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

## DESCRIPTION

The EUP3654 is a high efficiency charge pump white LED driver. It supports 6 white LEDs with regulated constant current for uniform intensity. The EUP3654 maintains the highest efficiency by utilizing a 1.5X fractional charge pump and low dropout current regulators. A low external parts count (two 2.2uF flying capacitors and two small 2.2uF capacitors at $V_{IN}$ and $V_{OUT}$) makes the EUP3654 ideally suited for small battery-powered applications.The charge pump provides backlight current utilizing six matched current sinks. The load and supply conditions determine whether the charge pump operates in 1x, 1.5x mode.

The EUP3654 uses single wire serial pulse interface which controls all functions of the device, including enabling the part and setting LED driver's current level with 32 steps.

The EUP3654 also provides an external PWM dimming control while DPWM duty cycle is controlled directly from an external PWM signal, adjusting brightness further based on image contents. And Direct PWM dimming signal frequency range is from 200Hz to 1KHz.

With a 3mm×3mm TQFN-16 package and 4 small capacitors, the EUP3654 provides a complete LED driver solution with a minimal PCB footprint.

## FEATURES

- 1X/1.5X Mode for Ultra-High Efficiency
- 0.5mA 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 32-Step Scale
- External PWM Dimming with 200Hz - 1KHz Frequency Range
- High Backlight Current Matching ±0.5% Typical
- High Backlight Current Accuracy ±1.5% Typical
- Soft Start Function
- Built-In Short-Circuit Protection
- Built-in Thermal Protection
- $I_Q$<1uA in Shutdown
- TQFN 3mm×3mm TQFN-16 package
- RoHS Compliant and 100% Lead(Pb)-Free Halogen-Free

## APPLICATIONS

- Cell phones, smart phones, and PDAs
- Portable media players
- Digital cameras and GPS units
- Small LCD Backlighting
- Display/keypad backlighting and LED indicators

## Typical Application Circuit

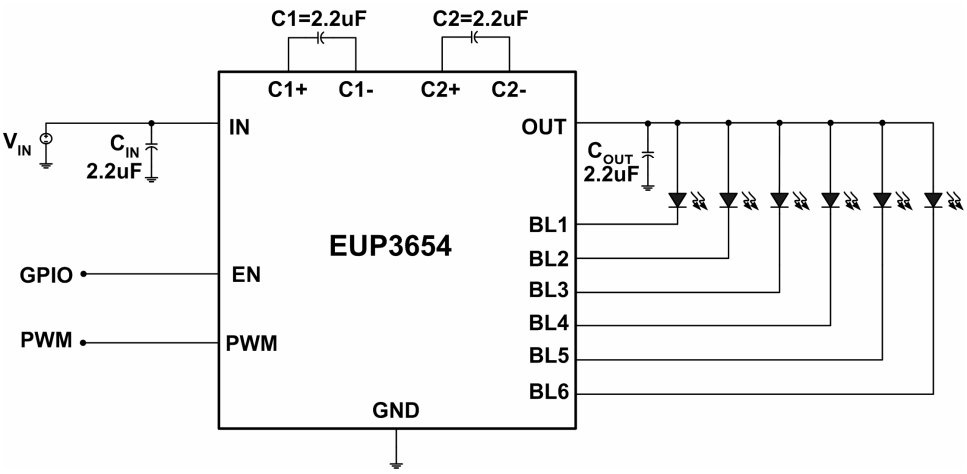
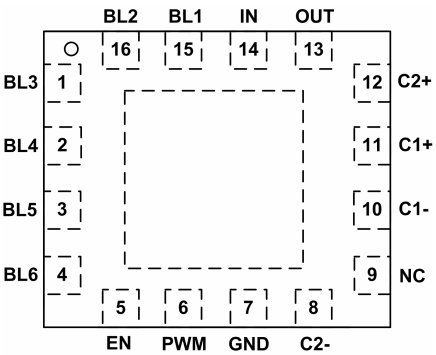



**Figure1.**

## Pin Configurations

| Package Type | Pin Configurations |
|---|---|
| TQFN-16 |  |



## Pin Description

| PIN | TQFN-16 | DESCRIPTION |
|---|---|---|
| 1 | BL3 | Current sink output for LED 3— connect this pin to OUT if unused |
| 2 | BL4 | Current sink output for LED 4— connect this pin to OUT if unused |
| 3 | BL5 | Current sink output for LED 5— connect this pin to OUT if unused |
| 4 | BL6 | Current sink output for LED 6— connect this pin to OUT if unused |
| 5 | EN | Serial interface line for 32step backlighting current |
| 6 | PWM | External direct PWM dimming pin |
| 7 | GND | Ground Pin |
| 8 | C2- | Negative connection to bucket capacitor 2 — requires a capacitor connected to C2+ |
| 9 | NC | Non-connect pin |
| 10 | C1- | Negative connection to bucket capacitor 1 — requires a capacitor connected to C1+ |
| 11 | C1+ | Positive connection to bucket capacitor 1 — requires a capacitor connected to C1- |
| 12 | C2+ | Positive connection to bucket capacitor 2 — requires a capacitor connected to C2- |
| 13 | OUT | Charge Pump output — all LED anode pins should be connected to this pin — requires a capacitor to GND |
| 14 | IN | Battery Voltage input — requires a capacitor to GND |
| 15 | BL1 | Current sink output for LED 1— connect this pin to OUT if unused |
| 16 | BL2 | Current sink output for LED 2— connect this pin to OUT if unused |

## Ordering Information

| Order Number | Package Type | Marking | Operating Temperature Range |
|---|---|---|---|
| EUP3654JIR1 | TQFN-16 | xxxxx<br>P3654 | -40 °C to 85°C |

EUP3654 □ □ □ □

- Lead Free Code
  1: Lead Free 0: Lead
- Packing
  R: Tape & Reel
- Operating temperature range
  I: Industry Standard
- Package Type
  J: TQFN

## Block Diagram

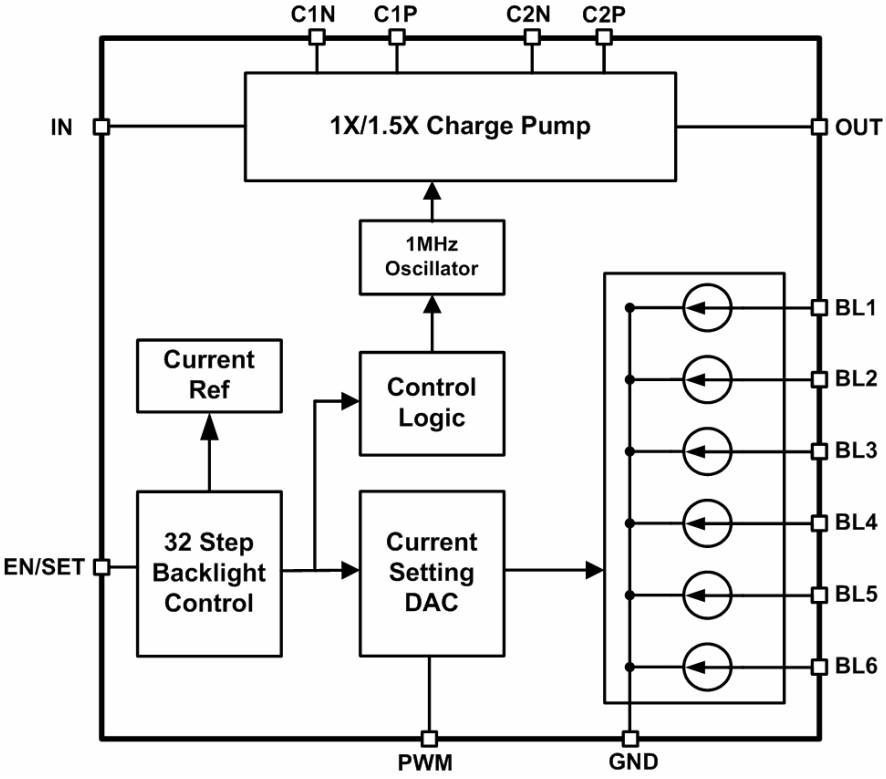



**Figure2. Block Diagram**

## Absolute Maximum Ratings (1)

- Input Voltage ($V_{IN}$) ---------- 6V
- Maximum Output Current ($I_{OUT}$) ---------- 150mA
- En to GND voltage ($V_{EN}$) ---------- -0.3V to +6V
- PWM to GND voltage ($V_{PWM}$) ---------- -0.3V to +6V
- Storage Temperature ($T_S$) ---------- -65°C to +150°C
- Reflow Temperature (soldering,10sec) ---------- 260°C
- ESD protection ---------- 2kV

## Recommend Operating Conditions (2)

- Supply Voltage ($V_{IN}$) ---------- 2.7V to 5.5V
- Operating Temperature ($T_A$) ---------- -40℃ to +85℃

*Note (1): Stress beyond those listed under "Absolute Maximum Ratings" may damage the device.*

*Note (2): The device is not guaranteed to function outside the recommended operating conditions.*

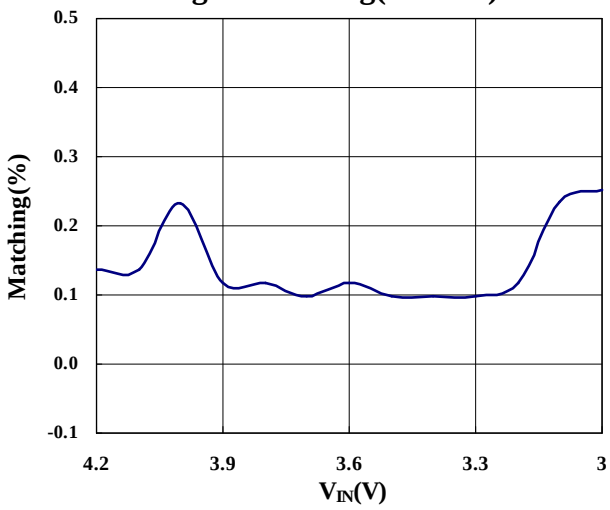
## Electrical Characteristics

Unless otherwise noted, $T_A$= +25°C for Typ, -40°C to+85°C for Min and Max, $V_{IN}$=3.6V;$C_{IN}$=$C_{OUT}$=2.2μF; $C_1$=$C_2$=2.2μF;$T_A$=25℃

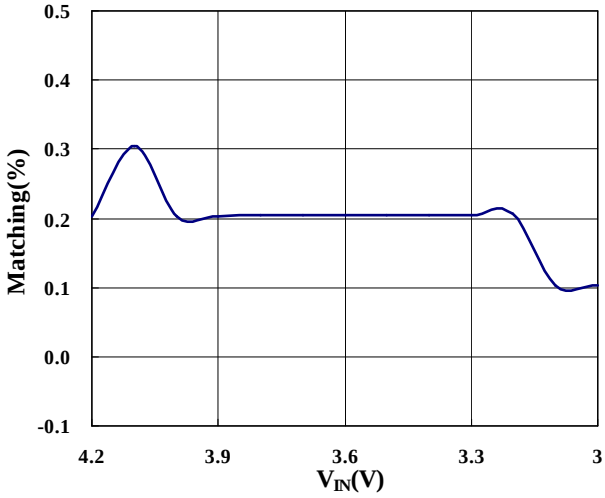
| Symbol | Parameter | Conditions | EUP3654 | | | Units |
|---|---|---|---|---|---|---|
| | | | Min. | Typ. | Max. | |
| $I_{OUTMAX}$ | Maximum Total Output Current | IN > 2.9V, sum of all active LED currents | 150 | | | mA |
| $I_{BLN}$ | Backlight Current Setting | Nominal setting for BL1 thru BL6 | 0.5 | | 25 | mA |
| $I_{BL-BL}$ | Backlight Current Matching | IBLn = 12 mA | -3.5 | ±0.5 | +3.5 | % |
| $I_{BL-ACC}$ | Backlight Current Accuracy | IBLn = 12 mA | -8 | ±1.5 | +8 | % |
| $V_{TRANS1x}$ | 1x Mode to 1.5x Mode Falling Transition Input Voltage | $I_{OUT}$=90mA,$I_{BLn}$ = 15mA | | 3.4 | | V |
| $V_{HYST1x}$ | 1.5x Mode to 1x Mode Hysteresis | | | 300 | | mV |
| $f_{PUMP}$ | Charge Pump frequency | VIN=3.2V | | 1000 | | kHz |
| $I_{OUT\ (SC)}$ | Output Short Circuit Current Limit | OUT pin shorted to GND | | 60 | | mA |
| $I_{Q\ (OFF)}$ | Shutdown Current | | | 0 | 1 | μA |
| $I_Q$ | Quiescent Current | Charge pump in 1x mode, 2.9V <VIN<4.2V | | 0.8 | 1.8 | mA |
| | | Charge pump in 1.5x mode, 2.9V <VIN<4.2V | | 1.8 | 3 | |
| $V_{UVLO}$ | UVLO | Falling VIN | 2.2 | 2.4 | 2.6 | V |
| | | Hyst | | 200 | | mV |
| $V_{OVP}$ | Over-Voltage Protection | OUT pin open circuit, $V_{OUT}$=$V_{OVP}$ | | 5.7 | 6.0 | V |
| $T_{OT}$ | Over-Temperature Protection | Rising Temperature | | 165 | | ℃ |
| | | OT Hysteresis | | 20 | | ℃ |

## Typical Operating Characteristics

### Backlight Matching(6 LEDs) -25mA

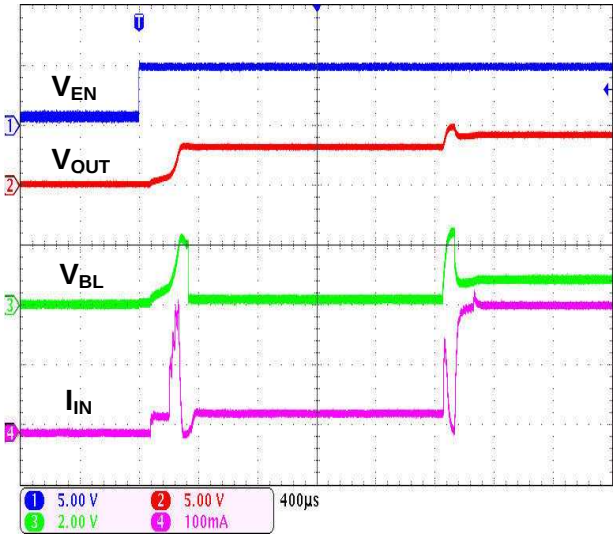



### Backlight Matching(6 LEDs) -5mA



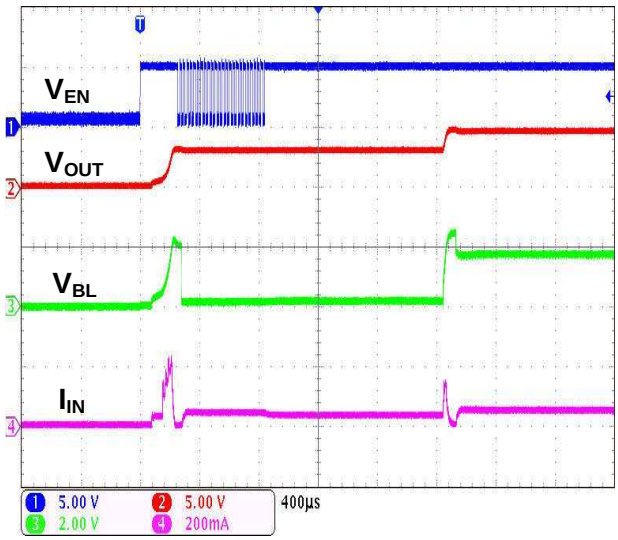

### Enable Transient Response

$V_{IN}$=3.2V, 6LEDs---- $I_{LED}$=25mA each channel



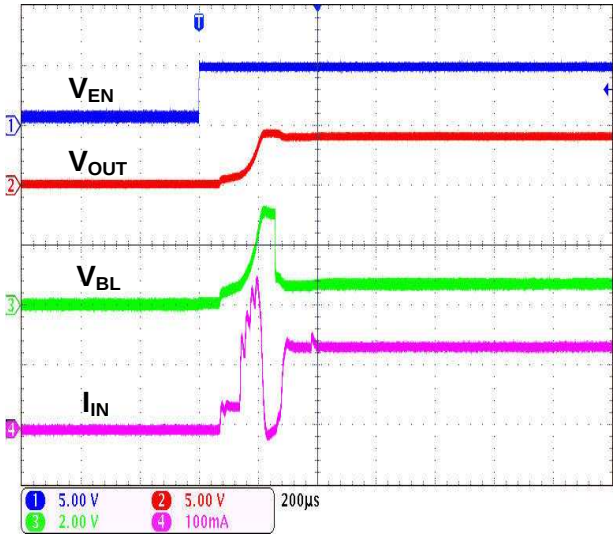

### Enable Transient Response

$V_{IN}$=3.2V, 6LEDs---- $I_{LED}$=5mA each channel



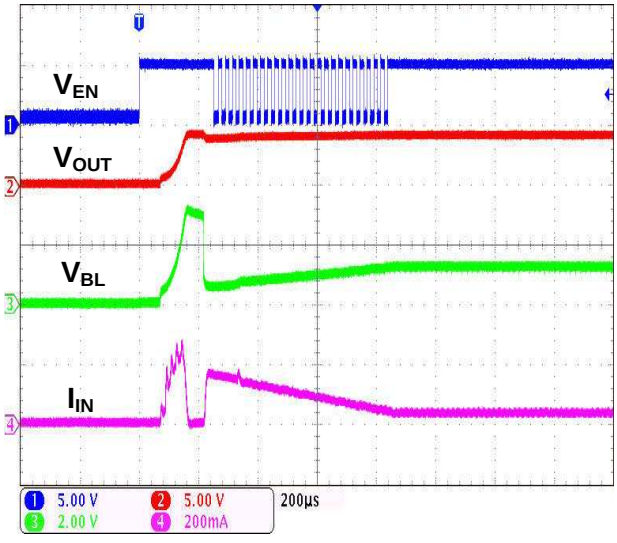

### Enable Transient Response

$V_{IN}$=4.2V, 6LEDs---- $I_{LED}$=25mA each channel



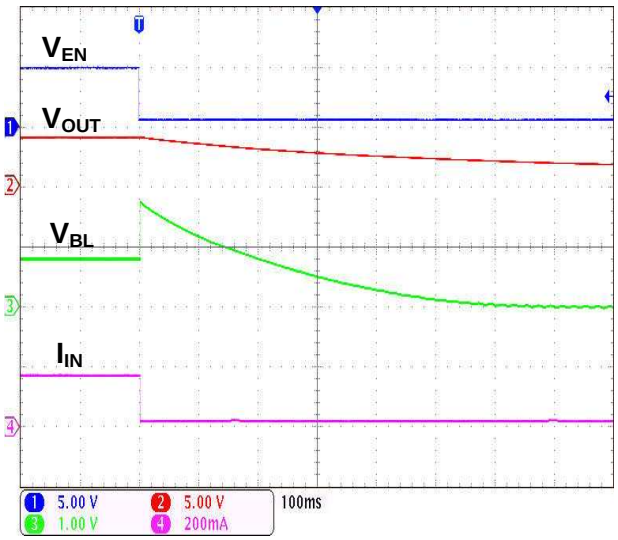

### Enable Transient Response

$V_{IN}$=4.2V, 6LEDs---- $I_{LED}$=5mA each channel



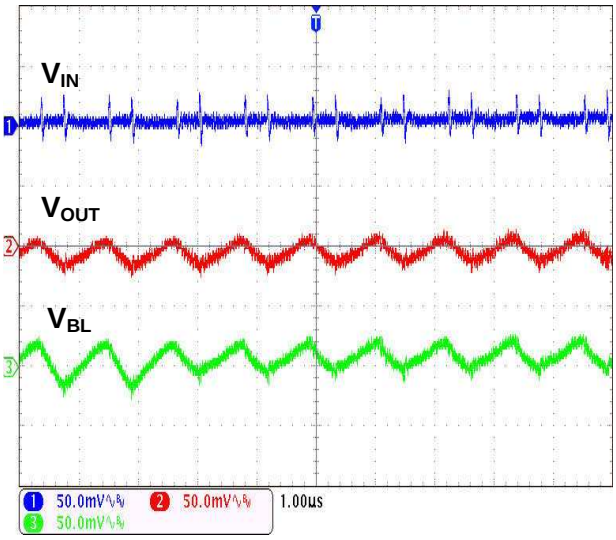
**Shutdown Timeout**

**$V_{IN}$=4.2V, 6LEDs---- $I_{LED}$=25mA each channel**



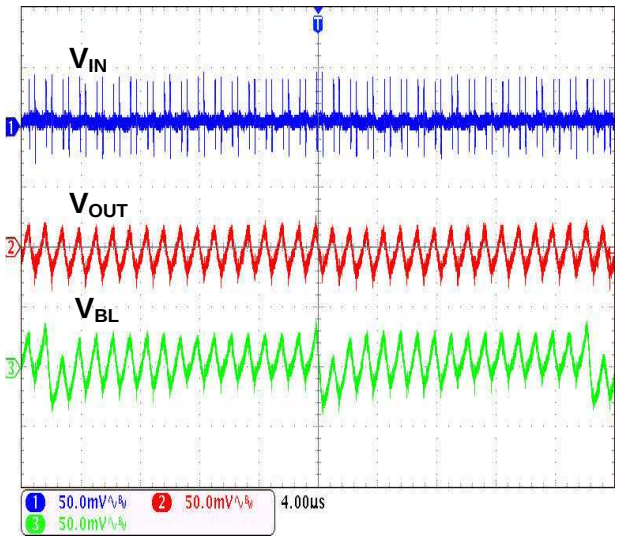

**Ripple----1.5X Mode ,$C_{IN}$= $C_{OUT}$=2.2 uF,**

**$V_{IN}$=3.2V, 6LEDs---- $I_{LED}$=15mA each channel**



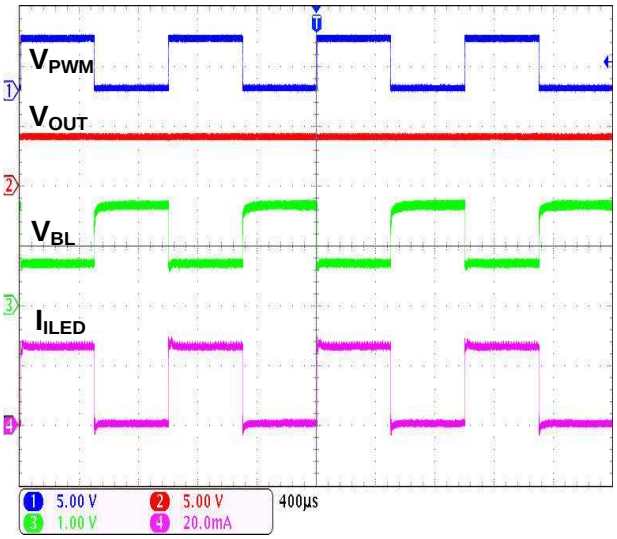

**Ripple----1.5X Mode ,$C_{IN}$= $C_{OUT}$=2.2 uF,**

**$V_{IN}$=3.2V, 6LEDs---- $I_{LED}$=25mA each channel**



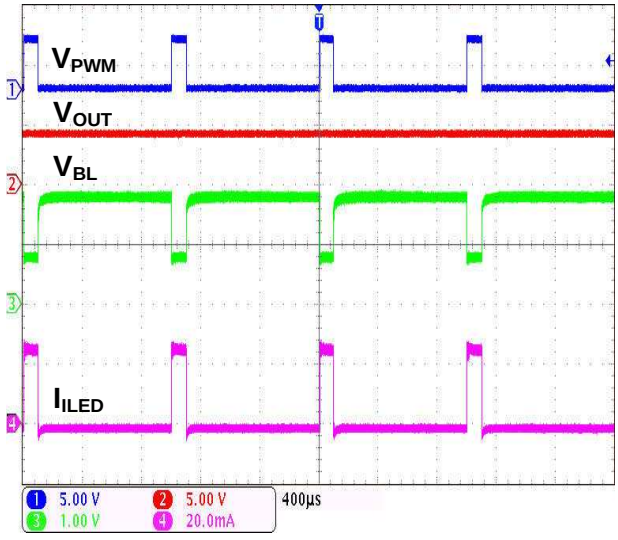

**External Direct PWM Dimming Mode**

**$V_{IN}$=4.2V, $F_{PWM}$=1KHz，PWM duty cycle=50%**




**External Direct PWM Dimming Mode**

**$V_{IN}$=4.2V $F_{PWM}$=1KHz，PWM duty cycle=10%**



## Functional Description

The EUP3654 charge pumps drives up to six LEDS in the main display for backlighting, with regulated constant current for uniform intensity. By utilizing a multi-mode high efficiency charge pump, and six programmable LED drivers, high efficiency and performance is achieved over the full 1-cell Li+ battery voltage range.1MHz fixed-frequency switching allows for tiny external components and low input ripple. The load and supply conditions determine whether the charge pump operates in 1x or 1.5x mode. IN DPWM mode, the LED brightness is adjusted by the duty cycle of external PWM signal.

### 1X to 1.5X Switchover

At power-up the EUP3654 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 falling to a level where the regulated currents cannot be maintained, the device automatically switched into 1.5X mode(after a fixed delay time of 1ms).In 1.5X mode, the output voltage is approximately equal to 1.5 times the input supply voltage(less than internal voltage losses).If the device detects a sufficient input voltage is present to driver all LED currents in 1X mode, it will change automatically back to 1X mode.

### The Single-Wire Pulse Interface

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

The EUP3654 support serial pulse dimming. When EN go high,the LEDs are enabled at full brightness. Each subsequent low-going pulse (500ns to 250μs pulse width) reduces the LED current as Table1. Figure3 shows a timing diagram for singe-wire pulse dimming.

- The device requires a minimum 64μs delay $T_{SETUP}$ to ensure the initialization of the internal logic at power-up.
- $T_{LO}$ and $T_{HI}$ must be between 500ns to 250μs.
- To power-down the device, the EN input should be kept low for a duration $T_{SHDN}$ of 2ms or more.

### Dimming using Single-Wire Pulse

LED brightness can be configured by single wire pulse. When EN go high the LEDS are enabled at full brightness(25mA), Each subsequent low-going pulse reduces the LED current by steps of approximately 1mA as shown in Table 1 and Figure 4, so after one pulse, the LED current is 0.8mA reduction. The 31st pulse reduces the current from 1mA to 0.5mA.The 32nd pulse sets the LED current back to 25mA.

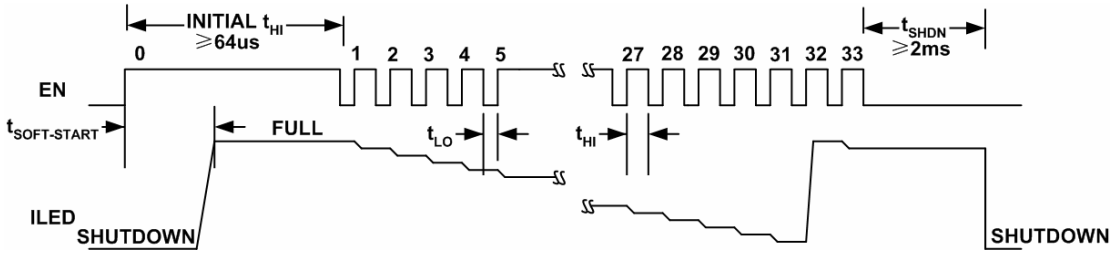



**Figure3. Single-Wire Pulse Dimming Timing Diagram**

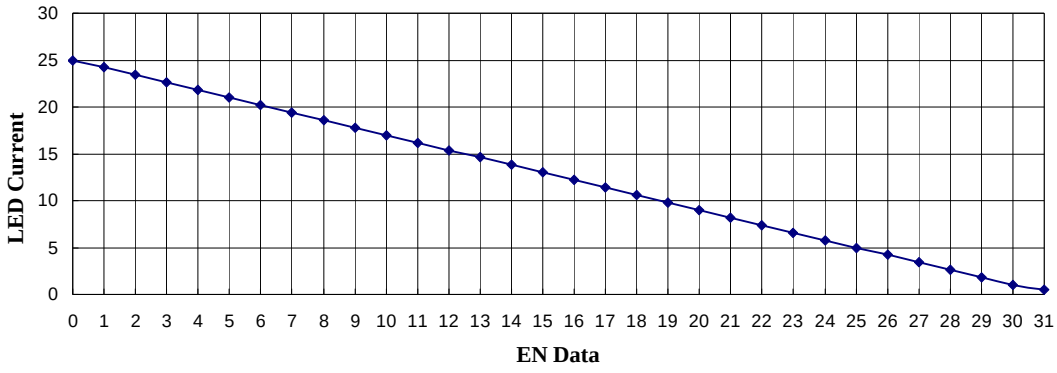



**Figure4. EN Data vs. LED Current**

**Table1. LED Current vs. EN Falling Edges**

| EN Falling Edges | LED Current (mA) | EN Falling Edges | LED Current (mA) |
|---|---|---|---|
| 0 | 25 | 16 | 12.2 |
| 1 | 24.2 | 17 | 11.4 |
| 2 | 23.4 | 18 | 10.6 |
| 3 | 22.6 | 19 | 9.8 |
| 4 | 21.8 | 20 | 9.0 |
| 5 | 21 | 21 | 8.2 |
| 6 | 20.2 | 22 | 7.4 |
| 7 | 19.4 | 23 | 6.6 |
| 8 | 18.6 | 24 | 5.8 |
| 9 | 17.8 | 25 | 5.0 |
| 10 | 17 | 26 | 4.2 |
| 11 | 16.2 | 27 | 3.4 |
| 12 | 15.4 | 28 | 2.6 |
| 13 | 14.6 | 29 | 1.8 |
| 14 | 13.8 | 30 | 1.0 |
| 15 | 13 | 31 | 0.5 |

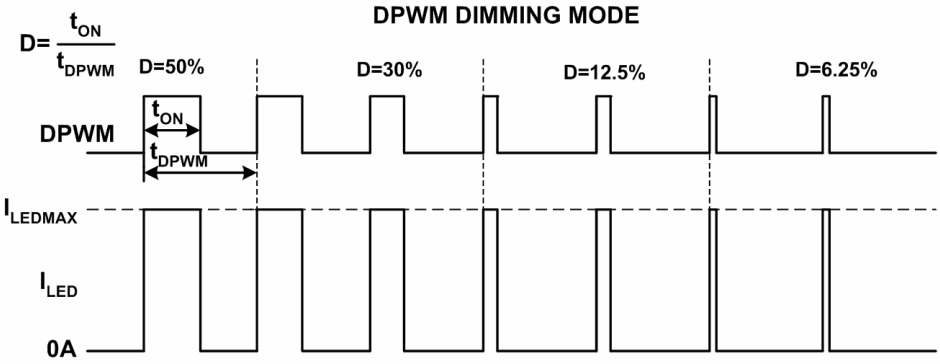



**Figure5. LED Current Control by External PWM Signal in Dimming**

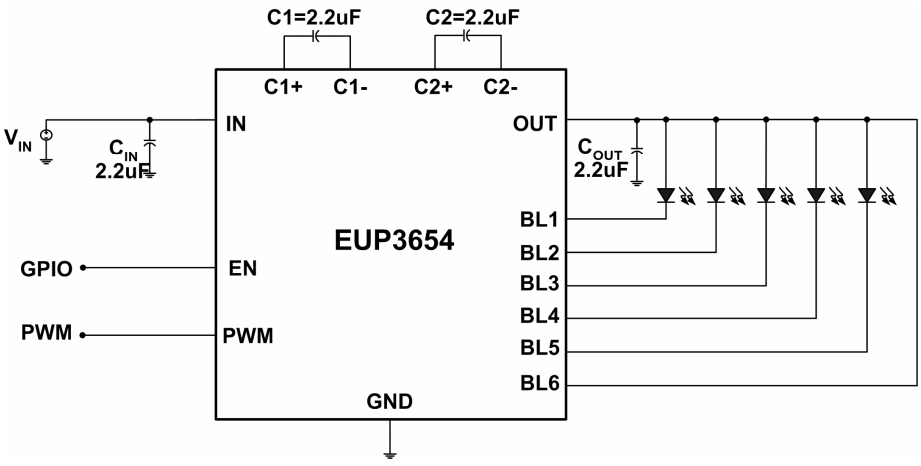



**Figure6. 5LEDs Application**

**Dimming using External PWM Signal**

LED brightness can be verified based upon the duty cycle of the external PWM signal. The PWM signal frequency range is from 200Hz to 1KHz.The resulting current is chopped and synchronized to the PWM signal. When filtered by the slow response time of the human eye, the overall brightness is modulated in consistent flicker-free manner.
The full-scale LED current (ILEDMAX) in the PWM dimming is determined by single-wire interface. And the output LED current is determined by the duty cycle of PWM signal:

$$I_{LED} = D \times I_{LEDMAX}$$

**Unused LED Channels**

For application with 5 LEDs or less, Unused LEDs can also be disabled by connecting the BL pin directly to $V_{OUT}$, as shown on Figure 6. If LED pin voltage is within 1V of $V_{OUT}$, then the channel is switched off and a 8μA test current is placed in the channel to sense when the channel moves below $V_{OUT}$-1V.

**Protection Mode**

If an LED is disconnected, the output voltage $V_{OUT}$ automatically limits at about 5.7V.This is to preventing the output pin from exceeding its absolute maximum rating.

**Thermal Shutdown**

Thermal shutdown protects EUP3654 from excessive power dissipation. If the die temperature exceeds 165°C, the Driver will be shut off. When the device temperature drops by about 20°C the device will resume normal operation.

**Under-Voltage Lockout**

Whenever the input voltage falls below approximately 2.4V, the charge pump is quickly turned off. The UVLO also keeps the charge pump from being turned on until the power supply has reached at least 2.6 V, even if the switch is enabled. On reinsertion, the charge pump is turned on, with a controlled rise time to reduce EMI and voltage overshoots.

**External Component**

The driver requires two external 2.2μF 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 2.2μF is sufficient.
In 1X mode, the device operates in linear mode and does not introduce switching noise back into the supply.

**LED Selection**

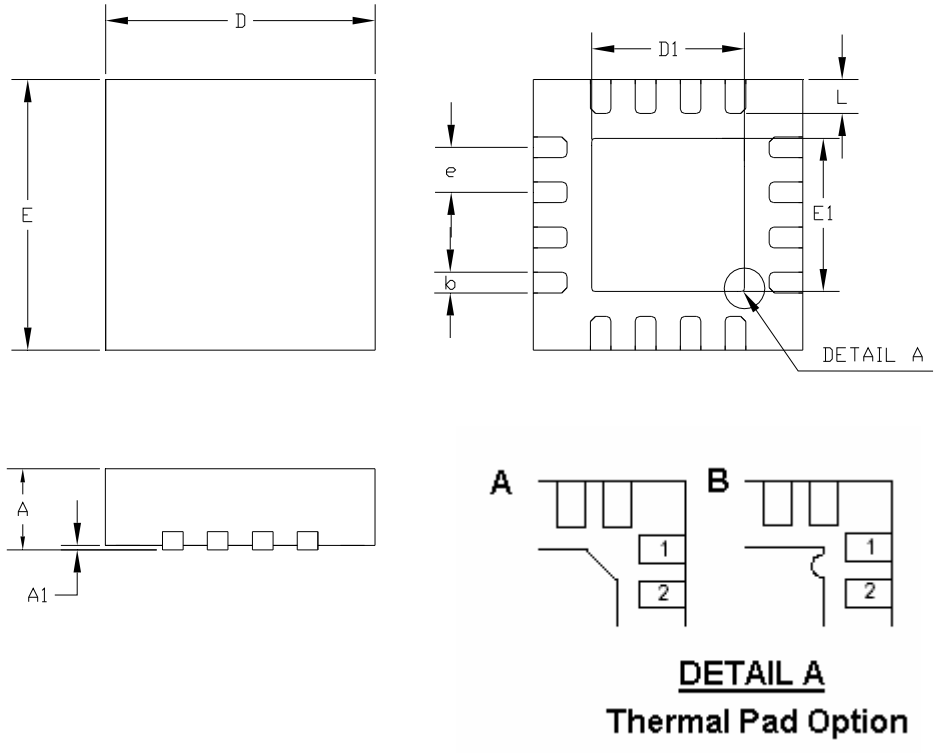
LEDs with forward voltages($V_F$) ranging from 1.3V to 4V may be using with the EUP3654.Selecting LEDs with lower $V_F$ is recommended in order to improve the efficiency by keeping the driver in 1X mode longer as the battery voltage decreases.
For example, if a white LED with a $V_F$ of 3.5V,the EUP3654 will stay in 1X mode for lower supply voltage of 0.2V.This helps improve the efficiency and extends battery life.

**Layout Consideration**

Due to the switching frequency and high transient current of EUP3654, careful consideration of PCB layout is necessary. The $C_{IN}$ should be connected as close to the IC as possible. The ground of $C_{IN}$ and $C_{OUT}$ should be placed as close as possible. To achieve the best performance of EUP3654, 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 TQFN exposed pad (TAB) must be connected to the ground plane underneath. The use of multiple via improves the package heat dissipation.

**Packaging Information**

**TQFN-16**




| 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 | 1.70 | | 0.067 | |
| E1 | 1.70 | | 0.067 | |
| e | 0.50 | | 0.020 | |
| L | 0.30 | 0.50 | 0.012 | 0.020 |