3-Channel Ultra High Efficiency Quad-Mode® LED Driver with 32 Dimming Levels

FEATURES

- High efficiency 1.33x charge pump
- Quad-mode charge pump: 1x, 1.33x, 1.5x, 2x
- Drives up to 3 LEDs at 30mA each
- 1-wire EZDim™ 32 linear steps
- 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
- RoHS-compliant 16-pad TQFN package

APPLICATION

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

ORDERING INFORMATION

Part Number	Package	Marking
CAT3647HV3-GT2	TQFN-16 3mm x 3mm(1)	JAAP

Notes:

(1) NiPdAu Plated Finish (RoHS-compliant)

(2) Quantity per reel is 2000

DESCRIPTION

The CAT3647 is a high efficiency quad-mode fractional charge pump that can drive up to three 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.

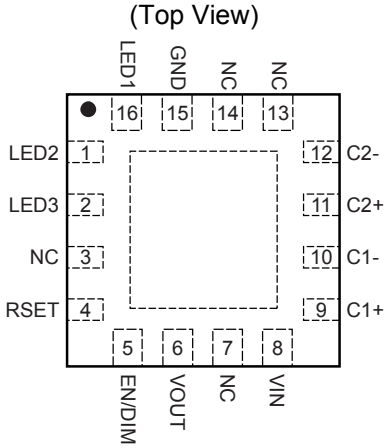
Low noise input ripple is achieved by operating at a constant switching frequency which allows the use of small external ceramic capacitors. The multi-fractional charge pump supports a wide range of input voltages from 2.4V to 5.5V.

The EN/DIM logic input functions as a chip enable and a digital dimming interface for setting the current in all the LED channels. The 1-wire pulse-dimming interface supports 32 linear steps from full-scale down to zero current.

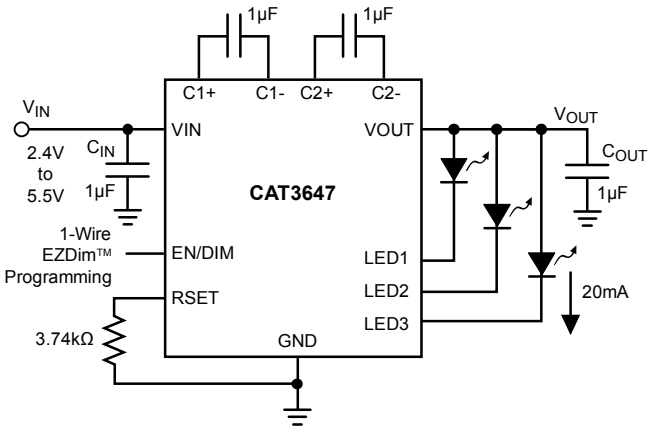
The device is available in the tiny 16-pad TQFN 3mm x 3mm package with a max height of 0.8mm.

Catalyst Semiconductor's Quad-Mode® 1.33x, charge pump switching architecture is patented.

PIN CONFIGURATION



TYPICAL APPLICATION CIRCUIT



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ABSOLUTE MAXIMUM RATINGS

Parameter	Rating	Unit
VIN, LEDx, C1±, C2±, EN/DIM, RSET voltage	6	V
VOUT voltage	7	V
Storage Temperature Range	-65 to +160	°C
Junction Temperature Range	-40 to +150	°C

RECOMMENDED OPERATING CONDITIONS

Parameter	Rating	Unit
VIN	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

Typical application circuit with external components is shown on page 1.

ELECTRICAL OPERATING CHARACTERISTICS

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

Symbol	Name	Conditions	Min	Typ	Max	Units
I_Q	Quiescent Current	1x mode, excluding load 1.33 x mode, excluding load 1.5x mode, excluding load 2x mode, excluding load		1.0 1.7 2.2 2.4		mA mA mA mA
I_{QSHDN}	Shutdown Current	V_{EN} = 0V			1	µA
$I_{LED-ACC}$	LED Current Setting	RSET = 3.74kΩ RSET = 7.50kΩ		20 10		mA
$I_{LED-ACC}$	LED Current Accuracy	(I_{LEDAVG} – $I_{NOMINAL}$) / $I_{NOMINAL}$ RSET = 4.99kΩ		±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} = 3V 1.5x mode, V_{IN} = 2.7V 2x mode, V_{IN} = 2.4V		0.8 5 5 10		Ω Ω Ω 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 MHz
I_{SC_MAX}	Output short circuit Current Limit	V_{OUT} < 0.5V		50		mA
I_{IN_MAX}	Input Current Limit	V_{OUT} > 1V, 1x mode		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}	Mode Transition Filter Delay			120		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

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RECOMMENDED EN/DIM TIMING

For 2.4V ≤ V_{IN} ≤ 5.5V, over full ambient temperature range -40ºC to +85ºC.

Symbol	Name	Conditions	Min	Typ	Max	Units
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

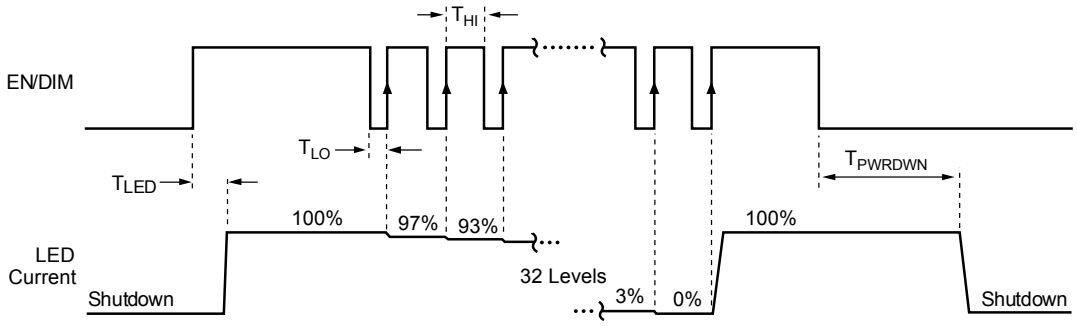


Figure 1. EN/DIM Digital Dimming Timing Diagram

LED Current Setting

The full scale LED current is set by the external resistor connected between the RSET pin and ground. Table 1 lists standard resistor values for several LED current settings.

Table 1. Resistor RSET and LED Current

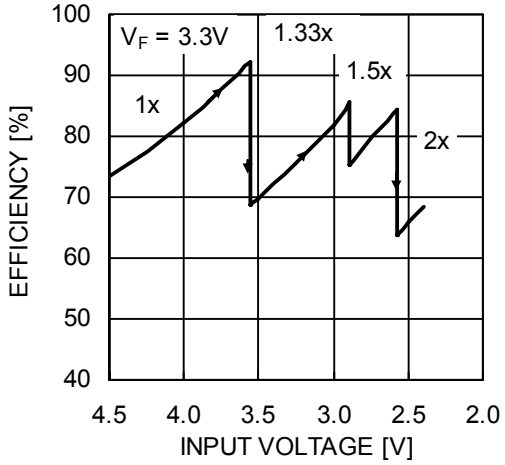
Full Scale LED Current [mA]	RSET [kΩ]
2	37.4
5	14.7
10	7.50
15	4.99
20	3.74
25	3.00
30	2.49

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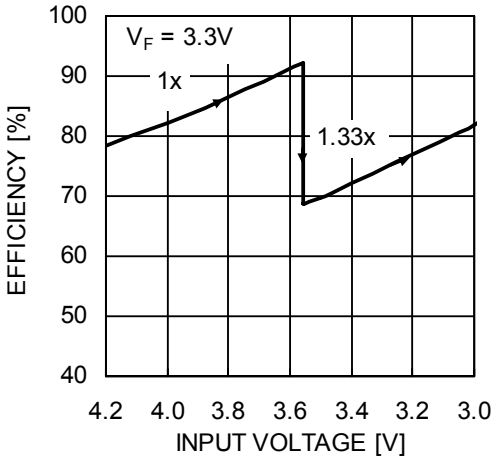
TYPICAL PERFORMANCE CHARACTERISTICS

V_{IN} = 3.6V, I_{OUT} = 60mA (3 LEDs at 20mA), C_{IN} = C_{OUT} = C_1 = C_2 = 1µF, T_{AMB} = 25°C unless otherwise specified.

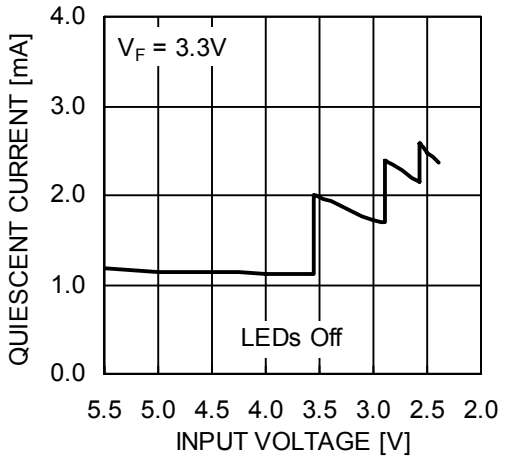
Efficiency vs. Input Voltage



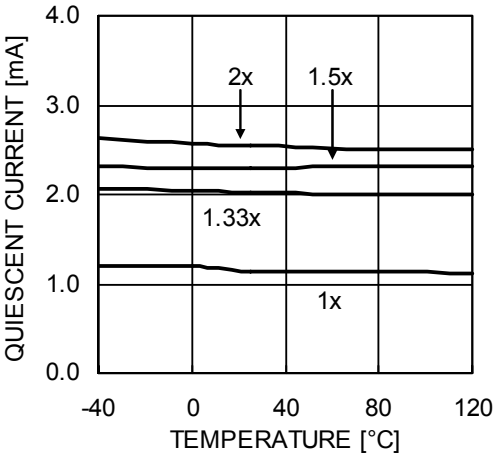
Efficiency vs. Li-Ion Voltage



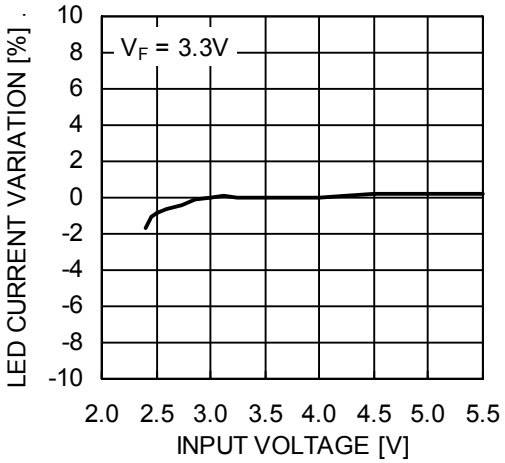
Quiescent Current vs. Input Voltage



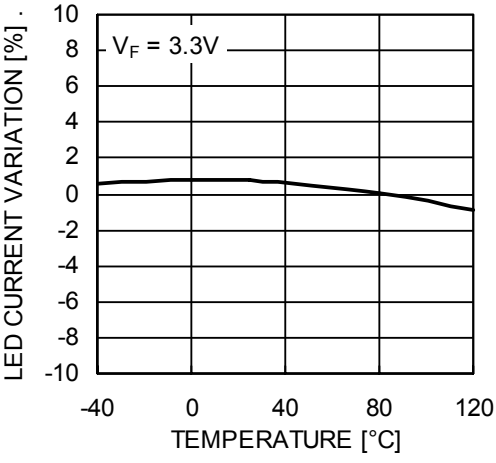
Quiescent Current vs. Temperature



LED Current Change vs. Input Voltage



LED Current Change vs. Temperature

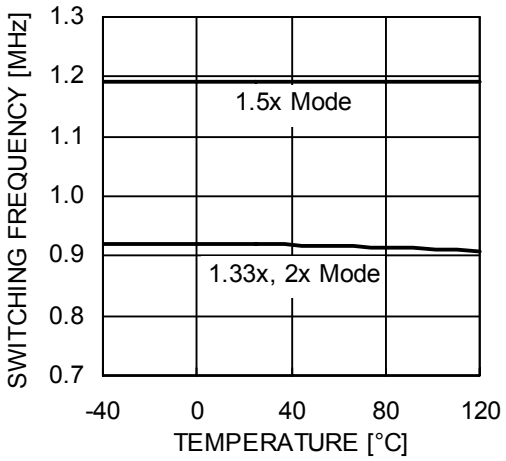


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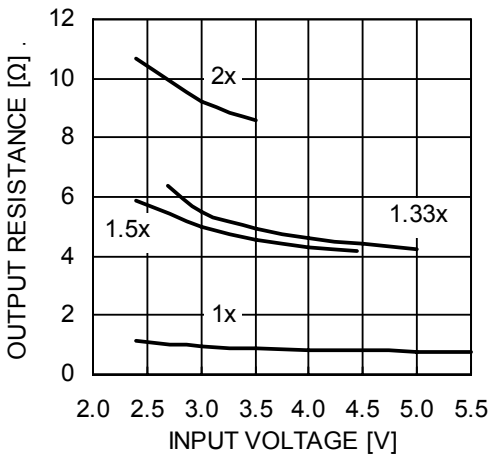
TYPICAL PERFORMANCE CHARACTERISTICS

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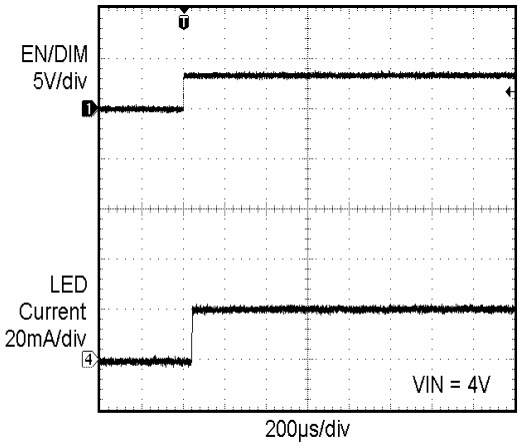
Switching Frequency vs. Temperature



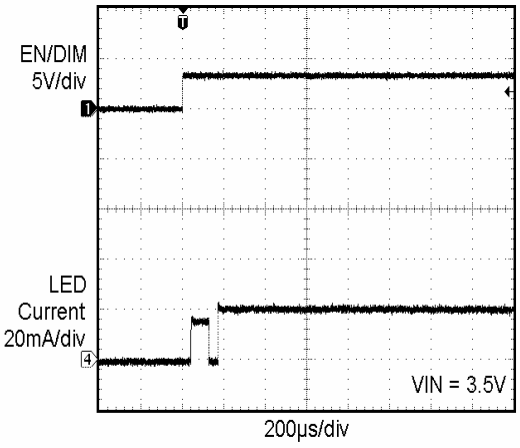
Output Resistance vs. Input Voltage



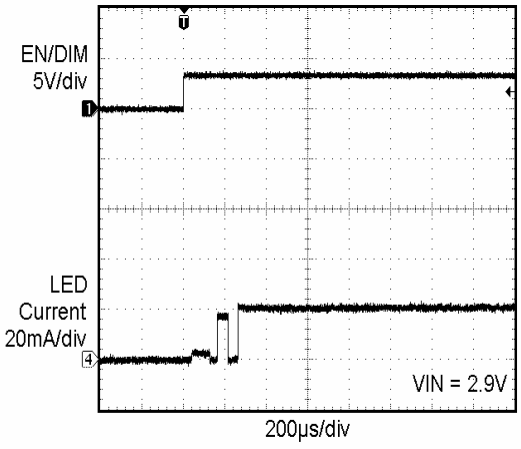
Power Up in 1x Mode



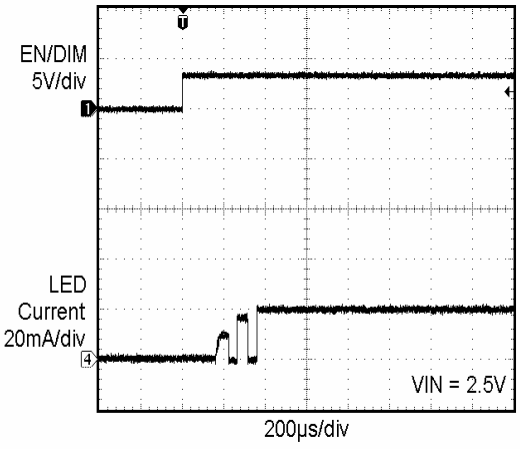
Power Up in 1.33x Mode



Power Up in 1.5x Mode



Power Up in 2x Mode

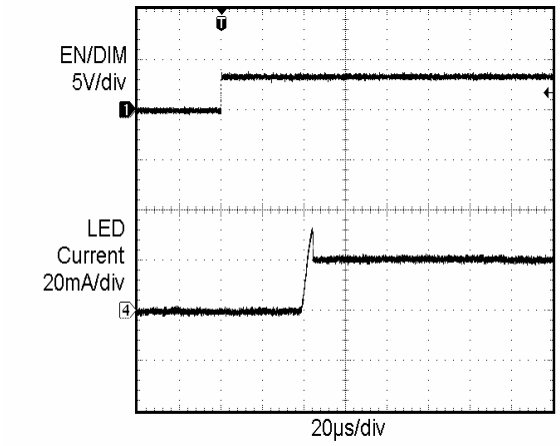


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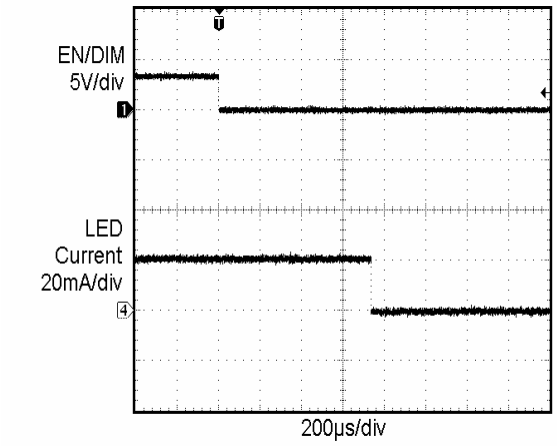
TYPICAL PERFORMANCE CHARACTERISTICS

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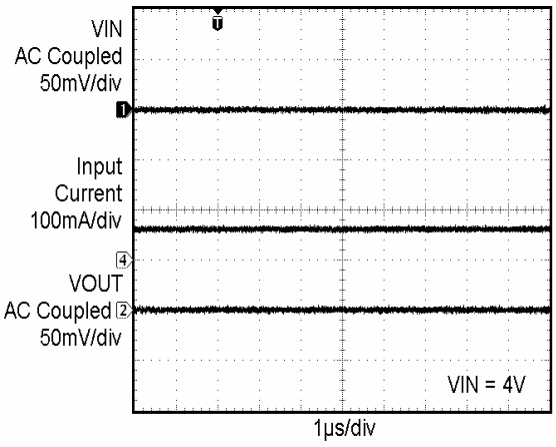
Power Up Delay (1x Mode)



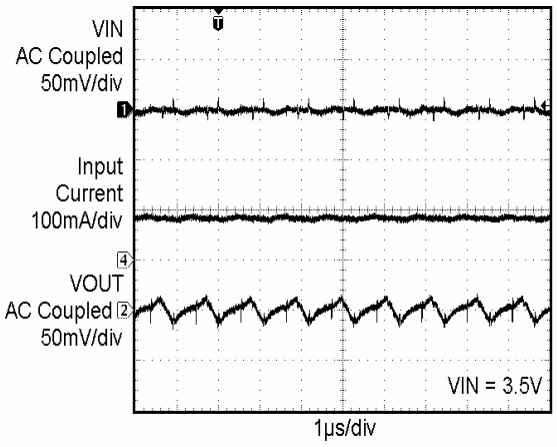
Power Down Delay (1x Mode)



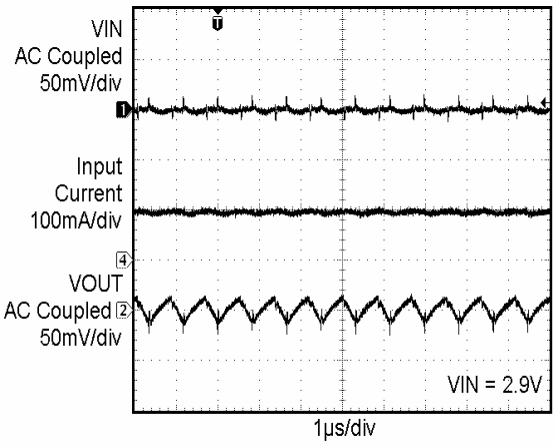
Operating Waveforms in 1x Mode



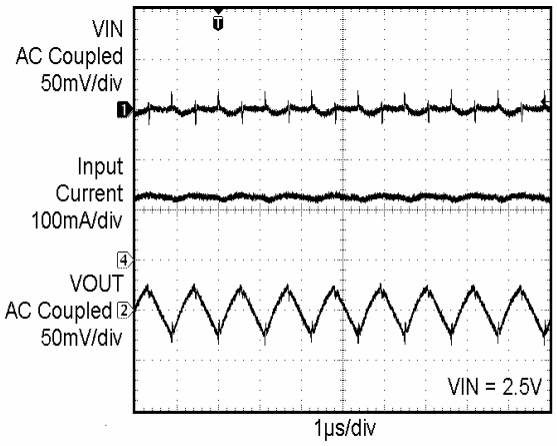
Switching Waveforms in 1.33x Mode



Switching Waveforms in 1.5x Mode



Switching Waveforms in 2x Mode

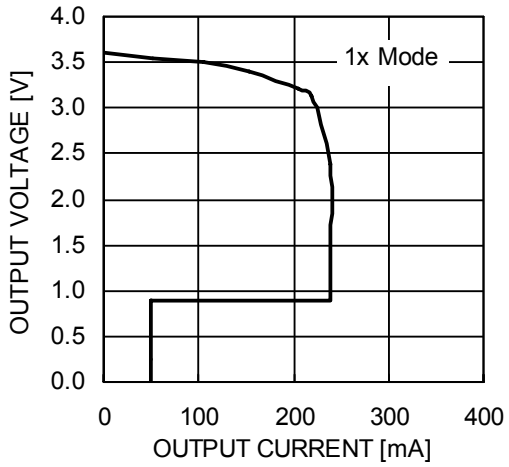


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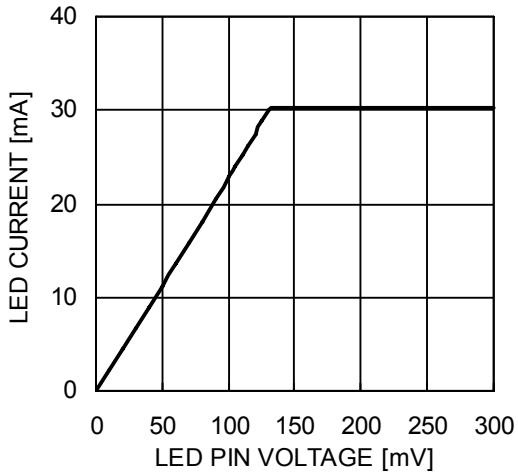
TYPICAL PERFORMANCE CHARACTERISTICS

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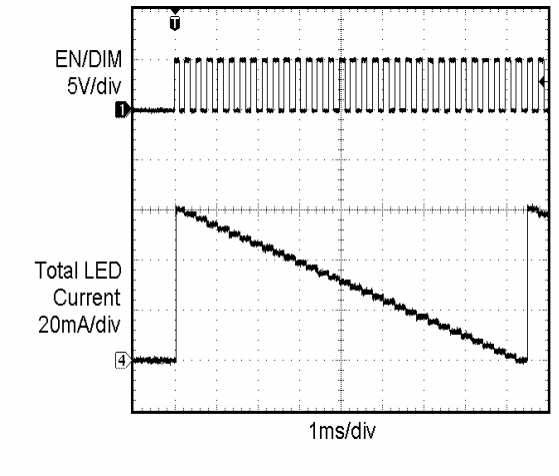
Foldback Current Limit



LED Current vs. LED Pin Voltage



Dimming Waveform



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PIN DESCRIPTION

Name	Function
LED1	LED1 cathode terminal.
LED2	LED2 cathode terminal.
LED3	LED3 cathode terminal.
RSET	Connect resistor RSET to set the LED current.
EN/DIM	Device enable (active high) and Dimming Control.
VOUT	Charge pump output connected to the LED anodes.
VIN	Charge pump input, connect to battery or supply.
C1+	Bucket capacitor 1 Positive terminal
C1-	Bucket capacitor 1 Negative terminal
C2+	Bucket capacitor 2 Positive terminal
C2-	Bucket capacitor 2 Negative terminal
GND	Ground Reference
NC	Not connected inside package.
GND	Connect to GND on the PCB.

PIN FUNCTION

VIN is the supply pin for the charge pump. A small 1µF ceramic bypass capacitor is required between the VIN pin and ground near the device. The operating input voltage range is from 2.5V to 5.5V. Whenever the input supply falls below the under-voltage threshold (1.8V), 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 1.3V and 0.4V 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 1.5ms.

VOUT is the charge pump output that is connected to the LED anodes. A small 1µF ceramic bypass capacitor is required between the VOUT 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, LED2, LED3 provide the internal regulated current sources 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 0.6V. 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.

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BLOCK DIAGRAM

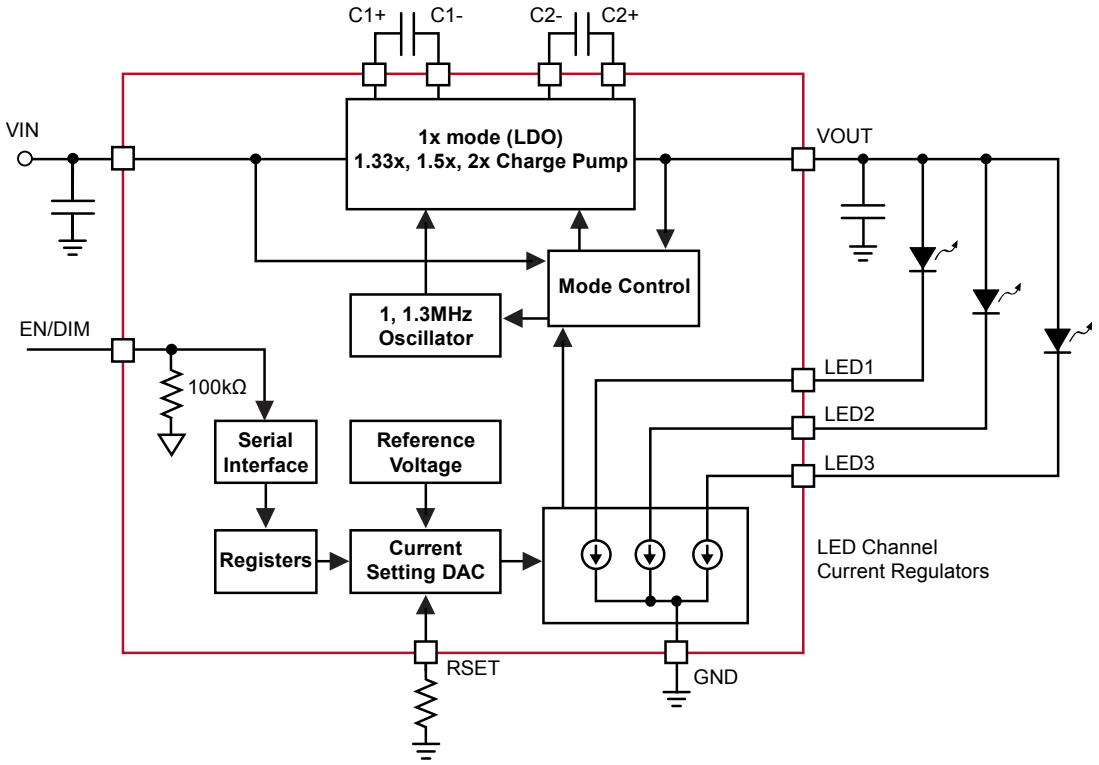


Figure 2. CAT3647 Functional Block Diagram

BASIC OPERATION

At power-up, the CAT3647 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 120µs). 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 400mV.

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LED Current Selection

After power-up, the LED current is set by the external resistor (R_{SET}) value and the number of pulses (n) on the EN/DIM input as follows:

$$\text{LED current} = 125 \times \frac{0.6V}{R_{SET}} \times \left(\frac{31-n}{31}\right)$$

The full scale current is calculated from the above formula with n equal to zero.

The EN/DIM pin has two primary functions. One function enables and disables the device. The other function is LED current dimming with 32 different levels by pulsing the input signal, as shown on Figure 3. On each consecutive pulse rising edge, the LED current is decreased by about 3.2% (1/31th of the full scale value). After 30 pulses, the LED current is 3.2% of the full scale current. On the 31st pulse, the current drops to zero, and then goes back to full scale on the following pulse.

Each pulse width should be between 200ns and 100µs. 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. By pulsing the EN/DIM signal at high frequency, the LED current can quickly be set to zero.

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

The dimming level is set by the number of pulses on the EN/DIM after the power-up, as shown in Table 2.

Table 2. Dimming Levels

Full Scale Current in %	Dimming Pulses [n]
100	0
97	1
94	2
90	3
87	4
84	5
81	6
77	7
74	8
71	9
68	10
65	11
61	12
58	13
55	14
52	15
48	16
45	17
42	18
39	19
35	20
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6	29
3	30
0	31
100	32

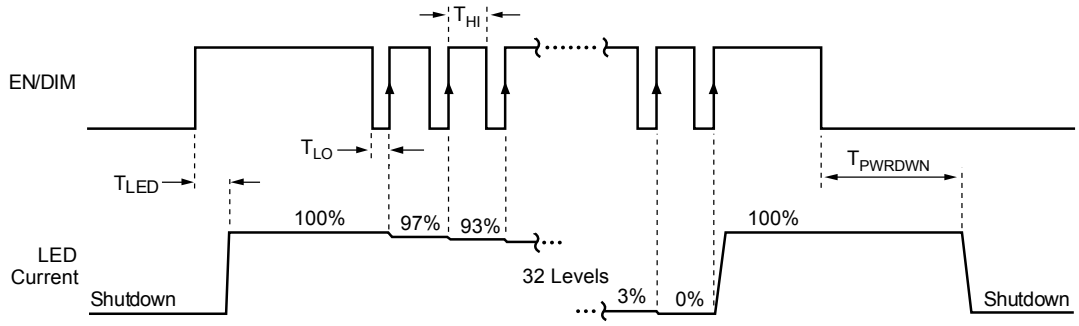


Figure 3. EN/DIM Digital Dimming Timing Diagram

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Unused LED Channels

For applications not requiring all the channels, it is recommended the unused LED pins be tied directly to VOUT (see Figure 4).

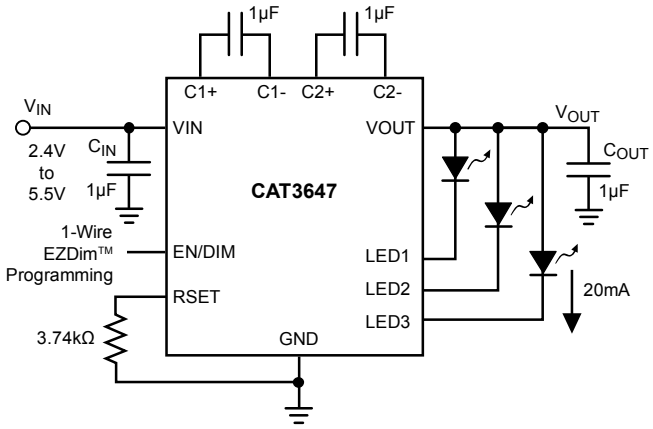


Figure 4. Application with 2 LEDs

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 6V, the driver resets itself and re-evaluates 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 1.3V to 4.3V 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 3.3V is selected over one with V_F of 3.5V, the driver will stay in 1x mode for lower supply voltage of 0.2V. This helps improve the efficiency and extends battery life.

External Components

The driver requires four external 1µF ceramic capaci–tors 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 1µF 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.

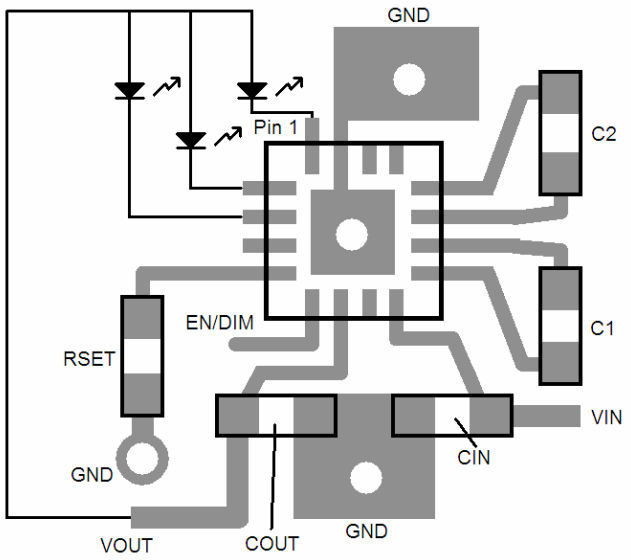
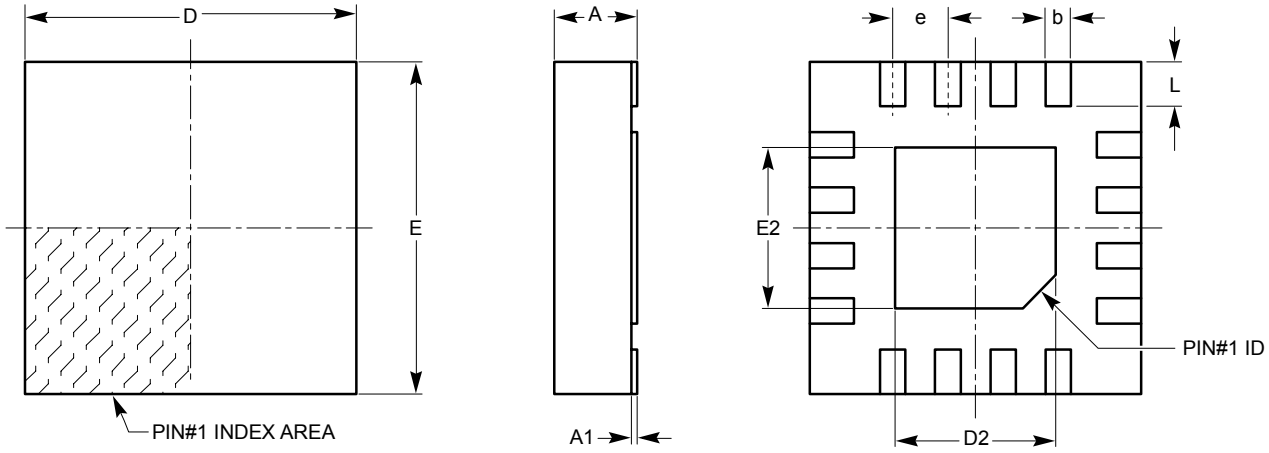


Figure 5. TQFN-16 Recommended Layout

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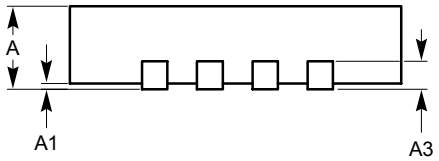
PACKAGE OUTLINE DRAWING

TQFN 16-Pad 3 x 3mm (HS3, HV3) [(1)(2)]



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



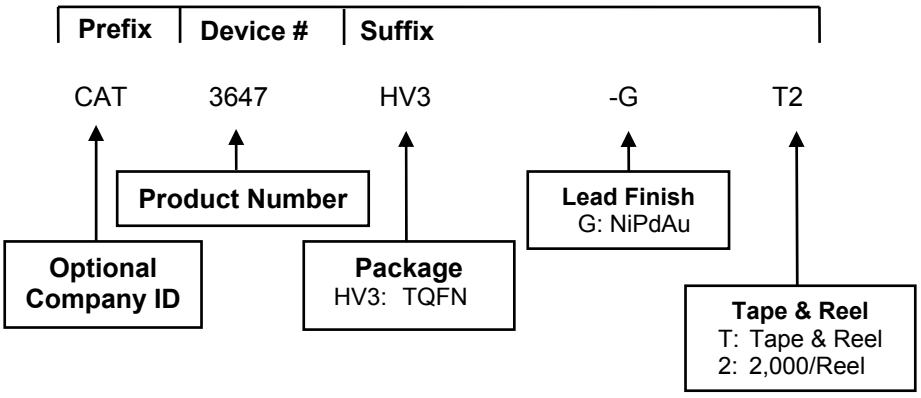
FRONT VIEW

For current Tape and Reel information, download the PDF file from: http://www.catsemi.com/documents/tapeandreel.pdf.

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

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EXAMPLE OF ORDERING INFORMATION (1)(2)



Notes:

(1) All packages are RoHS-compliant (Lead-free, Halogen-free).

(2) The standard lead finish is NiPdAu.

(3) The device used in the above example is a CAT3647HV3-GT2 (TQFN, NiPdAu, Tape & Reel, 2,000/Reel).

(4) For additional package and temperature options, please contact your nearest ON Semiconductor Sales office.

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REVISION HISTORY

Date	Revision	Description
02-Apr-08	A	Initial Release
07-Aug-08	B	Changed “Quad-Mode™” to “Quad-Mode®”
17-Nov-08	C	Change logo and fine print to ON Semiconductor

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