TPS60230 WLED Charge Pump

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PMP - Portable Power DC-DC Applications

ABSTRACT

The TPS60230 is a complete solution for driving up to five white light-emitting diodes from a single-cell Li-ion battery or power source up to 6.5 V. This application report breaks the part down into functional blocks and describes each of the blocks. Additionally, applications for improving current accuracy and overall efficiency, and reducing noise susceptibility are discussed.

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1 Introduction

The Texas Instruments TPS60230 and TPS60231 are white, light-emitting-diode (WLED) drivers and controllers. These drivers use a capacitor-based charge pump with minimum external components and minimum size to power the WLEDs. Two digital inputs, EN1 and EN2, provide digital control of brightness, pulse-width-modulation (PWM) dimming, and on/off control

2 Basic Operation

The TPS60230 takes the input voltage and regulates it to the correct voltage needed to efficiently drive up to five LEDs. This IC can step up or step down the input voltage as required. As shown in Figure 1, if the input voltage is below the required output voltage, the internal 1.5x-mode charge pump (CP) increases the input voltage by a factor of 1.5. The resulting voltage passes through an internal linear regulator function. If the input voltage is above the required output voltage, the charge pump effectively operates in 1x mode, and then the linear regulator function reduces the voltage. The resulting output voltage is supplied to all LEDs in parallel. The return for each LED is individually connected to a current source in the IC. A 1-to-260 current mirror controls the current through each LED's current source. The current out of the ISET pin sets the current into the current mirror. The digital inputs EN1 and EN2 control the voltage on the ISET pin.

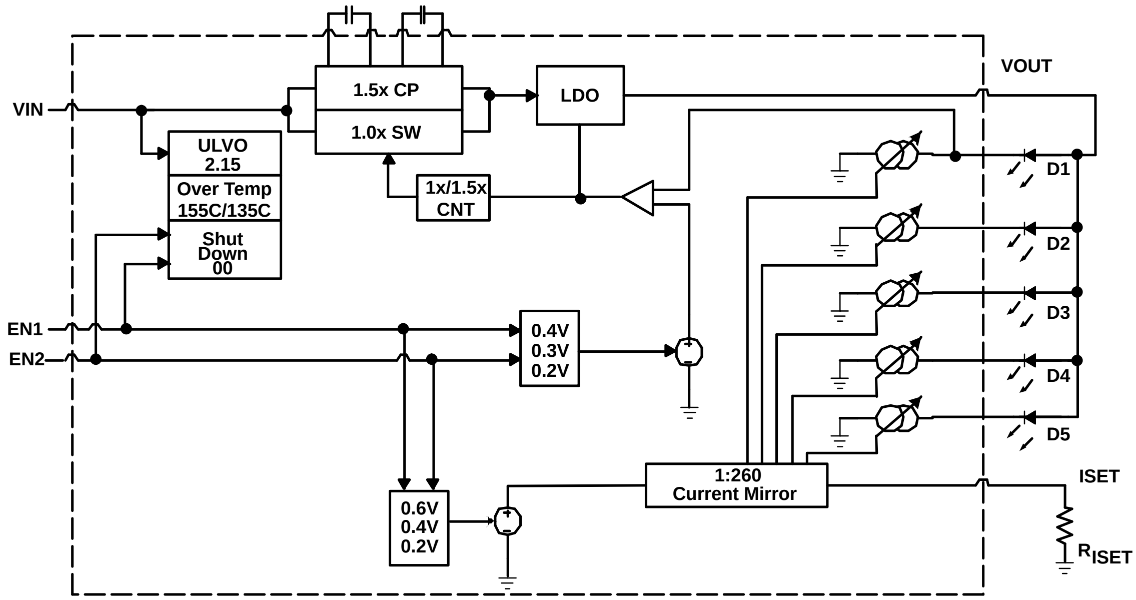


Figure 1. TPS60230 Block Diagram

3 Block Function

3.1 Charge Pump and Control

Input voltage is increased through a 1.5x charge pump using C1 and C2 switching at 1 MHz. If the input voltage does not need to be increased, the charge pump is bypassed and voltage goes directly to the internal LDO. The transition point between 1.5x mode and 1x mode is determined by the difference between Vin and Vout. If Vin – Vout is > 0.3 V, the charge pump will be in the 1X mode. If Vin – Vout is < 0.3 V, the charge pump will use the 1.5x mode. Typically, this transition occurs around a 3.6-V input.

3.2 Vout Block

The charge pump output is regulated down through a linear regulator function that is integrated into the charge pump itself. Vout is set by the voltage drop at pin D1, the return of LED D1. Vout is the voltage drop across WLED D1 plus the voltage at D1 current source. The EN1 and EN2 pins set voltage at the D1 current source. For example, if the EN1 and EN2 are a logic 1, the voltage at the cathode of D1 is regulated to 0.4 V. If the forward drop of D1 is 3.6 V, then the output voltage at the anode of D1 is regulated to 0.4 V + 3.6 V = 4 V.

Current limit is based on the total output current needed for the current sources, 5 times the D1 current.

3.3 Current Mirror Block

The current sources for each diode control the LED current. In turn, a 1:260 current mirror control these current sources. The ratio is referred to in the data sheet as *k* and typically has a value of 260 but with a minimum and maximum range of 230 to 280.

3.4 ISET Regulator

Current out of the ISET pin is used as the input to the LED current mirrors. An internal voltage source produces 200 mV, 300 mV, or 400 mV at ISET depending on the configuration of EN1 and EN2. External resistor Rset sets the current out of ISET pin. Voltage at the ISET pin along with Rset determines the LED current.

$$I_{LED} = \frac{V_{ISET}}{R_{SET}} \times k \qquad k = 260 \tag{1}$$

3.5 EN1/EN2 Control

The EN1/EN2 control performs three functions: turns the TPS60230 on or off, sets the LED current to three discrete levels, and controls the pulse-width-modulation (PWM) input.

Setting an input of (00) EN1=0 and EN2=0 places the unit in low-power shutdown mode with a current draw of less than 1 µA.

Input of (11) sets the LED current to the maximum as set by the current through the ISET pin.

An input of (10) or (01) reduces the LED current to 33% or 66% of the maximum value. PWM dimming can be applied to one or both of the pins.

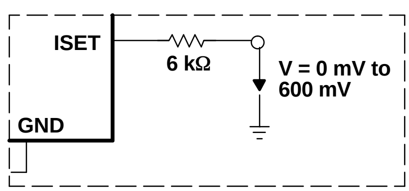
4 Design Features and Options

4.1 EN1/EN2 PWM Dimming

PWM dimming is possible through the EN1/EN2 pins. PWM frequencies of up to 50 kHz can be used. The dimming signal may be applied to one or both pins. If applied to both pins, the unit switches from maximum current to no current. The unit is placed into shutdown by holding both pins low for greater than 850 µs. If the PWM signal is applied to only one of the pins, the change in current is 33% or 66%.

4.2 Modulating ISET Pin

The current ratio between the ISET current and each LED's current is 260. An external drive to the ISET pin can modulate or adjust LED current. Increasing the current out of the ISET pin increases LED current.



5 Design Consideration

5.1 Current Matching Between LED and Current Sources

Internal current sources connected to LEDs D1 through D5 are matched to ±2% current accuracy, providing that the voltage on each output is equal. This condition requires the LED forward voltage drops to be equal. A significant source of current imbalance between LEDs is voltage mismatch at the current source caused by differences in LED forward voltage drop. To minimize this error, all LEDs should be the same type and same lot.

As shown in Figure 2, when the voltage on any output (cathode of the LED) is reduced below the set point (as programmed on the cathode of D1) current is reduced at a sharp rate. But as voltage is increased above the set point, the current source performs better with a lower percentage of error.

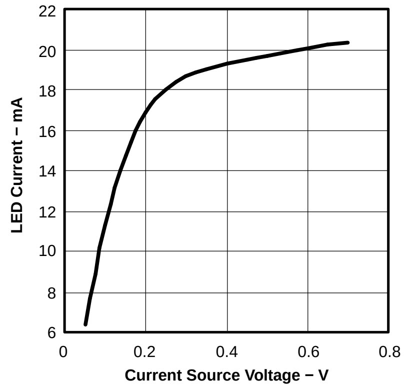


Figure 2. LED Current Variation as a Function of Current Source Voltage, EN1=EN2=1, Nominal I=19 mA and Nominal V=400 mV

One way to reduce this error is to ensure that the highest voltage drop occurs across the LED connected to D1. This can be done by adding a series resistor between D1 and its LED. The voltage at D1 is regulated to the same voltage, but the voltage drop across the LED-resistor is increased. This increases Vout which ensures that the voltages at the other input pins are higher than the voltage at D1. It is recommended that the voltage drop across the resistor not be larger than necessary to compensate for the differences in forward voltage drop in the LEDs. The maximum voltage drop should be limited to 600 mV.

$$RD1 = \frac{600\ mV}{ID1} \tag{2}$$

5.2 Noise-Sensitive Circuits and Layout Considerations

The ILED pin is high gain and amplifies current variations by a factor of 260. Etch runs to the ILED resistor should be kept short. The return for the resistor should be as short as possible and with low impedance to pin 14 analog ground.

In high RF fields, EN2 may require additional filtering. A 1000-pF ceramic capacitor located close to EN2 pin reduces noise sensitivity.

Also in an RF field, it is recommended to keep lead lengths short on all components; the ground plane should be broad and connected to all layers with vias.

5.3 Efficiency Improvement

Power dissipation in current sources D1 through D5 can be reduced by lowering the voltage drop across them. Setting EN1=1 and EN2=0 changes the voltage drop to its lowest setting, 0.2 V. Current through the LEDs can then be increased by recalculating Rset to produce the desired LED current when the control inputs are set to (10). If reduced LED brightness is required while using this method to increase overall efficiency, PWM must be used.

5.4 Reduced Components Option for Fixed Vin

The charge pump increases Vin to typically 4.1 V. If input voltage does not go below the typical LED operating voltage plus the regulation voltage at D1, the charge pump is not used. The unit stays in the 1x mode. In this mode, the flying capacitors on pins 9, 10, 11, and 12 are not needed and may be omitted from the design.

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