



# 4-Channel, 1X/1.5X Charge Pump White LED Driver

## DESCRIPTION

The EUP3651 is a high efficiency charge pump white LED driver. It supports 4 white LEDs with regulated constant current for uniform intensity. The EUP3651 maintains the highest efficiency by utilizing a 1.5X fractional charge pump and low dropout current regulators. A low external parts count (two 1uF flying capacitors and two small 1uF capacitors at  $V_{IN}$  and  $V_{OUT}$ ) makes the EUP3651 ideally suited for small battery-powered applications.

The EN logic input is used to enable, disable, and set current with a 16-step linear scale. The LED current can be configured between 5mA and 25mA. If EN is kept low for more than 1.5ms, the EUP3651 enters shutdown mode.

The EUP3651 is available in a 12-pin 3mm x 3mm TDFN package.

## FEATURES

- 1X/1.5X Mode for Ultra-High Efficiency
- Up to 25mA Output Current for Each Channel
- 2.7V to 5.5V Input Voltage
- 1MHz Fixed Switching Frequency
- Single-Wire Serial Pulse Interface to Set LED Current with 16-step Linear scale
- Soft Start Function
- Built-In Short-Circuit Protection
- Built-in Thermal Protection
- $I_Q < 1\mu A$  in Shutdown
- TDFN-12 Package
- RoHS Compliant and 100% Lead (Pb)-Free

## APPLICATIONS

- Mobile phone
- Small LCD Backlighting
- Programmable Current Sinks
- White Photo Flash for Digital Cameras

## Typical Application Circuit

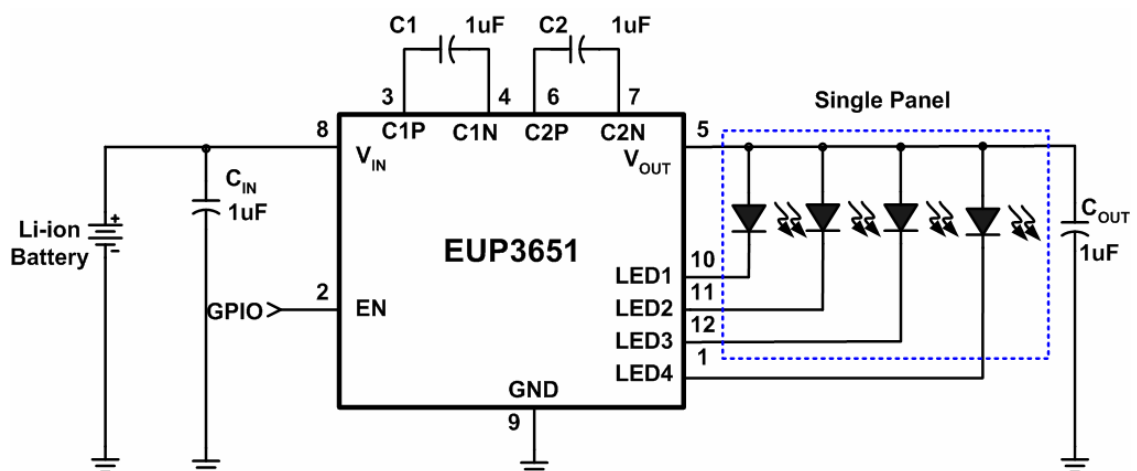


Figure 1.

Block Diagram

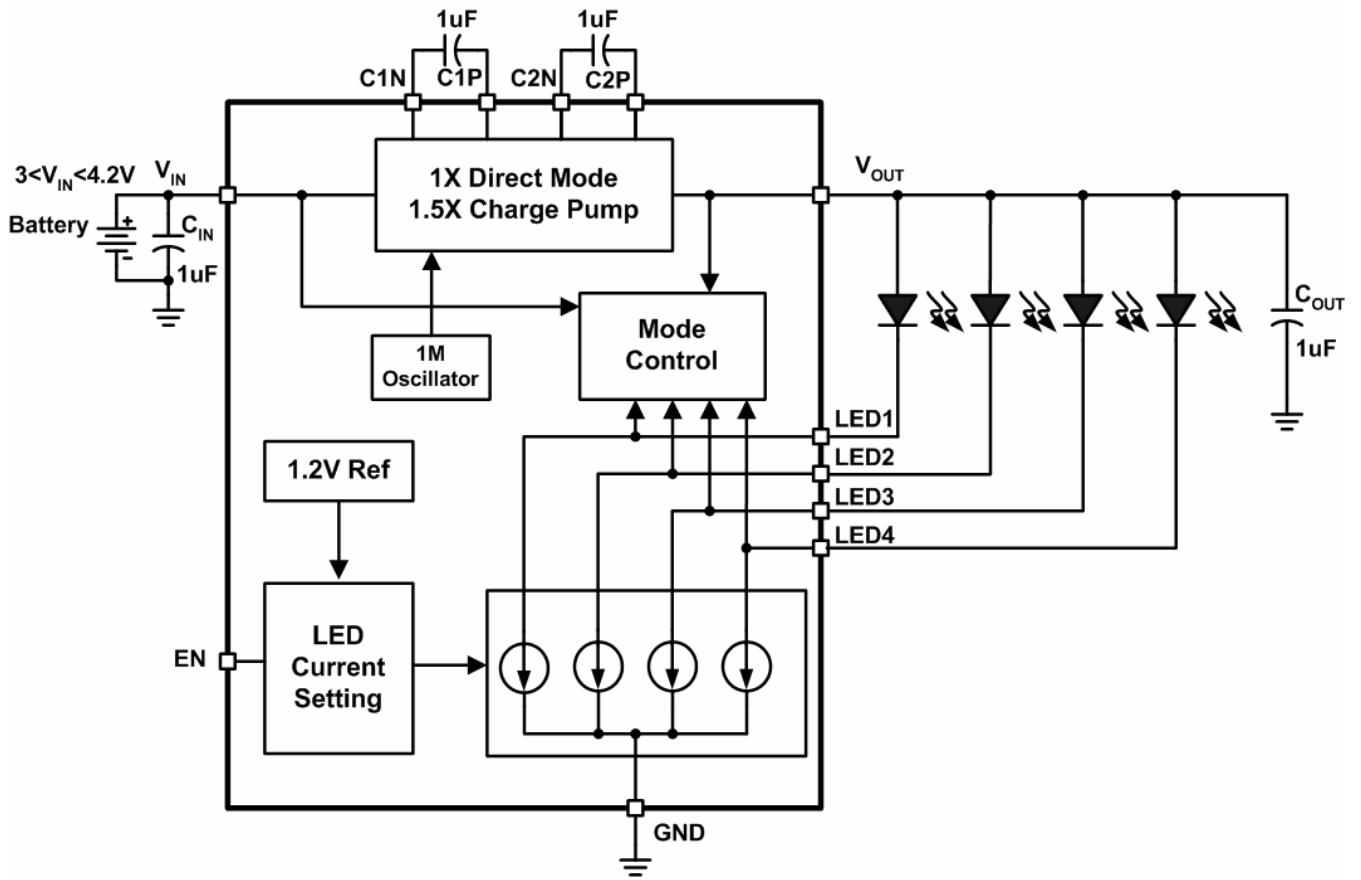


Figure 2.

## Pin Configurations

Package Type	Pin Configurations
TDFN-12	<p>LED4 1 12 LED3  EN 2 11 LED2  C1P 3 10 LED1  C1N 4 9 GND  V<sub>OUT</sub> 5 8 V<sub>IN</sub>  C2P 6 7 C2N</p>

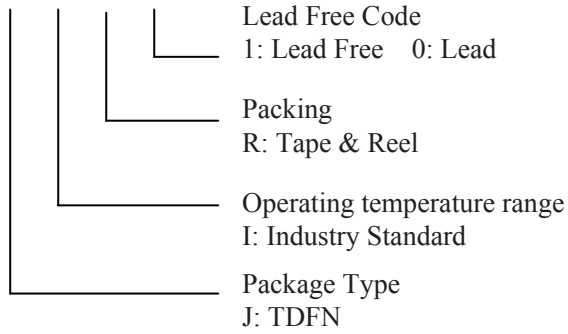
## Pin Description

PIN	NAME	DESCRIPTION
1	LED4	LED4 cathode terminal
2	EN	Device enable (active high) and 1 wire control input
3	C1P	Bucket capacitor 1, positive terminal
4	C1N	Bucket capacitor 1, negative terminal
5	V <sub>OUT</sub>	Charge pump output, connect to LED anodes
6	C2P	Bucket capacitor 2, positive terminal
7	C2N	Bucket capacitor 2, negative terminal
8	V <sub>IN</sub>	Charge pump input, connect to battery or supply
9	GND	Ground
10	LED1	LED1 cathode terminal
11	LED2	LED2 cathode terminal
12	LED3	LED3 cathode terminal
EP	TAB	Connect to GND on the PCB

**Ordering Information**

Order Number	Package Type	Marking	Operating Temperature range
EUP3651JIR1	TDFN-12	XXXXX P3651	-40 °C to 85°C

EUP3651



**Absolute Maximum Ratings**

- Input Voltage ( $V_{IN}$ ) ----- -0.3V to +6V
- EN/SET to GND Voltage ( $V_{EN/SET}$ ) ----- -0.3V to  $V_{IN} + 0.3V$
- Maximum DC Output Current ( $I_{OUT}$ ) ----- 150mA
- Operating Junction Temperature Range ( $T_J$ ) ----- -40°C to +150°C
- Maximum Soldering Temperature (at leads, 10 sec) ----- 300°C

**Operating Ratings**

- Maximum Power Dissipation ( $P_D$ ) ----- 2W
- Operating Temperature ( $T_{JA}$ ) ----- 50°C/W

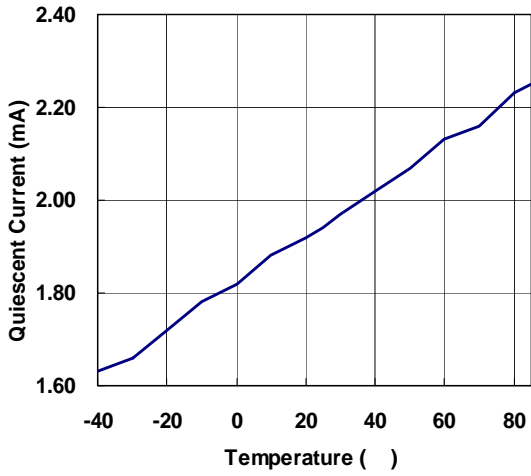
**Electrical Characteristics**

(Over recommended operating conditions unless specified otherwise)  $V_{IN} = 3.6V$ , EN = High,  $T_{AMB} = 25^\circ C$

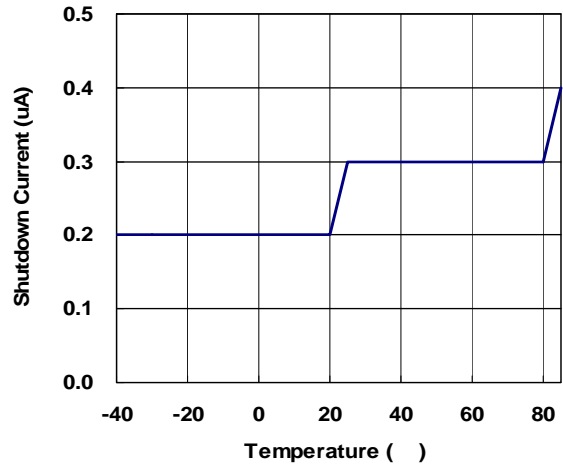
Symbol	Parameter	Conditions	EUP3651			Units
			Min	Typ	Max	
$V_{IN}$	Operating Voltage		<b>3</b>		<b>5.5</b>	V
$I_Q$	Quiescent Current	1X mode, no load		0.65	<b>1</b>	mA
		1.5X mode, no load		2	<b>2.5</b>	mA
$I_{SD}$	Shutdown Current	VEN = 0V			1	µA
$I_{LED-ERR}$	LED Current Accuracy	EN Falling Edges = 1	22.5	25	27.5	mA
$I_{LED-LED-ERR}$	LED Channel Matching	Any two channel mismatch	-3		3	%
$R_{OUT}$	Output Resistance (open loop)	1X mode, $I_{OUT} = 100mA$		1.75		Ω
		1.5X mode, $I_{OUT} = 100mA$		4		Ω
$F_{OSC}$	Charge Pump Frequency	1.5X mode	<b>0.75</b>	1	<b>1.25</b>	MHz
$I_{SC}$	Output short Circuit Current Limit	$V_{OUT} < 0.5V$		250		mA
$V_{HYS}$	1.5X to 1X Transition Hysteresis			400		mV
$T_{DLY}$	Transition Filter Delay			500		µs
$T_{SD}$	Thermal Shutdown			160		
$T_{HYS}$	Thermal Hysteresis			20		
$I_{EN}$	EN Input Leakage		<b>-1</b>		<b>1</b>	µA
$V_{HI}$	EN Logic High Level		<b>1.6</b>			V
$V_{LO}$	EN Logic Low Level				<b>0.4</b>	V
$T_{SETUP}$	EN setup from shutdown		<b>10</b>			µs
$T_{LO}$	EN program low time		<b>0.5</b>		<b>100</b>	µs
$T_{HI}$	EN program high time		<b>0.5</b>		<b>100</b>	µs
$T_{OFF}$	EN low time to shutdown		<b>1.5</b>			ms
$T_{DATADLY}$	EN Delay to DATA		<b>500</b>		<b>1000</b>	µs

Typical Operating Characteristics

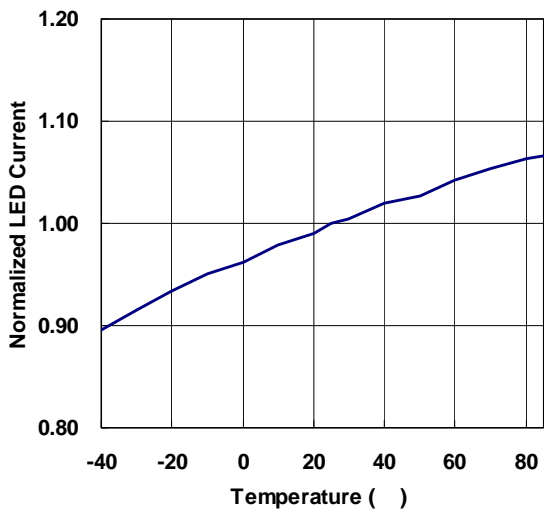
Quiescent Current vs. Temperature



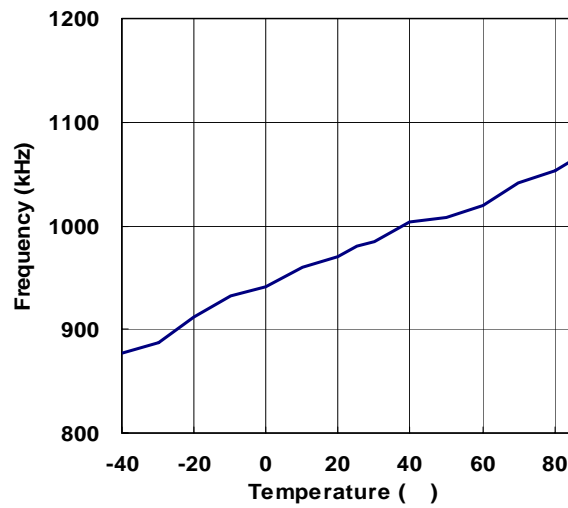
Shutdown Current vs. Temperature



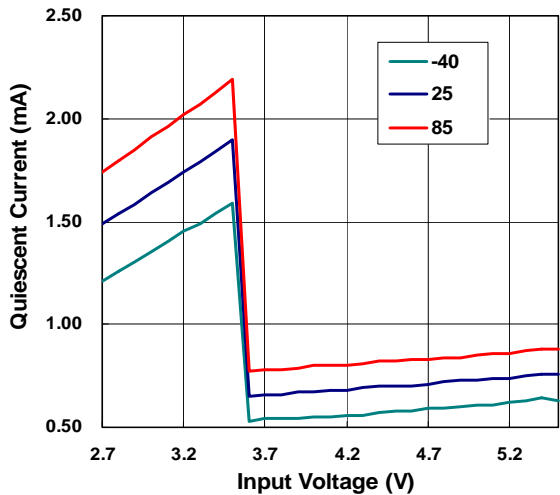
Normalized LED Current vs. Temperature



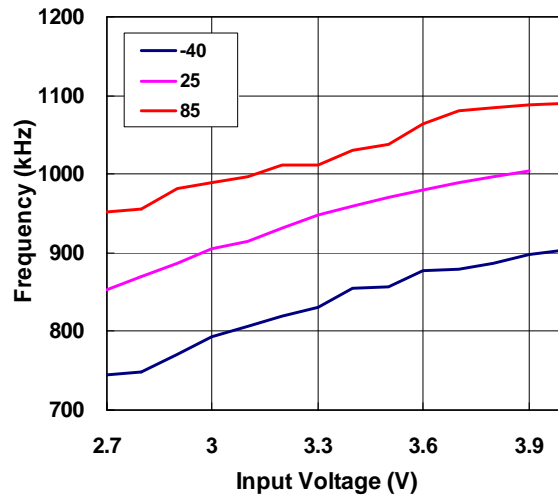
Frequency vs. Temperature



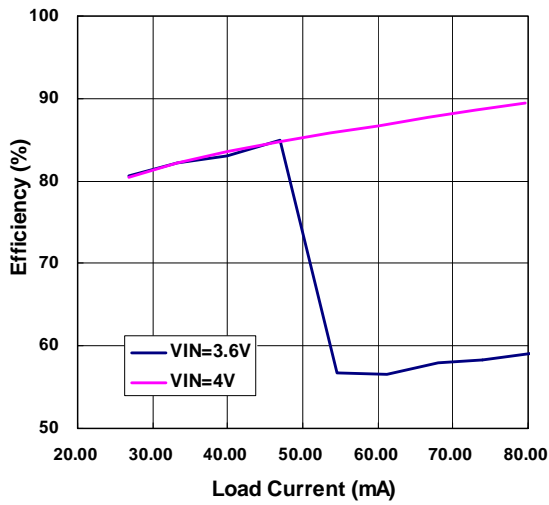
Quiescent Current vs. Input Voltage



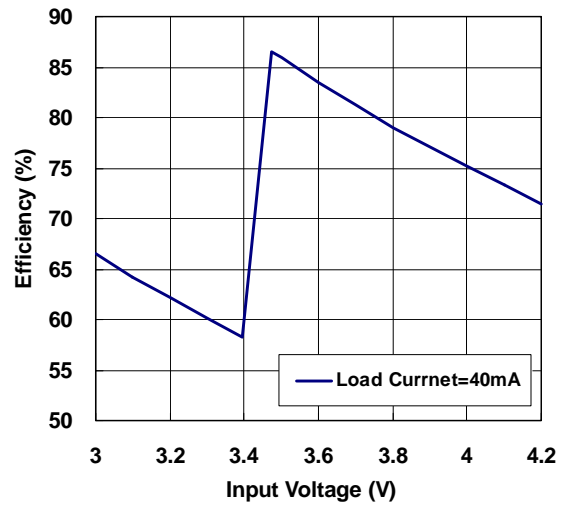
Frequency vs. Input Voltage



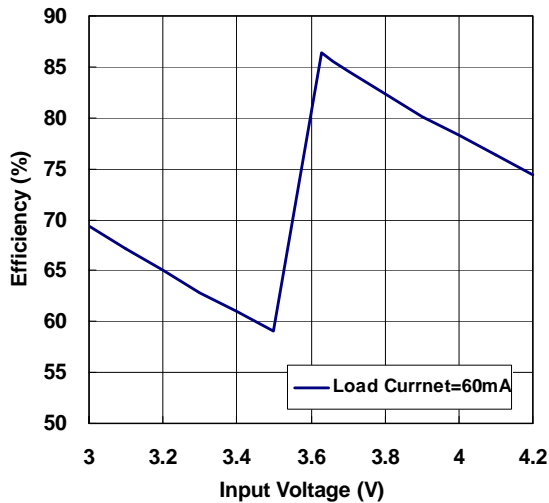
Efficiency vs. Load Current



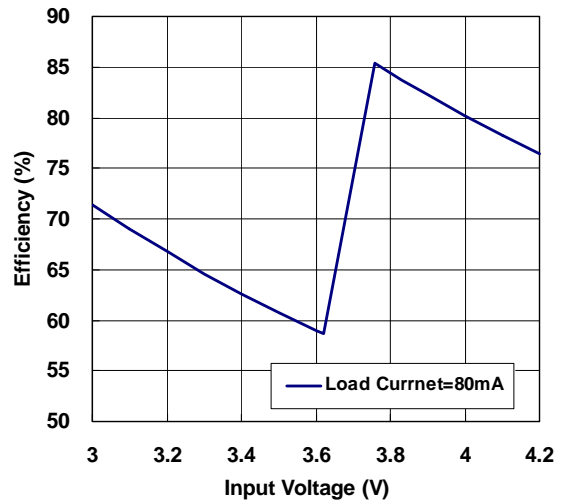
Efficiency vs. Input Voltage



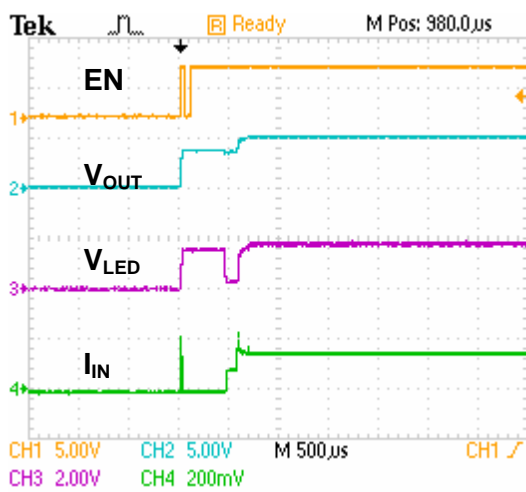
Efficiency vs. Input Voltage



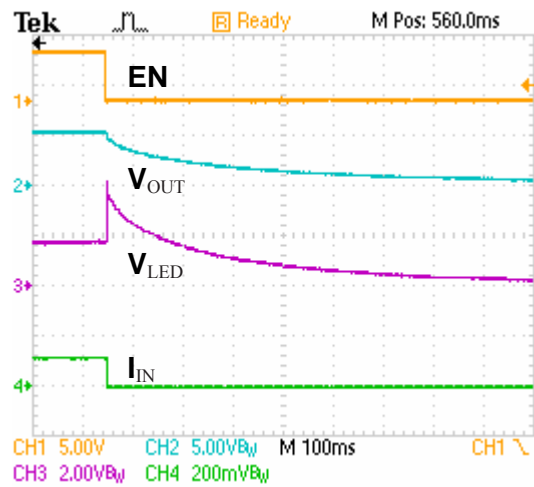
Efficiency vs. Input Voltage



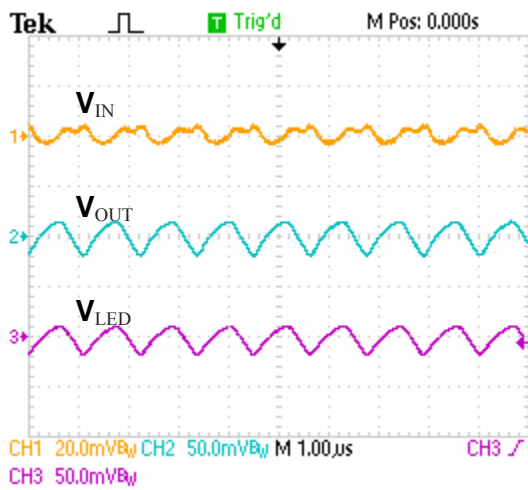
Enable Transient Response



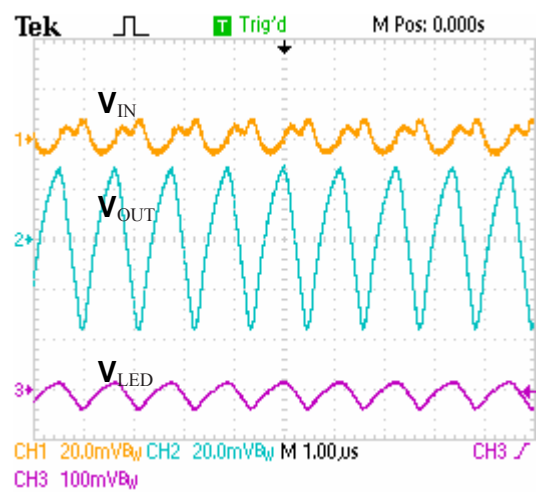
Shutdown Timeout



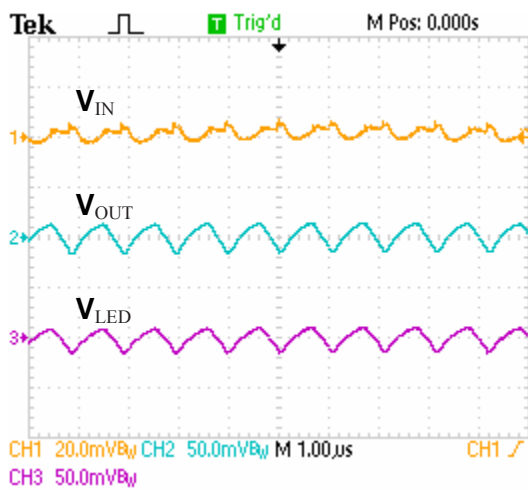
40mA Load at  $V_{IN}=3V$



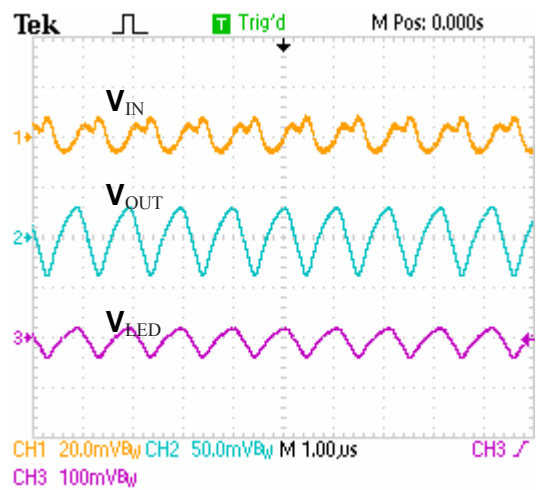
80mA Load at  $V_{IN}=3V$



40mA Load at  $V_{IN}=3.6V$



80mA Load at  $V_{IN}=3.6V$





## Basic Operation

At power-up, the EUP3651 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 1.5X mode (after a fixed delay time of about 500 $\mu$ s). In 1.5X mode, the output voltage is approximately equal to 1.5 times the input supply voltage (less any internal voltage losses).

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.

## The EN Serial Pulses Interface

The current of the four LED channels can be configured by the EN logic input. By pulsing this signal with a specific protocol, the internal registers can be written into and then configure LEDs with the desired current.

The EN serial pulses timing diagram see Figure 3.

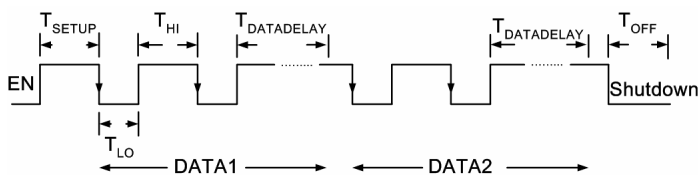


Figure 3. EN Timing Diagram

- The device requires a minimum 10 $\mu$ s delay  $T_{SETUP}$  to ensure the initialization of the internal logic at power-up.
- $T_{LO}$  and  $T_{HI}$  must be between within 500ns to 100 $\mu$ s.
- Once the final rising edge of DATA1 pulses transfer completed, the user must wait for more than 500 $\mu$ s before transferring another DATA2 pulse falling edge.
- To power-down the device, the EN input should be kept low for a duration  $T_{OFF}$  of 1.5ms or more.
- To power-down the device, the EN input should be kept low for a duration  $T_{OFF}$  of 1.5ms or more. When power-down, all registers data are lost and reset to default value.

The LED current vs. EN series pulses edges as the Figure 4.

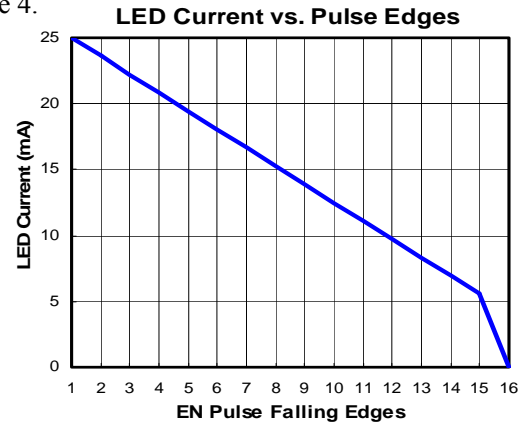


Figure 4. LED Current vs. Single Wire Series Pulse Falling Edges

## Unused LED Channels

For applications with 3 LEDs or less, unused LEDs can be disabled by connecting the LED pin directly to  $V_{OUT}$ , as shown in Figure 5. If LED pin voltage is within 1V of  $V_{OUT}$ , then the channel is switched off and a 8 $\mu$ A test current is placed in the channel to sense when the channel moves below  $V_{OUT} - 1V$ .

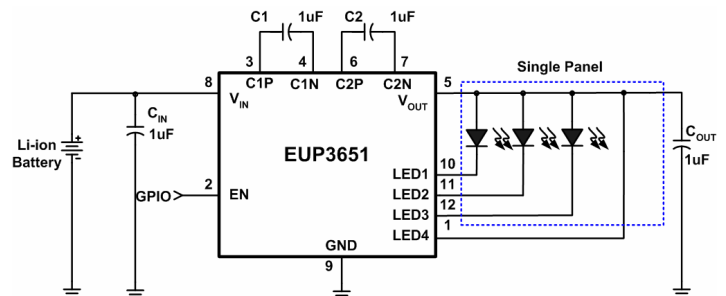


Figure 5. 3 LEDs Application

## Protection Mode

If an LED is disconnected, the output voltage  $V_{OUT}$  automatically limits at about 5.8V. This is to prevent the output pin from exceeding its absolute maximum rating.

If the die temperature exceeds 160 $^{\circ}$ C the driver will enter a thermal protection shutdown mode. When the device temperature drops by about 20 $^{\circ}$ C the device will resume normal operation.

## LED Selection

LEDs with forward voltages ( $V_F$ ) ranging from 1.3V to 4V may be used with the EUP3651. 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 EUP3651 will stay in 1X mode for lower supply voltage of 0.2V. This helps improve the efficiency and extends battery life.

## External Component

The driver requires two external 1 $\mu$ F 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 charge pump modes, the input current ripple is kept very low by design and an input bypass capacitor of 1 $\mu$ F is sufficient.

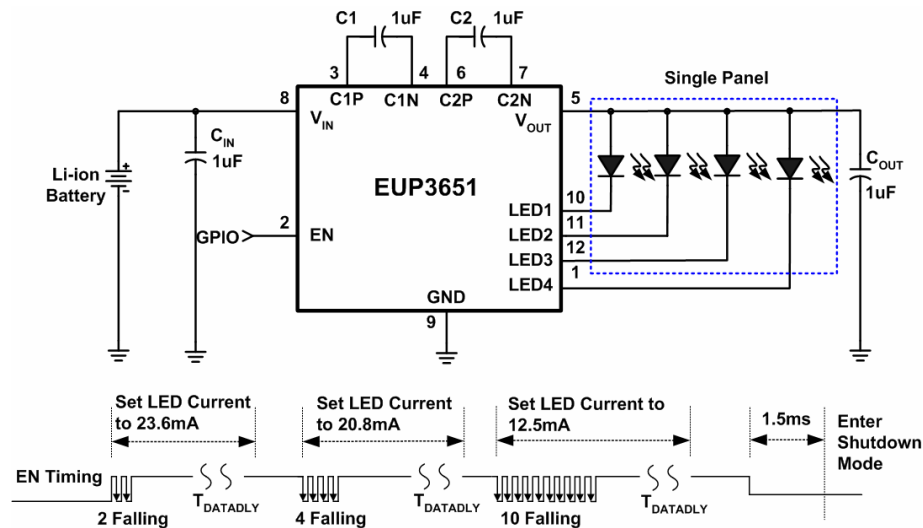
In 1X mode, the device operates in linear mode and does not introduce switching noise back onto the supply.

## Layout Consideration

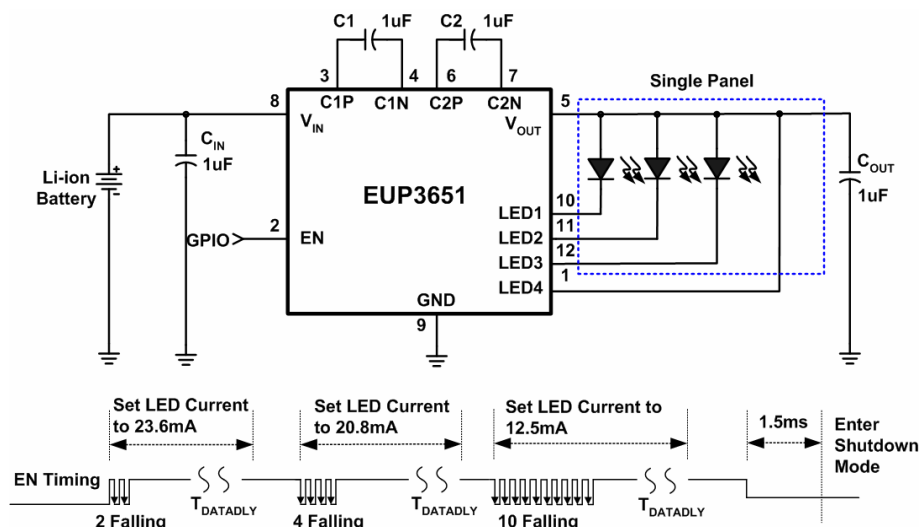
Due to the switching frequency and high transient current of EUP3651, careful consideration of PCB layout is necessary. The C<sub>IN</sub> should be connected as close to the IC as possible. The ground of C<sub>IN</sub> and C<sub>OUT</sub> should be placed as close as possible. To achieve the best performance of EUP3651, minimize the distance between every two components and also minimize every connection length with a maximum trace width. Make sure each device connects to immediate ground plane. A copper area matching the TDFN exposed pad (TAB) must be connected to the ground plane underneath. The use of multiple via improves the package heat dissipation.

## Applications Examples

I. Use the EUP3651 to drive four LEDs for one panel backlighting.

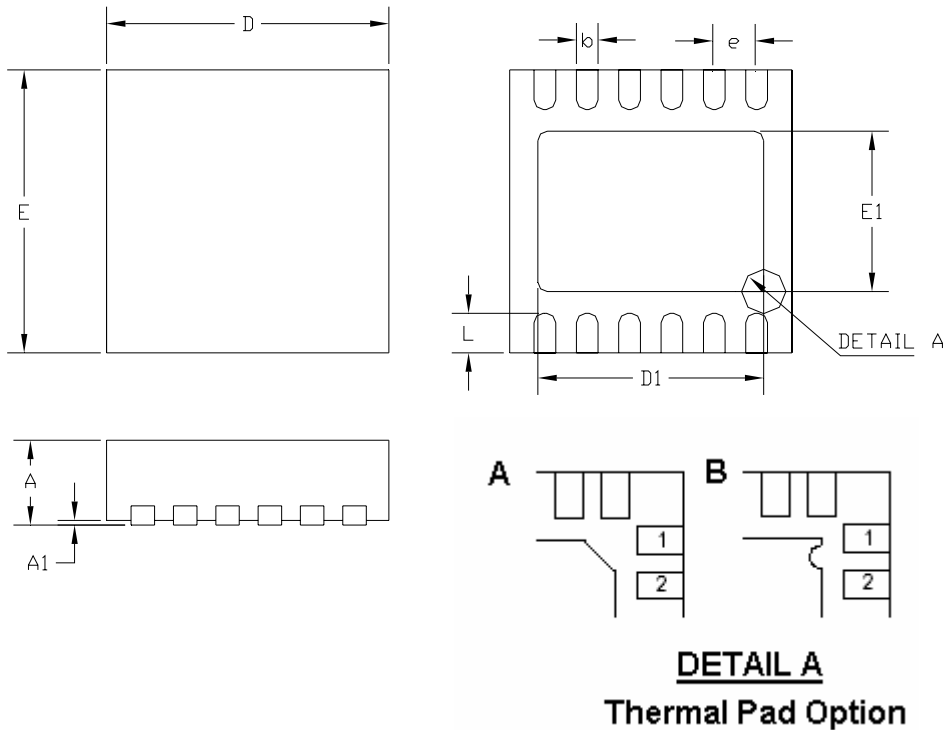


II. Use the EUP3651 to drive 3 LEDs for one panel backlighting. The unused channel should be connected to V<sub>OUT</sub>.



Packaging Information

TDFN-12



SYMBOLS	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	0.70	0.80	0.028	0.031
A1	0.00	0.05	0.000	0.002
b	0.18	0.30	0.007	0.012
E	2.90	3.10	0.114	0.122
D	2.90	3.10	0.114	0.122
D1	2.40		0.094	
E1	1.70		0.067	
e	0.45		0.018	
L	0.30	0.50	0.012	0.020