



# 6-Channel Charge Pump LED Driver with EZDim™



## FEATURES

- 6 LED channels with tight matching
- Independent Main and Sub channels
- 1-wire EZDim™ Programmable LED Current
- Accurate 1mA Dimming Level
- Power efficiency up to 91%
- Fractional pump 1x/1.5x
- Low noise input ripple
- Fixed High Frequency Operation 1MHz
- “Zero” Current Shutdown Mode
- Soft start and current limiting
- Short circuit protection
- Thermal shutdown protection
- RoHS-compliant 16-pad TQFN 4mm x 4mm package

## APPLICATION

- Main and sub-display backlight
- Color LCD and keypad Backlighting
- Cellular Phones
- Handheld Devices
- Digital Cameras

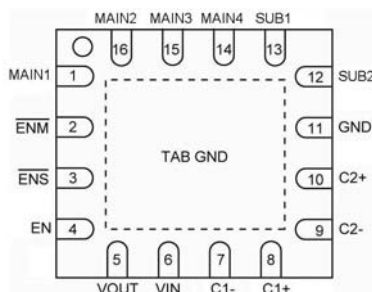
## ORDERING INFORMATION

Part Number	Package	Quantity per Reel	Package Marking
CAT3616HV4-T2	TQFN-16 <sup>(1)</sup>	2000	G616
CAT3616HV4-GT2	TQFN-16 <sup>(2)</sup>	2000	CDAH

Notes: (1) Matte-Tin Plated Finish (RoHS-compliant).  
 (2) NiPdAu Plated Finish (RoHS-compliant).

## PIN CONFIGURATION

TQFN 16-pad 4 x 4mm (Top view)



## DESCRIPTION

The CAT3616 is a high efficiency 1x/1.5x fractional charge pump with programmable dimming current in six LED channels. To ensure uniform brightness in LCD backlight applications, each LED channel delivers an accurate regulated current.

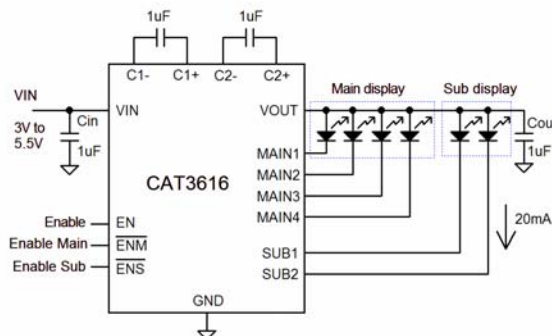
Low noise and input ripple is achieved by operating at a constant switching frequency of 1MHz which allows the use of small external ceramic capacitors. The 1x/1.5x fractional charge pump supports a wide range of input voltages from 3V to 5.5V with efficiency up to 91%, and is ideal for Li-Ion battery powered devices.

Two groups of LEDs, main (MAIN1 to MAIN4) and sub (SUB1 and SUB2) are programmable through the ENM (active low) and ENS inputs. Independent current from 1mA to 31mA with a 1mA step are set by toggling the ENM and ENS inputs. The enable EN input pin allows to shutdown the device with zero quiescent current.

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

For Ordering Information details, see page 13.

## TYPICAL APPLICATION CIRCUIT



Note: Unused LED channels must be connected to VOUT.

**ABSOLUTE MAXIMUM RATINGS**

Parameter	Rating	Unit
V <sub>IN</sub> , LEDxx voltage	6	V
V <sub>OUT</sub> , C1±, C2± voltage	7	V
EN, $\overline{\text{ENM}}$ , $\overline{\text{ENS}}$ voltage	V <sub>IN</sub> + 0.7V	V
Storage Temperature Range	-65 to +160	°C
Junction Temperature Range	-40 to +150	°C
Lead Temperature	300	°C

**RECOMMENDED OPERATING CONDITIONS**

Parameter	Range	Unit
V <sub>IN</sub>	3 to 5.5	V
Ambient Temperature Range	-40 to +85	°C
I <sub>LED</sub> per LED pin	0 to 31	mA
I <sub>OUT</sub> Total Output Current	0 to 150	mA

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

**ELECTRICAL OPERATING CHARACTERISTICS**

V<sub>IN</sub> = 3.6V, EN = High, ambient temperature of 25°C (over recommended operating conditions unless specified otherwise)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
I <sub>Q</sub>	Quiescent Current	1x mode, all LEDs Off 1x mode, all LEDs On 1.5x mode, all LEDs Off		0.5 2.2 3.5		mA mA mA
I <sub>QSHDN</sub>	Shutdown Current	V <sub>EN</sub> = 0V		0	1	µA
I <sub>LED</sub>	LED Current Range with 6 LEDs		0		31	mA
I <sub>LED-ACC</sub>	LED Current Accuracy	1mA ≤ I <sub>LED</sub> ≤ 31mA		±3		%
I <sub>LED-DEV</sub>	LED Channel Matching	(I <sub>LED</sub> - I <sub>LEDAVG</sub> ) / I <sub>LEDAVG</sub>		±3		%
R <sub>OUT</sub>	Output Resistance (open loop)	1x mode, I <sub>OUT</sub> = 120mA 1.5x mode, I <sub>OUT</sub> = 120mA		0.5 2.2		Ω Ω
F <sub>OSC</sub>	Charge Pump Frequency		0.8	1	1.3	MHz
I <sub>SC_MAX</sub>	Output short circuit Current Limit	V <sub>OUT</sub> < 0.5V		60		mA
I <sub>IN_MAX</sub>	Input Current Limit	1x mode, V <sub>OUT</sub> > 1V		300		mA
I <sub>EN/DIM</sub> V <sub>HI</sub> V <sub>LO</sub>	EN/DIM Pin • Input Leakage • Logic High Level • Logic Low Level		-1 1.3		1 0.4	µA V V
T <sub>SD</sub>	Thermal Shutdown			165		°C
T <sub>HYS</sub>	Thermal Hysteresis			20		°C
V <sub>UVLO</sub>	Undervoltage lock out (UVLO) threshold			2		V

**RECOMMENDED EN, ENM AND ENS TIMING**

For  $3V \leq V_{IN} \leq 5.5V$ , over full ambient temperature range  $-40$  to  $+125^{\circ}C$ .

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$T_{SETP}$	EN setup from shutdown		10			$\mu s$
$T_{LO}$	$\overline{ENM}$ , $\overline{ENS}$ program low time		0.3		200	$\mu s$
$T_{HI}$	$\overline{ENM}$ , $\overline{ENS}$ program high time		0.3			$\mu s$
$T_{OFF}$	EN low time to shutdown		1.5			ms
$T_D$	LED current enable			40		$\mu s$
$T_{DEC}$	LED current decrement			0.1		$\mu s$

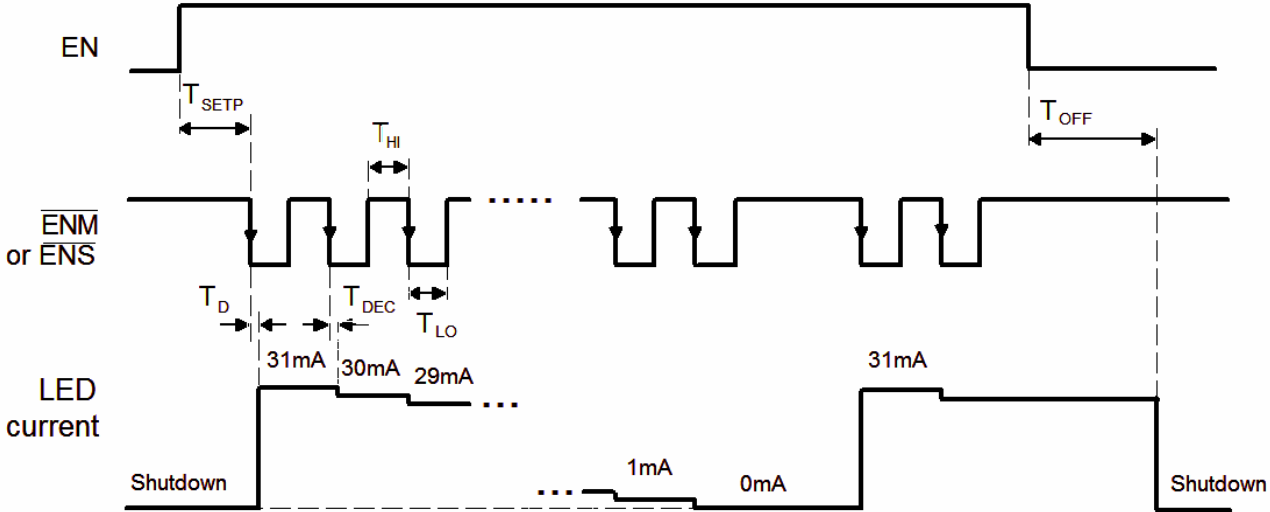
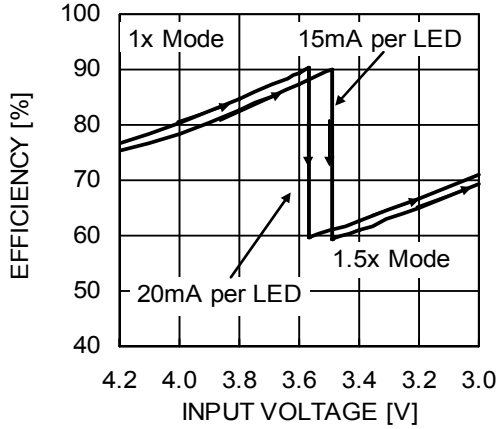


Figure 1. Enable LED Timing Diagram

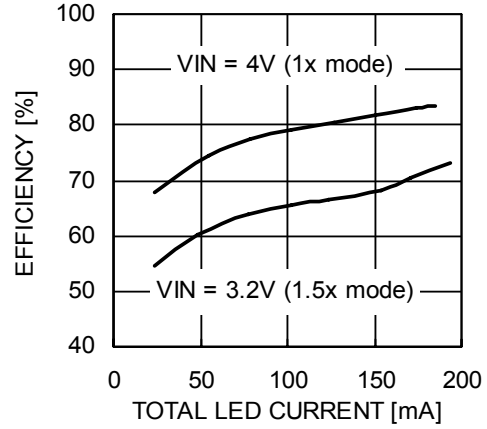
**TYPICAL CHARACTERISTICS**

$V_{IN} = 3.6V$ ,  $I_{OUT} = 90mA$  (6 LEDs at 15mA),  $\overline{EN} = \overline{VIN}$ ,  $\overline{ENM} = \overline{ENS} = GND$ ,  $C_{IN} = C1 = C2 = C_{OUT} = 1\mu F$ ,  $T_{AMB} = 25^\circ C$ , unless otherwise specified.

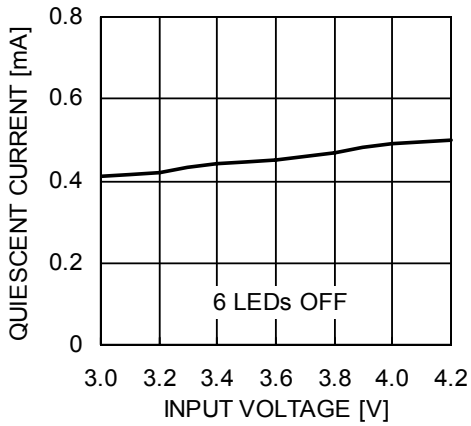
**Efficiency vs. Input Voltage (6 LEDs on)**



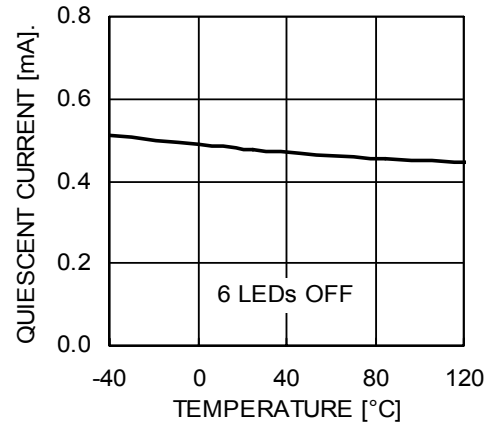
**Efficiency vs. Total LED Current (6 LEDs)**



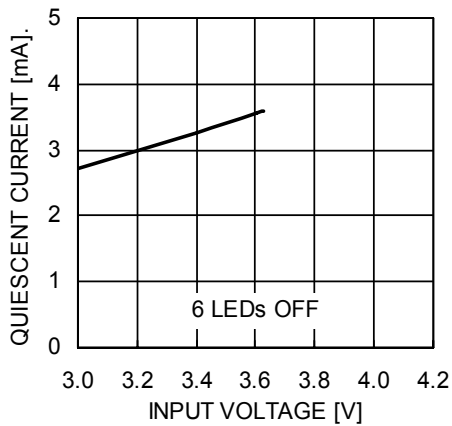
**Quiescent Current vs. Input Voltage (1x Mode)**



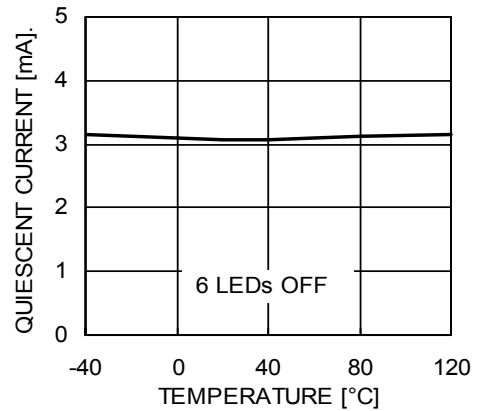
**Quiescent Current vs. Temperature (1x Mode)**



**Quiescent Current vs. Input Voltage (1.5x Mode)**



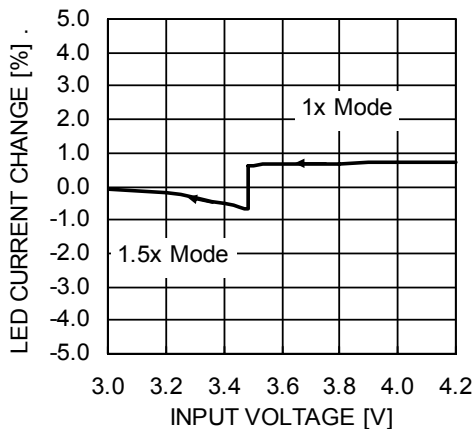
**Quiescent Current vs. Temperature (1.5x Mode)**



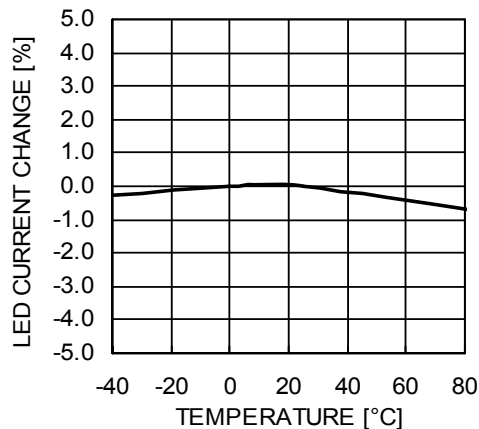
**TYPICAL CHARACTERISTICS**

V<sub>IN</sub> = 3.6V, I<sub>OUT</sub> = 90mA (6 LEDs at 15mA), EN = V<sub>IN</sub>,  $\overline{\text{ENM}} = \overline{\text{ENS}} = \text{GND}$ , C<sub>IN</sub> = C1 = C2 = C<sub>OUT</sub> = 1μF, T<sub>AMB</sub> = 25°C, unless otherwise specified.

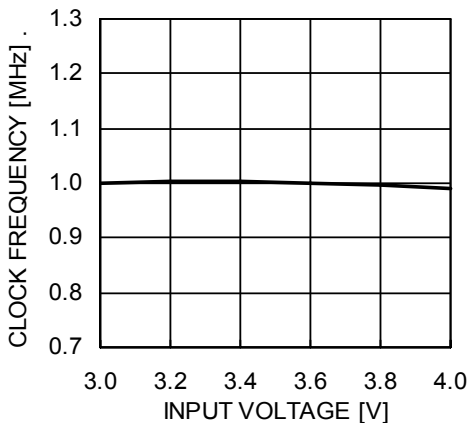
**LED Current Change vs. Input Voltage**



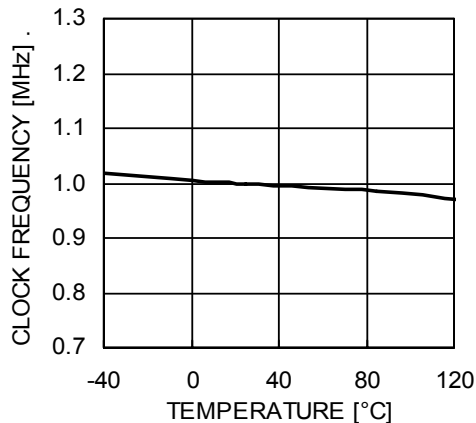
**LED Current Change vs. Temperature**



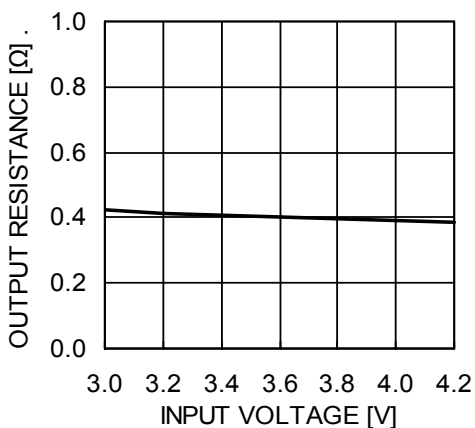
**Oscillator Frequency vs. Input Voltage**



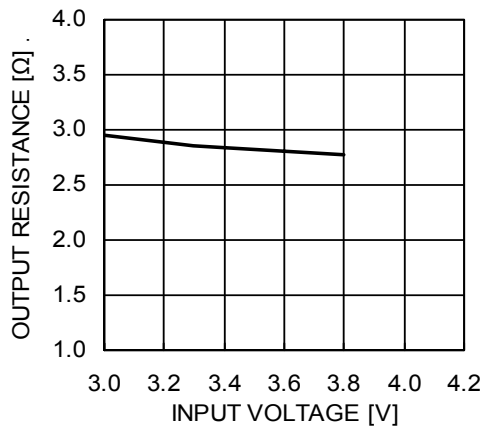
**Oscillator Frequency vs. Temperature**



**Output Resistance vs. Input Voltage (1x Mode)**



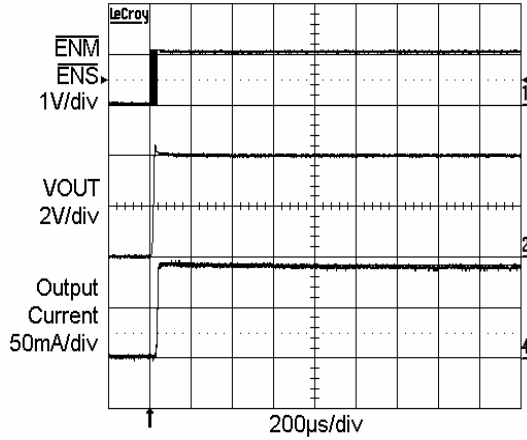
**Output Resistance vs. Input Voltage(1.5x Mode)**



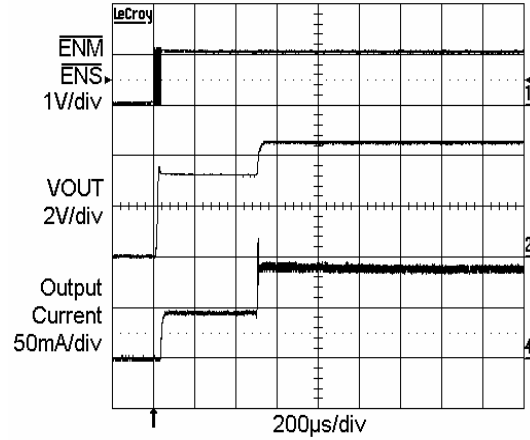
**TYPICAL CHARACTERISTICS**

VIN = 3.6V, IOUT = 90mA (6 LEDs at 15mA), EN = VIN, ENM = ENS = GND, CIN = C1 = C2 = COUT = 1μF, TAMB = 25°C, unless otherwise specified.

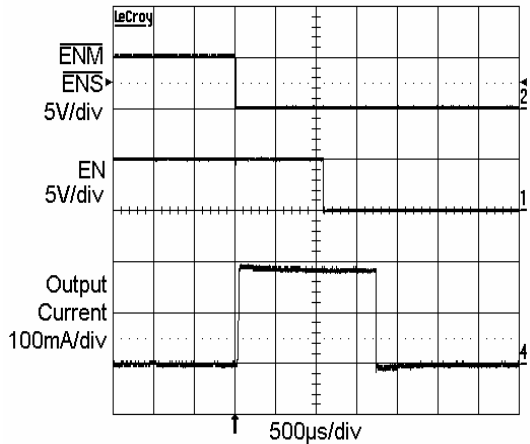
**Power Up with 6 LEDs at 15mA (1x Mode)**



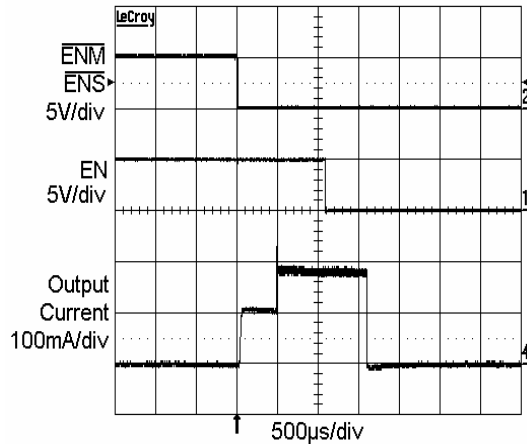
**Power Up with 6 LEDs at 15mA (1.5x Mode)**



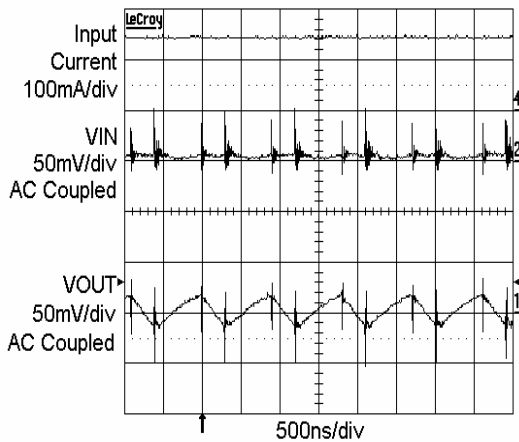
**Enable Power Down Delay (1x Mode)**



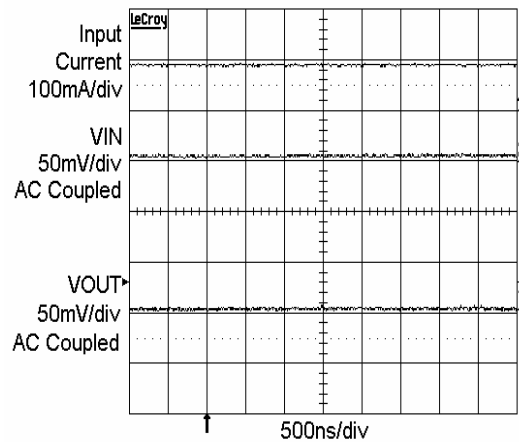
**Enable Power Down Delay (1.5x Mode)**



**Switching Waveforms in 1.5x Mode**



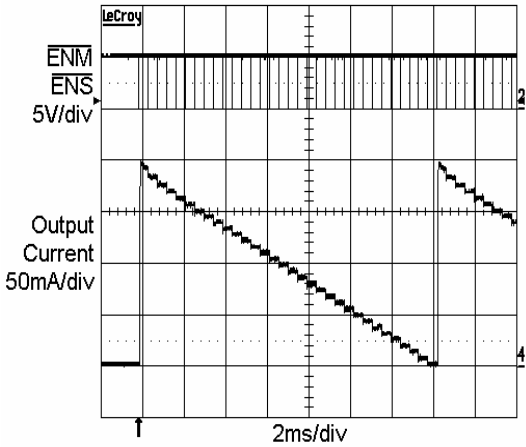
**Operating Waveforms in 1x Mode**



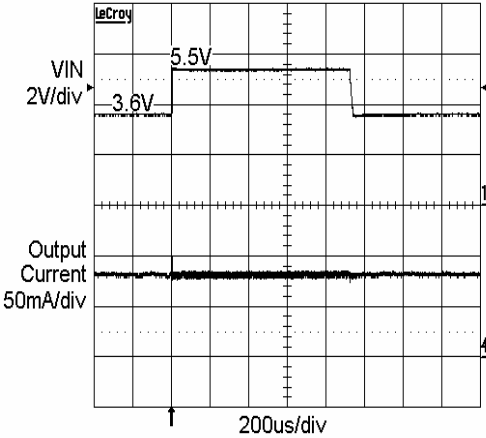
**TYPICAL CHARACTERISTICS**

V<sub>IN</sub> = 3.6V, I<sub>OUT</sub> = 90mA (6 LEDs at 15mA), EN = V<sub>IN</sub>, ENM = ENS = GND, C<sub>IN</sub> = C<sub>1</sub> = C<sub>2</sub> = C<sub>OUT</sub> = 1μF, T<sub>AMB</sub> = 25°C, unless otherwise specified.

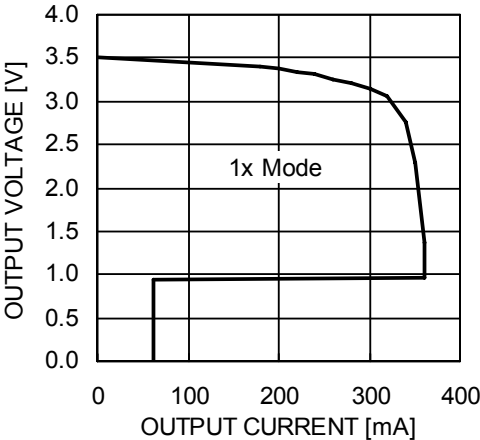
**ENM, ENS and Output Current Dimming**



**Line Transient Response (3.6V to 5.5V) 1x Mode**



**Foldback Current Limit**



## PIN DESCRIPTIONS

Pin #	Name	Function
1	MAIN1	MAIN1 LED cathode terminal (if not used, connect to VOUT) <sup>1</sup>
2	$\overline{\text{ENM}}$	Enable main LED (MAIN1 to MAIN4) input. Active low
3	$\overline{\text{ENS}}$	Enable sub LED (SUB1, SUB2) input. Active low
4	EN	Device enable input. Active high.
5	VOUT	Charge pump output connected to the LED anodes
6	VIN	Supply voltage.
7, 8	C1-, C1+	Bucket capacitor 1 terminal
9, 10	C2-, C2+	Bucket capacitor 2 terminal
11	GND	Ground reference
12	SUB2	SUB2 LED cathode terminal (if not used, connect to VOUT) <sup>1</sup>
13	SUB1	SUB1 LED cathode terminal (if not used, connect to VOUT) <sup>1</sup>
14	MAIN4	MAIN4 LED cathode terminal (if not used, connect to VOUT) <sup>1</sup>
15	MAIN3	MAIN3 LED cathode terminal (if not used, connect to VOUT) <sup>1</sup>
16	MAIN2	MAIN2 LED cathode terminal (if not used, connect to VOUT) <sup>1</sup>
TAB	TAB	Connect to Ground on PCB

**Note:**

(1) MAIN1 to MAIN4, SUB1, SUB2 pins should not be left floating. They should be connected to the LED cathode, or tied to VOUT pin if not used.

## PIN FUNCTION

**VIN** is the supply pin for the charge pump. A small 1 $\mu$ F ceramic bypass capacitor is required between the VIN pin and ground near the device. The operating input voltage range is up to 5.5V. When the input supply falls below the undervoltage threshold (2V), all LED channels are disabled.

**EN** is the enable logic input. Logic level for high and low are set at 1.3V and 0.4V respectively. When EN is initially taken high, the device becomes enabled and all LED currents remain at 0mA. To place the device into zero current shutdown mode, the EN pin must be held low for 1.5ms or more.

$\overline{\text{ENM}}$ ,  $\overline{\text{ENS}}$  are the active low enable/ dimming control logic inputs for respectively main and sub LED channels. The falling edge of the first pulse applied to ENM and ENS sets the current for respectively the main and sub LED channels to their full scale of 31mA. On each consecutive falling edge of the pulse applied to ENM and ENS, the LED current is decreased by 1mA step. On the 32<sup>nd</sup> pulse, the LED current is set to zero. The next pulse resets the current back to the full scale of 31mA.

**VOUT** is the charge pump output that is connected to the LED anodes. A small 1 $\mu$ F 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 1 $\mu$ F ceramic bucket capacitor C1.

**C2+**, **C2-** are connected to each side of the 1 $\mu$ F ceramic bucket capacitor C2.

**MAIN1-4**, **SUB1-2** provide the internal regulated current for each of the LED cathodes. These pins enter a high impedance zero current state whenever the device is placed in shutdown mode. In applications using less than six LEDs, the unused channels should be wired directly to VOUT. This ensures the channel is automatically disabled dissipating less than 200 $\mu$ A.

**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.



## BLOCK DIAGRAM

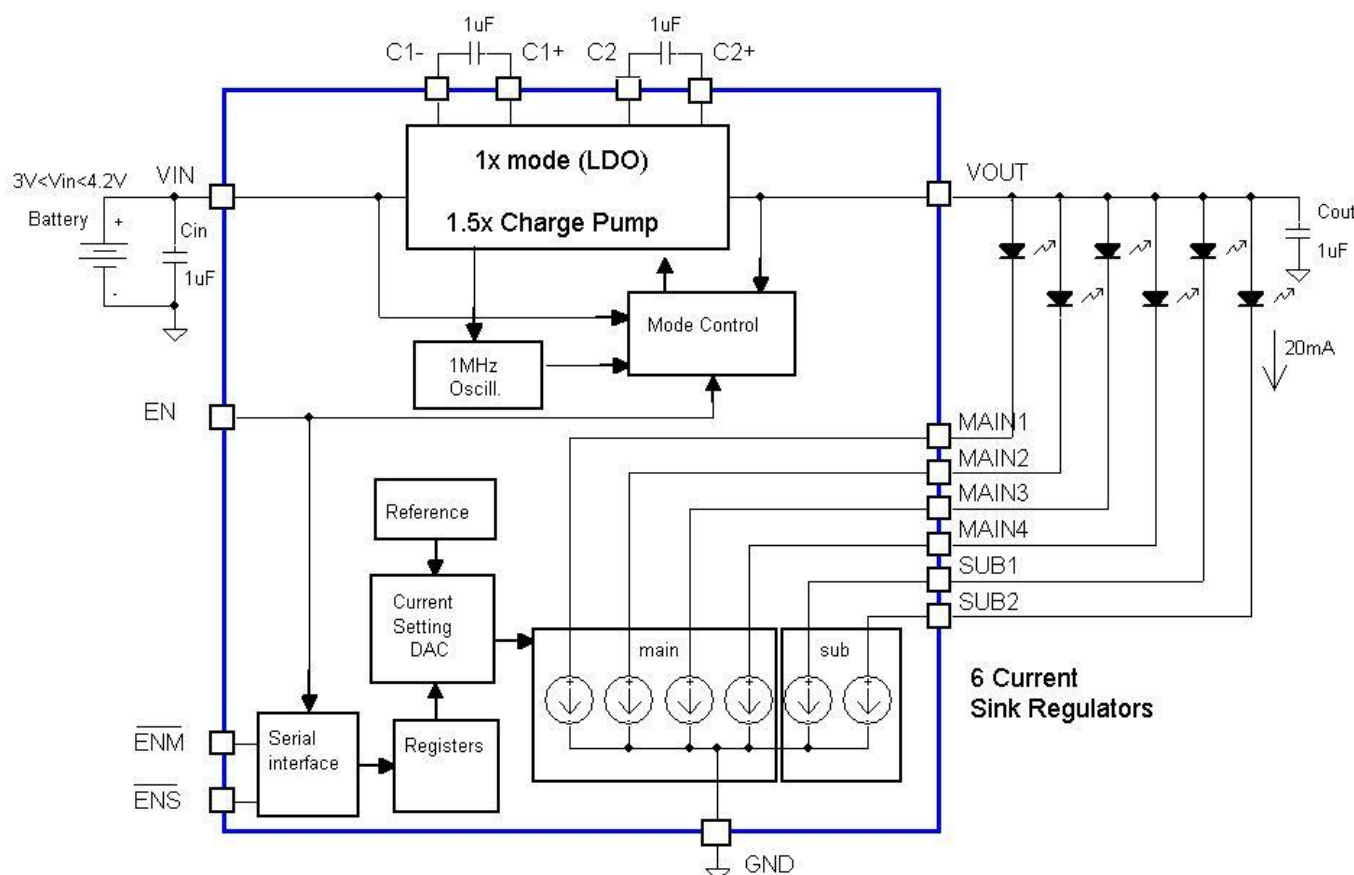


Figure 2. CAT3616 Functional Block Diagram

## BASIC OPERATION

At power-up, the CAT3616 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 (after 400 $\mu$ s) into 1.5x mode.

In 1.5x mode, the output is approximately equal to 1.5 times the input supply voltage (less any internal voltage losses).

The above sequence is repeated each and every time the chip is powered-up or is taken out of shutdown mode (via EN pin).

## LED CURRENT SETTING

The LED current is controlled by toggling the input signals ENM and ENS. ENM controls the four LED channels MAIN1 to MAIN4. ENS controls the two LED lines SUB1 and SUB2. ENM and ENS work the same way. The chip must first be enabled by setting the enable input EN high. On the first ENM or ENS transition from high to low, the LED current in the associated LEDs is set to the full scale 31mA. On each consecutive falling edge of ENM or ENS, the LED current is decreased by 1mA. On the 32<sup>nd</sup> pulse, the LED channel is turned off and the current drops to 0mA. One additional ENM or ENS pulse resets the full current to 31mA, as shown on Figure 1.

Consecutive pulses should be separated by 300ns or more. Pulsing frequencies from 5kHz up to 1MHz are supported during dimming operations. When the EN is held low for 1.5ms or more, the CAT3616 enters the shutdown mode and draws “zero” current. When the enable EN input is low, toggling ENM or ENS has no effect.

Unused LED channels can be disabled independently by connecting the corresponding main or sub LED pin to VOUT.

### Protection Mode

If an LED becomes open-circuit, the output voltage VOUT is internally limited to about 5.5V. This is to prevent the output pin from exceeding its absolute maximum rating.

The driver enters a thermal shutdown mode as soon as the die temperature exceeds about +165°C. When the device temperature drops down by about 20°C, the device resumes normal operation.

### External Components

The driver requires a total of four external 1µF ceramic capacitors: two for decoupling input and output, and two for the charge pump. Both capacitor types X5R and X7R are recommended for the LED driver application. In the 1.5x charge pump mode, the input current ripple is kept very low by design, and an input bypass capacitor of 1µF is sufficient. In 1x mode, the device operating in linear mode does not introduce switching noise back onto the supply.

### Recommended Layout

In 1.5x charge pump mode, the driver switches internally at a high frequency of 1MHz. 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 Cin and Cout can be implemented with the use of multiple via. A copper area matching the TDFN exposed pad (GND) must be connected to the ground plane underneath. The use of multiple via improves the package heat dissipation.

## APPLICATION INFORMATION

### Single wire Dimming Application

The dimming control can be achieved through a single wire interface by connecting together all three logic input signals EN, ENM and ENS as shown on Figure 3.

The common enable signal is set high to enable the driver. On the first negative going pulse, the LEDs turn

full on. The pulse low state duration (between the falling and rising edges) must be shorter than 0.5msec. Any consecutive pulses reduce the LED current by 1mA. The enable signal is kept low for more than 1.5msec to turn off all the LED channels and set the driver in shutdown mode, as shown on Figures 4.

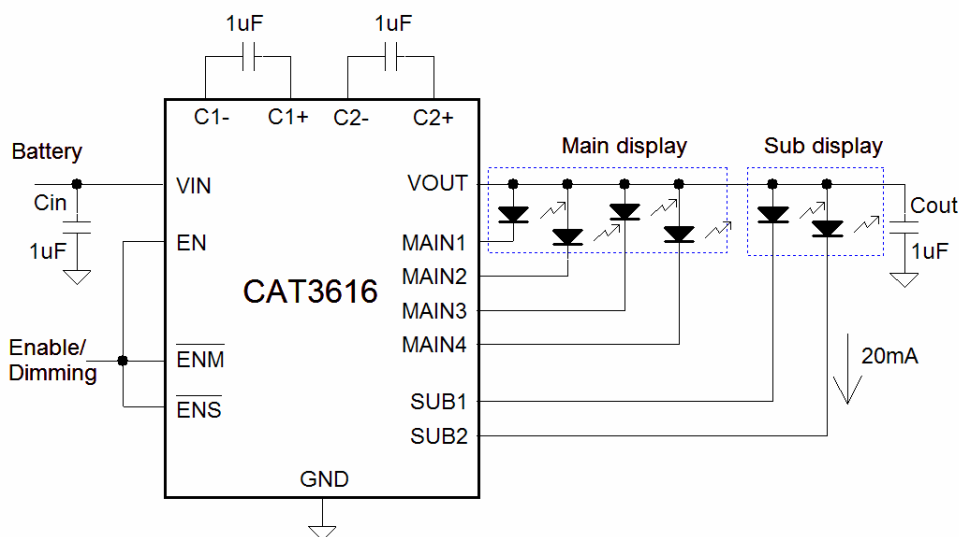


Figure 3. Single Wire Dimming Control

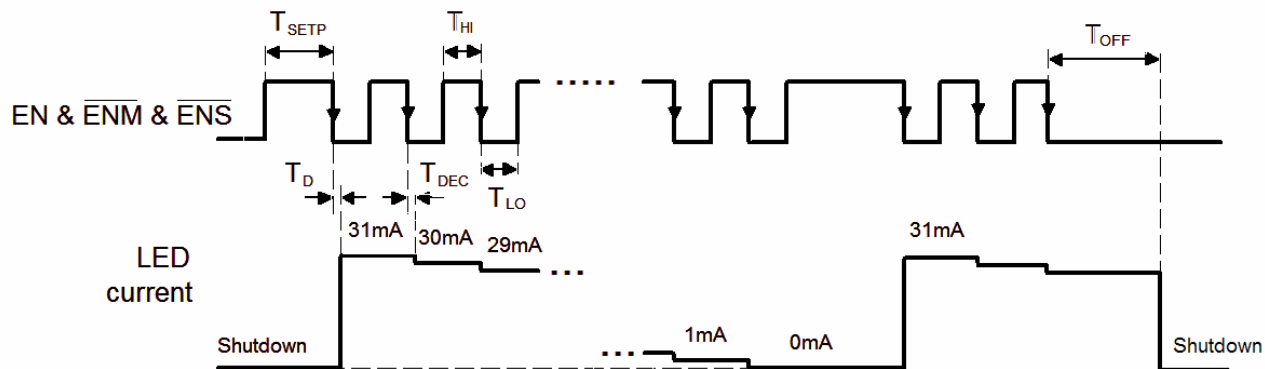
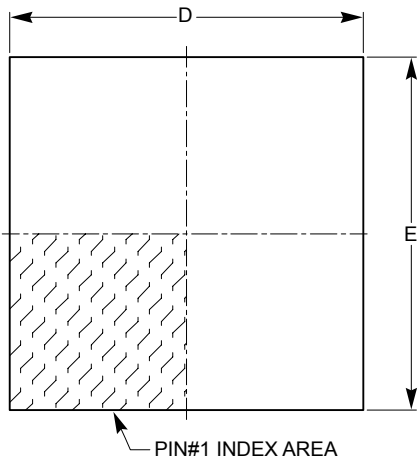


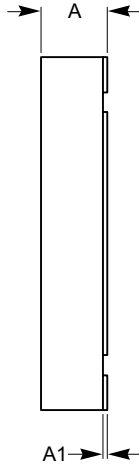
Figure 4. Single Enable Timing Diagram

**PACKAGE OUTLINE DRAWING**

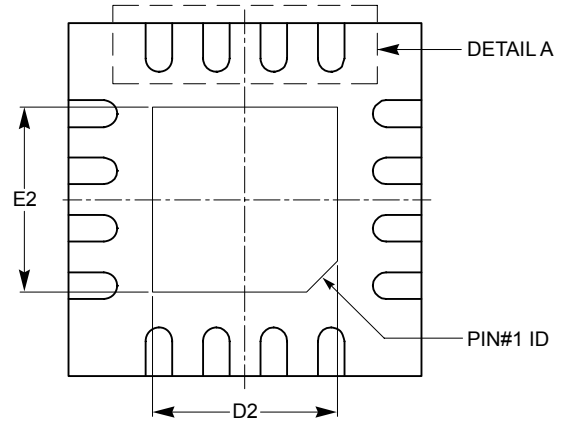
**TQFN 16-Pad 4 x 4mm (HV4) <sup>(1)(2)</sup>**



**TOP VIEW**

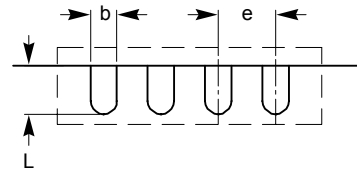


**SIDE VIEW**

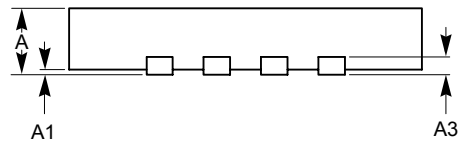


**BOTTOM VIEW**

SYMBOL	MIN	NOM	MAX
A	0.70	0.75	0.80
A1	0.00	0.02	0.05
A3	0.20 REF		
b	0.25	0.30	0.35
D	3.90	4.00	4.10
D2	2.00	–	2.25
E	3.90	4.00	4.10
E2	2.00	–	2.25
e	0.65 BSC		
L	0.45	–	0.65



**DETAIL A**

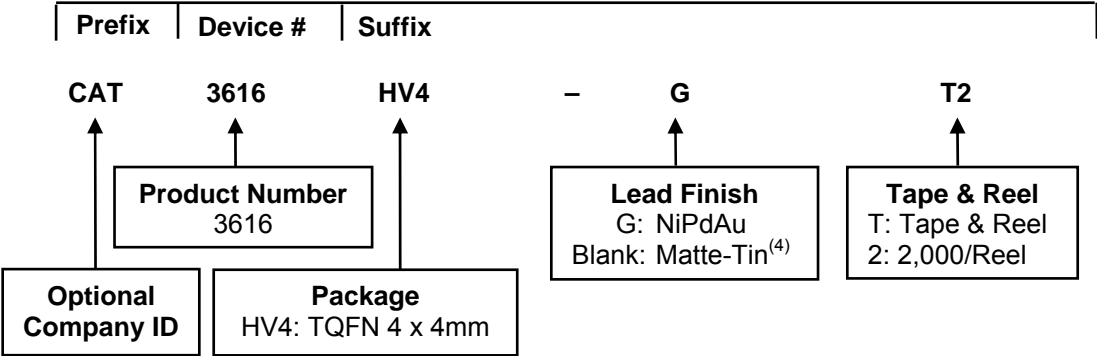


**FRONT VIEW**

**Notes:**

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

EXAMPLE OF ORDERING INFORMATION




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 CAT3616HV4-GT2 (TQFN, NiPdAu Plated Finish, Tape & Reel, 2,000/Reel).
- (4) For Matte-Tin package option, please contact your nearest ON Semiconductor Sales office.

**REVISION HISTORY**

Date	Rev.	Description
20-Jul-06	A	Initial Issue
07-Jan-08	B	Add NiPdAu lead finish Add Extended Temperature range Update Package Outline Drawing Update Example of Ordering Information Add "MD-" to Document Number
30-May-08	C	Update Package Outline Drawing Add Top Mark Code Link
12-Nov-08	D	Change logo and fine print to ON Semiconductor

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