

## Parallel White-LED Driver

### DESCRIPTION

The EUP3595 is a parallel white-LED driver with four matched current outputs. It can supply a total output current of 100mA over an input voltage range of 3.0V to 5.5V. The amount of constant current sourced to the outputs is user selectable using one external sense resistor.

EUP3595 typically draws 0.01 $\mu$ A when placed in shutdown, and 180 $\mu$ A when operating in the no-load condition. If any of the outputs are not used, leave the pin(s) unconnected.

Brightness can be controlled by PWM techniques or by adding a DC voltage. A PWM signal can be applied to the EN/PWM pin to vary the perceived brightness of the LED.

The EUP3595 uses an active-high enable level. The EUP3595 is available in TDFN-8 and TSSOP-8 package.

### FEATURES

- Regulated  $I_{OUT}$  With  $\pm 0.3\%$  Matching Between Constant Current Outputs
- Drives One, Two, Three or Four White LED's with No Ballast Resistors
- 3.0V to 5.5V Input Voltage
- Up to 100mA Output Current
- Active-High Enable
- Very Small Solution Size
- Very Low Shutdown Current (0.01 $\mu$ A typical)
- Available in TDFN-8 ,TSSOP-8 Package
- RoHS Compliant and 100% Lead(Pb)-Free

### APPLICATIONS

- Portable devices using white or blue LEDs with display and backlight or front-light
- Keypad LEDs
- Strobe LEDs

### Typical Application Circuit

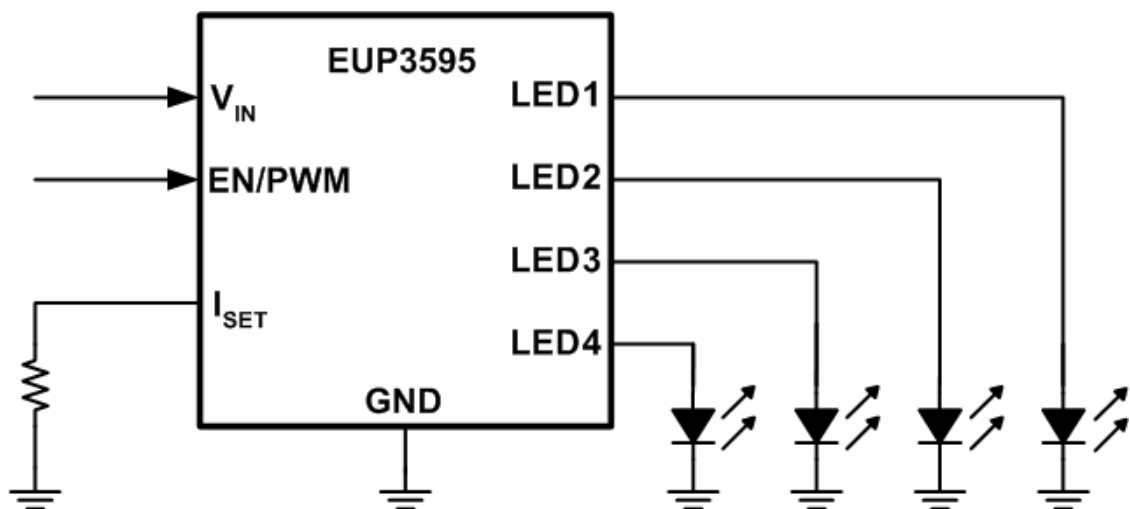


Figure 1.

## Block Diagram

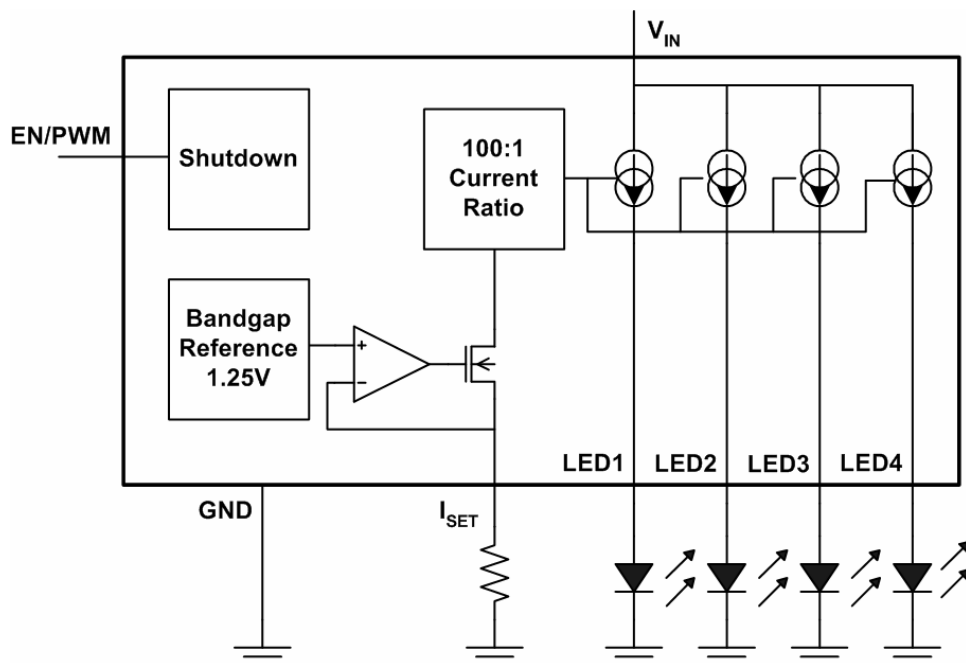


Figure 2.

## Pin Configurations

| Package Type | Pin Configurations | Package Type | Pin Configurations |
|--------------|--------------------|--------------|--------------------|
| TDFN-8       | <p>(Top View)</p>  | TSSOP-8      | <p>(Top View)</p>  |

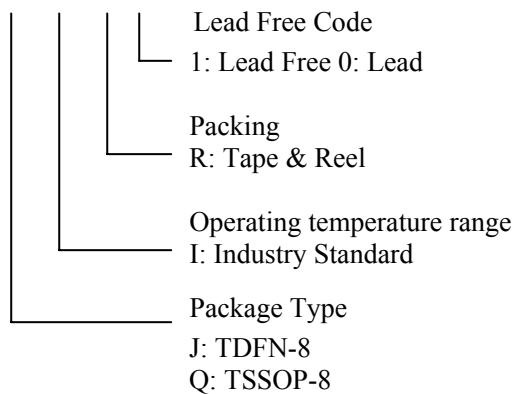
## Pin Description

| PIN       | TDFN-8 | TSSOP-8 | DESCRIPTION   |
|-----------|--------|---------|---|
| $V_{IN}$  | 1      | 1       | Input Voltage   |
| GND       | 2      | 2       | Ground  |
| EN/PWM    | 3      | 3       | Active-High Enable Input – There is no internal pull-down resistor.                             |
| $I_{SET}$ | 4      | 4       | Current Set Input- The resistor value tied between this pin and ground sets the output current. |
| LED1-4    | 8-5    | 8-5     | Current Source Outputs 1- 4 - Connect directly to LED's   |

**Ordering Information**

| Order Number | Package Type | Marking       | Operating Temperature range |
|--------------|--------------|---------------|-----------------------------|
| EUP3595JIR1  | TDFN-8       | XXXX<br>3595A | -40 °C to 85°C              |
| EUP3595QIR1  | TSSOP-8      | XXXX<br>3595A | -40 °C to 85°C              |

EUP3595-



## Absolute Maximum Ratings

- $V_{IN}$  ----- -0.3V to 6V max
- EN/PWM----- -0.3V to ( $V_{IN}+0.3V$ ) w/ 6 max
- Continuous Power Dissipation ----- Internally Limited
- TDFN-8L ,  $3 \times 3, \theta_{JA}$  ----- 50°C/W
- TSSOP-8L ,  $\theta_{JA}$  ----- 70°C/W
- Junction Temperature ( $T_J$ ) ----- 150°C
- Storage Temperature Range ----- -65°C to 150°C
- Lead Temp (Soldering, 5sec) ----- 260°C
- ESD Rating Human Body Model ----- 2kV

## Operating Conditions

- Input Voltage ( $V_{IN}$ ) ----- 3V to 5.5V
- Ambient Temperature ( $T_A$ ) ----- -40°C to 85°C

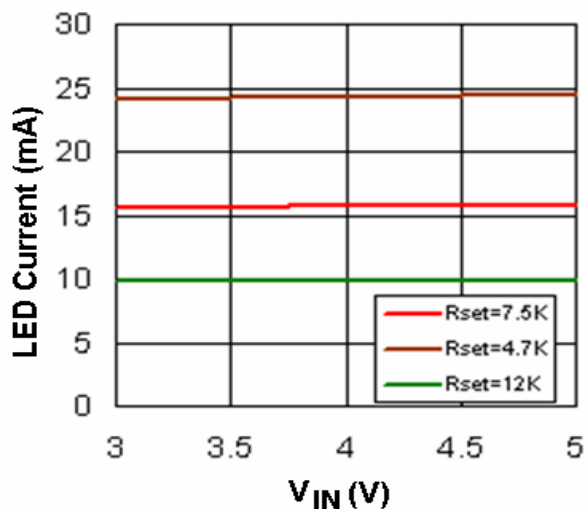
## Electrical Characteristics

Limits in standard typeface and typical values apply for  $T_A=25^\circ\text{C}$ . Limits in **boldface** type apply over the operating junction temperature range (-40°C~+85°C). Unless otherwise specified:  $V_{IN}=5V$ ,  $V_{LEDX}=3.6V$ ,  $R_{SET}=7.5k$ ,  $V(EN/PWM)=V_{IN}$ .

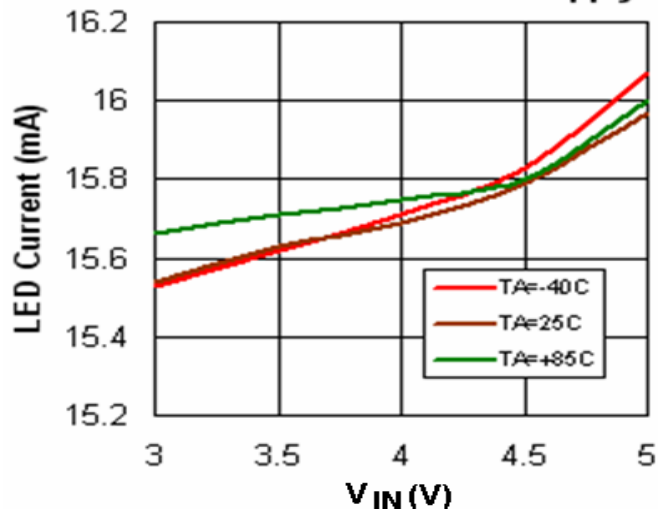
| Symbol             | Parameter                                | Conditions  | EUP3595                      |           |                              | Unit |
|--------------------|--|---|------------------------------|-----------|------------------------------|------|
|                    |  |   | Min                          | Typ       | Max.                         |      |
| $I_{LEDX}$         | LED Current                              | $3.0V \leq V_{IN} \leq 5.5V$<br>$2.0V \leq V_{LEDX} \leq (V_{IN}-0.4V)$<br>$R_{SET}=7.5k$ | <b>14.3</b><br><b>(-10%)</b> | 15.8      | <b>17.3</b><br><b>(+10%)</b> | mA   |
| $I_{LEDX-MATCH}$   | Current Matching Between Any Two Outputs |   |                              | $\pm 0.3$ | <b><math>\pm 1</math></b>    | %    |
| $V_{SET}$          | $I_{SET}$ Pin Voltage                    |   | <b>1.06</b><br><b>(-8%)</b>  | 1.18      | <b>1.3</b><br><b>(+8%)</b>   | V    |
| $I_{LEDX}/I_{SET}$ | Output Current to Current Set Ratio      |   |                              | 100       |                              |      |
| $V_{HR}$           | Current Source Headroom Voltage          | $I_{LED}=95\% \times I_{LED(nom)}$ , $R_{SET}=4.7K$<br>( $I_{LED(nom)}$ approx. 25mA)     |                              | 320       | <b>440</b>                   | mV   |
|                    |  | $I_{LED}=95\% \times I_{LED(nom)}$ , $R_{SET}=12K$<br>( $I_{LED(nom)}$ approx. 10mA)      |                              | 130       | <b>220</b>                   | mV   |
| $I_Q$              | Quiescent Supply Current                 | $I_{LED}=0mA$ , $R_{SET}=Open$  |                              | 175       | <b>285</b>                   | uA   |
|                    |  | $I_{LED}=0mA$ , $R_{SET}=7.5k$  |                              | 325       |                              |      |
| $I_{SHUT-DOWN}$    | Shutdown Supply Current                  | EN/PWM=0  |                              | 0.01      | <b>1</b>                     | uA   |
| $V_{EN-H}$         | EN/PWM Input Logic High                  | $3.0V \leq V_{IN} \leq 5.5V$  | <b>1</b>                     |           | $V_{IN}$                     | V    |
| $V_{EN-L}$         | EN/PWM Input Logic Low                   | $3.0V \leq V_{IN} \leq 5.5V$  | 0                            |           | <b>0.5</b>                   | V    |

## Typical Operating Characteristics

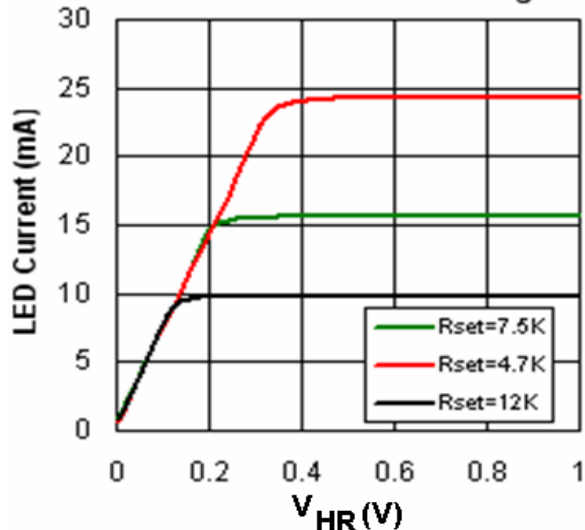
LED Current vs Power Supply



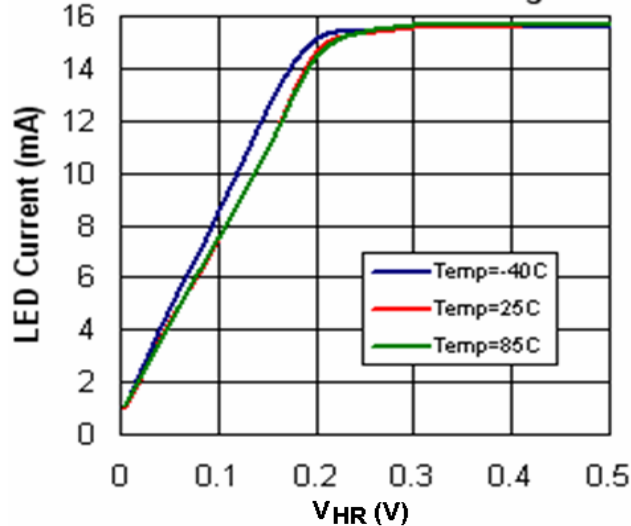
LED Current vs Power Supply



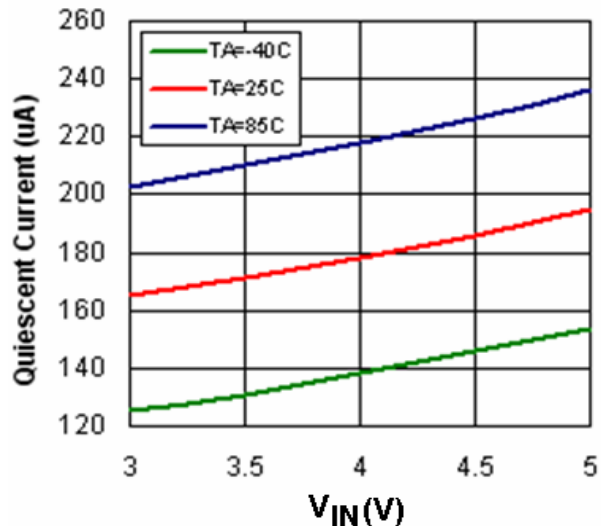
Iled vs Headroom Voltage



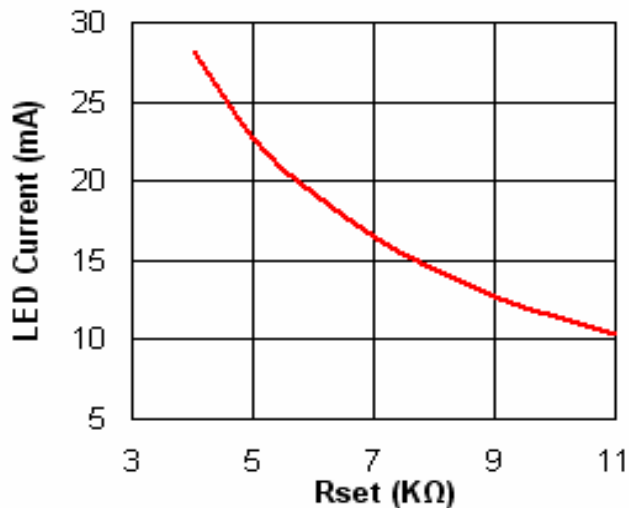
Iled vs Headroom Voltage



Quiescent Current vs Power Supply



LED Current vs Set Resistor



## Application Information

### Enable/Shutdown

When the voltage on the active-high-logic enable pin is low, the EUP3595 will be in shutdown. While disabled, the EUP3595 typically draws 0.01μA. There is no internal pull-up or pull-down on the PWM pin of the EUP3595, Do not let PWM pin floating.

### Output Current Capability

The EUP3595 is capable of providing up to 25mA of current to each of the four outputs given an input voltage of 3.0V to 5.5V. The outputs have a typical current matching of ± 0.3% between adjacent sources. An external resistor can be used to set the output current, as approximated with the following the equation:

$$R_{SET} = 100 \times (1.18V / I_{LEDX})$$

In order for the output currents to be regulated properly, sufficient headroom voltage ( $V_{HR}$ ) must be present. The headroom voltage refers to the minimum amount of voltage that must be present across the current source in order to ensure the desired current is realizable. To ensure the desired current is obtained, apply the following equations to find the minimum input voltage required:

$$V_{IN} - V_{LEDX} \geq V_{HR}$$

$V_{LEDX}$  is the diode forward voltage, and  $V_{HR}$  is defined by the following equation:

$$V_{HR} = K_{HR} \times (0.95 \times I_{LEDX})$$

$I_{LEDX}$  is the desired diode current, and  $k_{HR}$ , typically 15mV/mA in the EUP3595, is a proportionality constant that represents the ON-resistance of the internal current mirror transistors. For worst-case design calculations, using a  $k_{HR}$  of 20mV/mA is recommended. (Worst-case recommendation accounts for parameter shifts from part-to-part variation and applies over the full operating temperature range). Changes in headroom voltage from one output to the next, possible with LED forward voltage mismatch, will result in different output currents and LED brightness mismatch. Thus, operating the EUP3595 with insufficient headroom voltage across all current sources should be avoided.

**Table 1.  $I_{LEDX}$ ,  $R_{SET}$  and  $V_{HR-MIN}$   
 $k_{HR} = 20 \text{ mV/mA}$  (worst-case)**

| $I_{OUT}$ | $R_{SET}$ | $V_{HEADROOM}$ |
|-----------|-----------|----------------|
| 10mA      | 12kΩ      | 200mV          |
| 15mA      | 7.5kΩ     | 300mV          |
| 25mA      | 4.7kΩ     | 500mV          |

## Brightness Control

### (1) Using a PWM Signal to EN/PWM Pin

Brightness control can be implemented by pulsing a signal at the PWM pin. The  $R_{SET}$  value should be selected using the  $R_{SET}$  equation. LED brightness is proportional to the duty cycle (D) of the PWM signal. For linear brightness control over the full duty cycle adjustment range, the PWM frequency (f) should be limited to accommodate the turn-on time ( $T_{ON} = 20\mu s$ ) of the device.

$$D * (1 / f) > T_{ON}$$

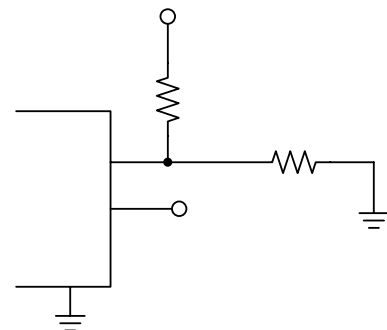
$$f_{MAX} = D_{MIN} / T_{ON}$$

If the PWM frequency is much less than 100Hz, flicker may be seen in the LEDs. For the EUP3595, zero duty cycle will turn off the LEDs and a 50% duty cycle will result in an average  $I_{LED}$  being half of the programmed LED current. For example, if  $R_{SET}$  is set to program 15mA, a 50% duty cycle will result in an average  $I_{LED}$  of 7.5mA, LED being half the programmed LED current.  $R_{SET}$  should be chosen not to exceed the maximum current delivery capability of the device.

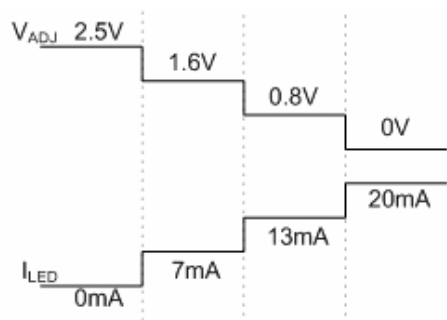
### (2) Using a DC Voltage Added to $R_{SET}$

Using an analog input voltage  $V_{ADJ}$  via a resistor  $R_{ADJ}$  connects to the  $R_{SET}$  pin can also be used to achieve setting LED current. Figure 3 shows this application circuit. For this application the LED's current can be derived from the following Equation. Figure 4 and table 2 shows the relation between  $V_{ADJ}$  and  $I_{LED}$  of a typical application example, where the  $V_{ADJ}$  from 0 to 2.5V,  $R_{SET}$  equals 11.5kΩ and  $R_{ADJ}$  equals 12.5kΩ.

$$I_{LED} = 100 \times \left[ 1.18 \times \left( \frac{1}{R_{SET}} + \frac{1}{R_{ADJ}} \right) - \frac{V_{ADJ}}{R_{ADJ}} \right]$$



**Figure3. The Application Circuit of Brightness which Uses a DC Voltage Into  $R_{SET}$**



**Figure 4. EUP3595 LED Current Setting Example**  
Which Using a DC Voltage to  $R_{SET}$

**Table 2. The LED Current vs  $V_{ADJ}$  With  $R_{ADJ}=12.5K$  and  $R_{SET}=11.5K$**

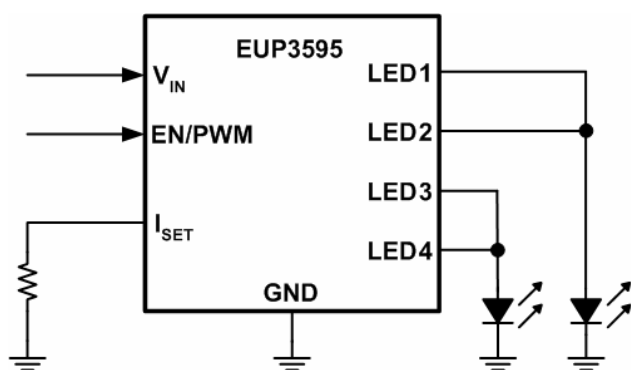
| $V_{ADJ}(V)$  | 0    | 0.2  | 0.4  | 0.6  | 0.8  | 1    | 1.2  |
|---------------|------|------|------|------|------|------|------|
| $I_{LED}(mA)$ | 19.7 | 18.1 | 16.5 | 14.9 | 13.3 | 11.7 | 10.1 |
| $V_{ADJ}(V)$  | 1.4  | 1.6  | 1.8  | 2    | 2.2  | 2.4  | 2.5  |
| $I_{LED}(mA)$ | 8.5  | 6.9  | 5.3  | 3.7  | 2.1  | 0.5  | 0    |

### LED Selection

The EUP3595 is designed to drive white-LEDs with a typical forward voltage of 3.0V to 4.0V. The maximum LED forward voltage that the EUP3595 can accommodate is highly dependant upon  $V_{IN}$  and  $I_{LEDX}$  (See the section on Output Current Capability for more information on finding maximum  $V_{LEDX}$ .) For applications that demand color and brightness matching, care must be taken to select LEDs from the same chromaticity group. Forward current matching is assured over the LED process variations due to the constant current outputs of the EUP3595.

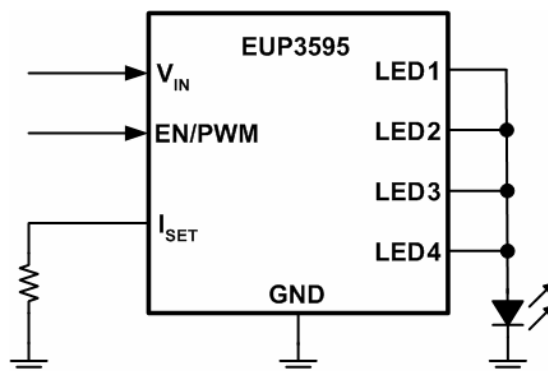
### Parallel LEDx Outputs for Increased Current Drive

Outputs LED1 through LED4 may be connected together in any combination to drive higher currents through fewer LEDs. For example in Figure 5, outputs LED1 and LED2 are connected together to drive one LED while LED3 and LED4 are connected together to drive a second LED.



**Figure 5. Two Parallel Connected LEDs**

With this configuration, two parallel current sources of equal value provide current to each LED.  $R_{SET}$  should therefore be chosen so that the current through each output is programmed to 50% of the desired current through the parallel connected LEDs. For example, if 30mA is the desired drive current for 2 parallel connected LEDs,  $R_{SET}$  should be selected so that the current through each of the outputs is 15mA. Other combinations of parallel outputs may be implemented in similar fashions, such as in Figure 6.

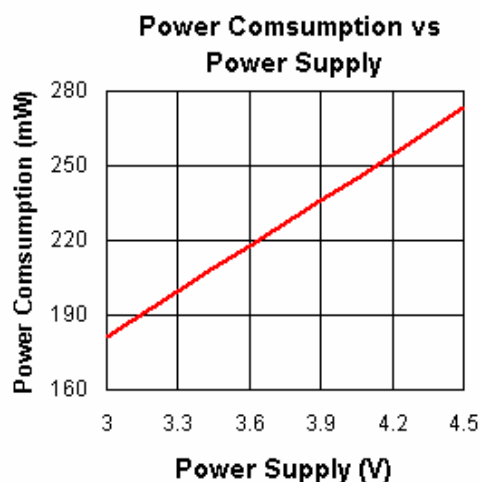


**Figure 6. One Parallel Connected LED**

Connecting outputs in parallel does not affect internal operation of the EUP3595 and has no impact on the Electrical Characteristics and limits previously presented. The available diode output current, maximum diode voltage, and all other specifications provided in the Electrical Characteristics table apply to parallel output configurations, just as they do to the standard 4-LED application circuit.

### Power Consumption

It is recommended that power consumed by the circuit ( $V_{IN} \times I_{IN}$ ) be evaluated rather than power efficiency. Figure 7 shows the power consumption of the EUP3595 Typical Application Circuit.



**Figure 7. 4LEDs, LED VF=2.7V,  $I_{LED}=15mA$**

**Power Dissipation**

The maximum allowable power dissipation that this package is capable of handling can be determined as follows:

$$P_{DMax} = (T_{JMax} - T_A) / \theta_{JA}$$

Where  $T$  is the maximum junction temperature,  $T$  is the ambient temperature, and  $\theta_{JA}$  is the junction-to-ambient thermal resistance of the specified package. The EUP3595 come in the TDFN-8 package that has a junction-to-ambient thermal resistance ( $\theta_{JA}$ ) equal to 50 °C/W. This value of  $\theta_{JA}$  is highly dependant upon the layout of the PC board. The actual power dissipated by the EUP3595 follows the equation:

$$P_{DISS} = (V_{IN} \times I_{IN}) - N(V_{LEDX} \times I_{LEDX})$$

Where  $N$  equals the number of active outputs,  $V_{LEDX}$  is the  $L_{EDX}$  LED forward voltage, and  $I_{LEDX}$  is the current supplied to the LEDX diode by the EUP3595. Power dissipation must be less than that allowed by the package. Please refer to the Absolute Maximum Rating of the EUP3595.

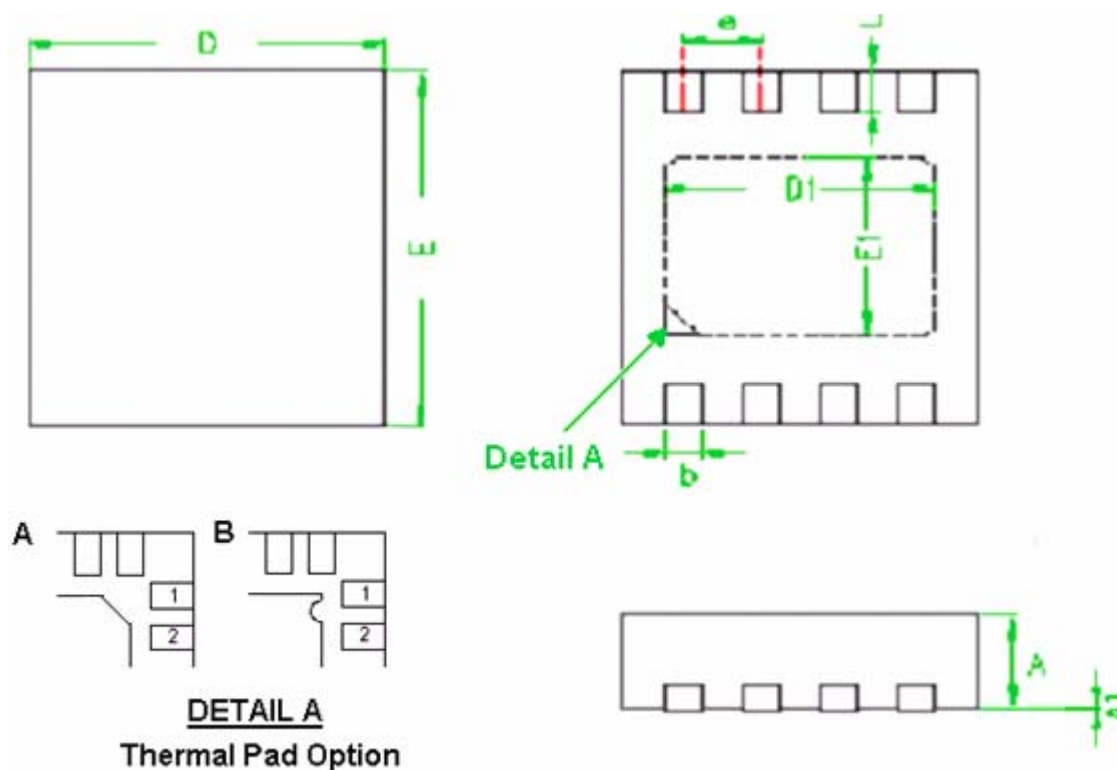
**Input Capacitor Selection**

The EUP3595 is designed to run off of a fixed input voltage. Depending on the stability and condition of this voltage rail, it may be necessary to add a small input capacitor to help filter out any noise that may be present on the line. In the event that filtering is needed, surface mount multi-layer ceramic capacitors are recommended. These capacitors are small and inexpensive. A capacitance of 0.1µF is typically sufficient.



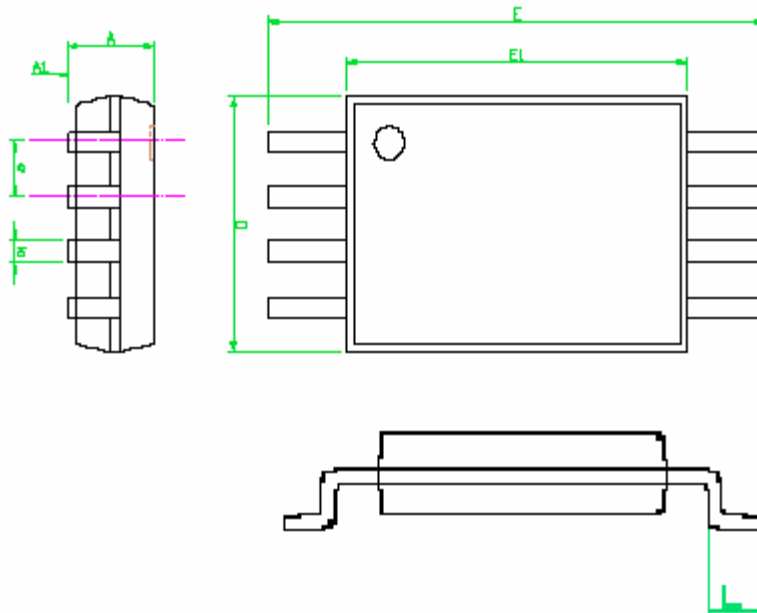
## Packaging Information

## TDFN-8



| 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       | 0.20        | 0.40 | 0.008  | 0.016 |
| D       | 2.85        | 3.15 | 0.112  | 0.124 |
| D1      | 2.30        |      | 0.090  |       |
| E       | 2.85        | 3.15 | 0.112  | 0.124 |
| E1      | 1.50        |      | 0.059  |       |
| e       | 0.65        |      | 0.026  |       |
| L       | 0.25        | 0.45 | 0.010  | 0.018 |

## TSSOP-8



| SYMBOLS | MILLIMETERS |      | INCHES |       |
|---------|-------------|------|--------|-------|
|         | MIN.        | MAX. | MIN.   | MAX.  |
| A       | -           | 1.20 | -      | 0.048 |
| A1      | 0.00        | 0.15 | 0.000  | 0.006 |
| b       | 0.19        | 0.30 | 0.007  | 0.012 |
| D       | 3.00        |      | 0.118  |       |
| E       | 6.20        | 6.60 | 0.244  | 0.260 |
| E1      | 4.40        |      | 0.173  |       |
| e       | 0.65        |      | 0.026  |       |
| L       | 0.45        | 0.75 | 0.018  | 0.030 |