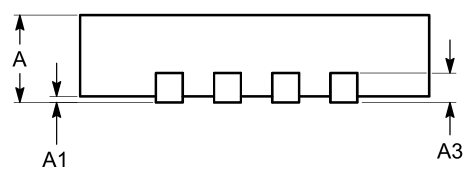
PACKAGE DIMENSIONS

TQFN16, 3x3
CASE 510AD−01
ISSUE A



TOP VIEW **SIDE VIEW** **BOTTOM VIEW**

SYMBOL	MIN	NOM	MAX
A	0.70	0.75	0.80
A1	0.00	0.02	0.05
A3	0.20 REF		
b	0.18	0.25	0.30
D	2.90	3.00	3.10
D2	1.40	−−−	1.80
E	2.90	3.00	3.10
E2	1.40	−−−	1.80
e	0.50 BSC		
L	0.30	0.40	0.50



FRONT VIEW

Notes:
(1) All dimensions are in millimeters.
(2) Complies with JEDEC MO-220.

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
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P.O. Box 5163, Denver, Colorado 80217 USA
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Email: orderlit@onsemi.com

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Phone: 421 33 790 2910
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