

## Description

The AP8800 is a step-down DC/DC converter designed to drive LEDs with a constant current. The device can drive up to seven LEDs, depending on the forward voltage of the LEDs, in series from a voltage source of 8V to 28V. Series connection of the LEDs provides identical LED currents resulting in uniform brightness and eliminates the need for ballast resistors. The AP8800 switches at frequency up to 0.6MHz. This allows the use of small size external components, hence minimizing the PCB area needed.

Maximum output current of AP8800 is set via an external resistor connected between the  $V_{IN}$  and SET input pins. Dimming is achieved by applying either a DC voltage or a PWM signal at the CTRL input pin. An input voltage of 0.2V or lower at CTRL shuts down the output at SW and puts the device into a low-current standby state.

## Features

- LED driving current up to 350mA
- Compatible with 12V & 24V standard systems
- High efficiency up to 92%
- High switching frequency up to 0.6MHz
- PWM/DC input for dimming control
- Built-in soft-start function
- Built-in output open-circuit protection
- SO-8, MSOP-8 and U-DFN3030-10: Available in "Green" Molding Compound (No Br, Sb) with lead Free Finish/ RoHS Compliant
  - **Totally Lead-Free & Fully RoHS Compliant (Notes 1 & 2)**
  - **Halogen and Antimony Free. "Green" Device (Note 3)**

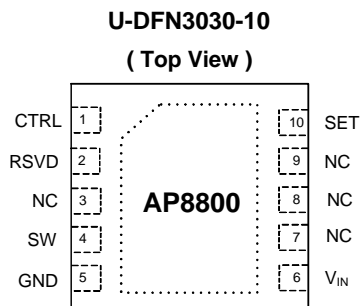
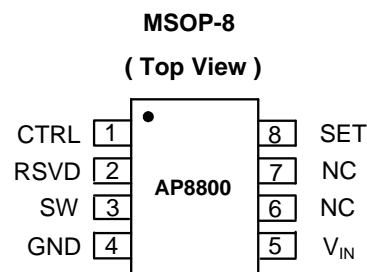
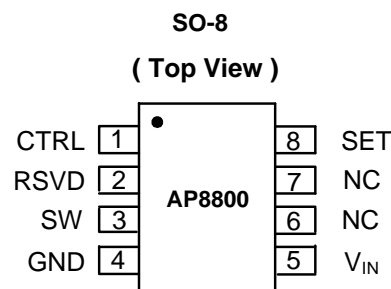
## Applications

- Commercial & Industrial Lighting
- Small LCD Panel Backlight
- Architecture Detail Lighting
- Appliances Interior Lighting

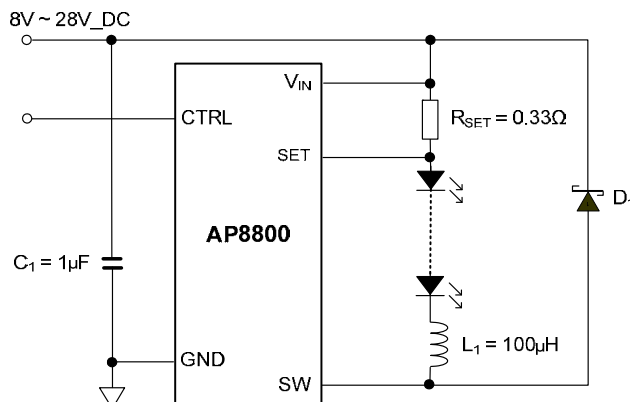
Notes:

1. No purposely added lead. Fully EU Directive 2002/95/EC (RoHS) & 2011/65/EU (RoHS 2) compliant.
2. See <http://www.diodes.com> for more information about Diodes Incorporated's definitions of Halogen and Antimony free, "Green" and Lead-Free.
3. Halogen and Antimony free "Green" products are defined as those which contain <900ppm bromine, <900ppm chlorine (<1500ppm total Br + Cl) and <1000ppm antimony compounds.

## Pin Assignments



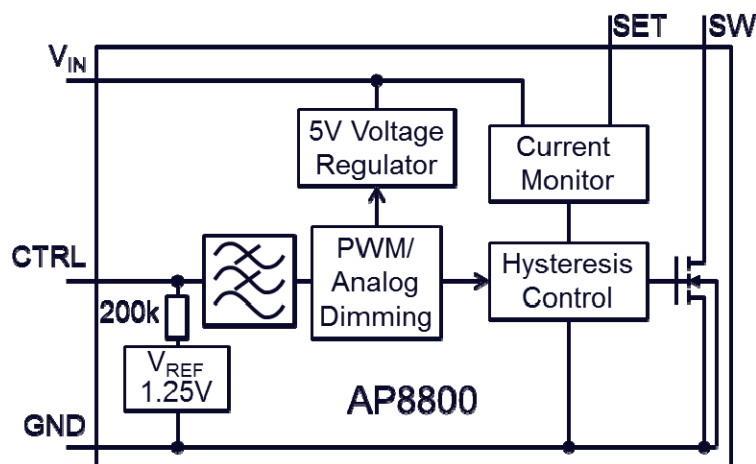
## Typical Applications Circuit



## Pin Descriptions

Pin Name	Pin Number			Function
	SO-8	MSOP-8	U-DFN3030-10	
SW	3	3	4	Switch Pin. Connect inductor/freewheeling diode here. Minimize trace area at this pin to reduce EMI.
GND	4	4	5	GND Pin
SET	8	8	10	Set Nominal Output Current Pin. To configure the output current of the device.
CTRL	1	1	1	Dual function dimming control pin. <ul style="list-style-type: none"> <li>Input voltage of 0.2V or lower forces the device into low current standby mode and shuts off the output.</li> <li>A PWM signal (driven by an open-drain/collector source) allows the output current to be adjusted over a wide range up to 100%.</li> <li>An analog voltage between 0.3V and 2.5V adjusts the output current between 25% and 200% of the current set by <math>0.2V/R_S</math>.</li> </ul> The input impedance is about 200k $\Omega$ , and if the pin is left open $V_{CTRL} = V_{REF}$
V <sub>IN</sub>	5	5	6	Input Supply Pin. Must be locally bypassed.
RSVD	2	2	2	Reserved. Normally connected to Ground
NC	6, 7	6, 7	2, 7, 8, 9	No Connection.

## Functional Block Diagram



## Absolute Maximum Ratings (@T<sub>A</sub> = +25°C, unless otherwise specified.)

Symbol	Parameter	Rating	Unit
V <sub>IN</sub>	V <sub>IN</sub> Pin Voltage	-0.3 to +30	V
V <sub>SET</sub>	Set Voltage Relative to V <sub>IN</sub>	V <sub>IN</sub> -5 to V <sub>IN</sub> +0.3	V
V <sub>SW</sub>	SW Voltage	-0.3 to +30	V
V <sub>CTRL</sub>	CTRL Pin Input Voltage	-0.3 to +5	V
T <sub>J</sub>	Maximum Junction Temperature	125	°C
T <sub>LEAD</sub>	Maximum Lead Temperature	300	°C
T <sub>ST</sub>	Storage Temperature Range	-55 to +125	°C

Caution: Stresses greater than the 'Absolute Maximum Ratings' specified above, may cause permanent damage to the device. These are stress ratings only; functional operation of the device at these or any other conditions exceeding those indicated in this specification is not implied. Device reliability may be affected by exposure to absolute maximum rating conditions for extended periods of time.

Semiconductor devices are ESD sensitive and may be damaged by exposure to ESD events. Suitable ESD precautions should be taken when handling and transporting these devices.

**Recommended Operating Conditions** (@T<sub>A</sub> = +25°C, unless otherwise specified.)

Symbol	Parameter	Min	Max	Unit
V <sub>IN</sub>	Operating Input Voltage relative to GND	8.0	28	V
V <sub>CTRLDC</sub>	Voltage Range for 24% to 200% DC Dimming Relative to GND (Note 2)	0.3	2.5	V
V <sub>CTRLLL</sub>	Voltage Low for PWM Dimming Relative to GND	0	0.2	V
f <sub>OSC</sub>	Maximum Switching Frequency		500	kHz
T <sub>A</sub>	Ambient Temperature Range	-40	+85	°C
Duty Cycle	Using Inductor ≥ 100μH (Note 3)	0.1	0.95	
V <sub>ENH</sub>	CTRL Input Voltage to Attain 100% LED Current	1.25		V
V <sub>ENL</sub>	CTRL Input Voltage Below Which Device Turns Off		0.2	

- Notes:
- For 100% brightness either leave floating or connect to 1.25V relative to GND.
  - For most applications the LED current will be within 8% over the duty cycle range specified. Duty cycle accuracy is also dependent on propagation delay. Smaller size inductors can be used but LED current accuracy may be greater than 8% at extremes of duty cycle. This is most noticeable at low duty cycles (less than 0.1) or when the input voltage is high and only one LED is being driven.

**Electrical Characteristics** (@T<sub>A</sub> = +25°C, unless otherwise specified.)

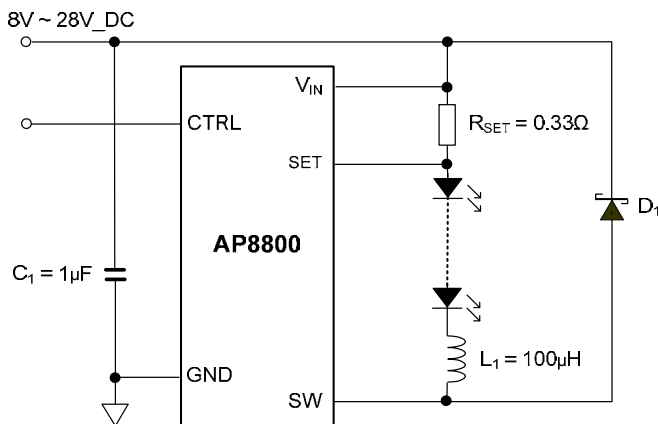
Symbol	Parameter	Conditions	Min	Typ	Max	Unit
I <sub>OUT</sub>	Continuous Switch Current	(Note 4)	—	—	350	mA
I <sub>Q</sub>	Quiescent Current		—	20	30	μA
V <sub>THD</sub>	Internal Current Sense Threshold Voltage	V <sub>IN</sub> - V <sub>SET</sub>	92	100	108	mV
V <sub>REF</sub>	Internal Reference Voltage		—	1.25	—	V
SET	SET Pin Input Current	V <sub>SET</sub> = V <sub>IN</sub> - 0.1	—	1.3	—	μA
R <sub>DS(on)</sub>	On-Resistance of Internal Switch		—	1.7	2.2	Ω
I <sub>SW_Leakage</sub>	Switch Pin Leakage Current		—	—	5	μA
θ <sub>JA</sub>	Thermal Resistance Junction-to-Ambient	SO-8 (Note 5)	—	92	—	°C/W
		MSOP-8 (Note 5)	—	120	—	°C/W
		U-DFN3030-10 (Note 5)	—	46	—	°C/W
θ <sub>JC</sub>	Thermal Resistance Junction-to-Case	SO-8 (Note 5)	—	60	—	°C/W
		MSOP-8 (Note 5)	—	98	—	°C/W
		U-DFN3030-10 (Note 5)	—	32	—	°C/W

- Notes:
- Refer to figure 8 for the device derating curve.
  - Test condition for SO-8, MSOP-8 and U-DFN3030-10: Device mounted on FR-4 PCB, 2"x 2", 2oz copper, minimum recommended pad layout on top layer and thermal vias to bottom layer ground plane. For better thermal performance, larger copper pad for heat-sink is needed.

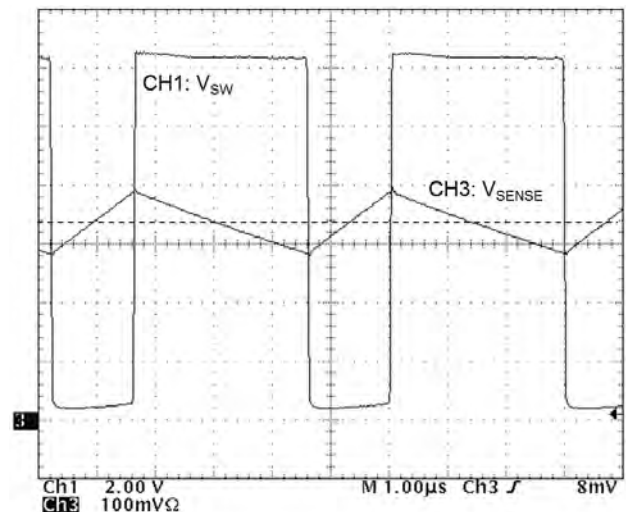
## Application Information

### AP8800 Operation

The AP8800 is a hysteretic LED current switching regulator sometimes known as an equal ripple switching regulator. In normal operation, when voltage is applied at  $V_{IN}$  (See Figure 1), the AP8800 internal switch is turned on. Current starts to flow through sense resistor  $R_1$ , inductor  $L_1$ , and the LEDs. The current ramps up linearly, and the ramp rate is determined by the input voltage  $+V_{IN}$ , and the inductor  $L_1$  (See Figure 2).



**Figure 1 Typical Configuration**



**Figure 2 Typical Switching Waveform**

This rising current produces a voltage ramp across  $R_{SET}$ . The internal circuit of the AP8800 senses the voltage across  $R_{SET}$  and applies a proportional voltage to the input of the internal comparator.

When this voltage reaches an internally set upper threshold, the internal switch is turned off. The inductor current continues to flow through  $R_{SET}$ ,  $L_1$ , the LEDs and the schottky diode  $D_1$ , and back to the supply rail, but it decays, with the rate of decay determined by the forward voltage drop of the LEDs and the schottky diode.

This decaying current produces a falling voltage at  $R_{SET}$ , which is sensed by the AP8800. A voltage proportional to the sense voltage across  $R_{SET}$  is applied at the input of the internal comparator. When this voltage falls to the internally set lower threshold, the internal switch is turned on again. This switch-on-and-off cycle continues to provide the average LED current set by the sense resistor  $R_{SET}$ , with a switching current determined by the input voltage and LED chain voltage.

In normal operation the off time is relatively constant (determined mainly by the LED chain voltage) with only the on-time varying as the input voltage changes. At duty cycles up to around 80% the ramp of the LED/switch current is very linear; however, as the duty cycle approaches 95% the LED current ramp starts to become more exponential. This has two effects:

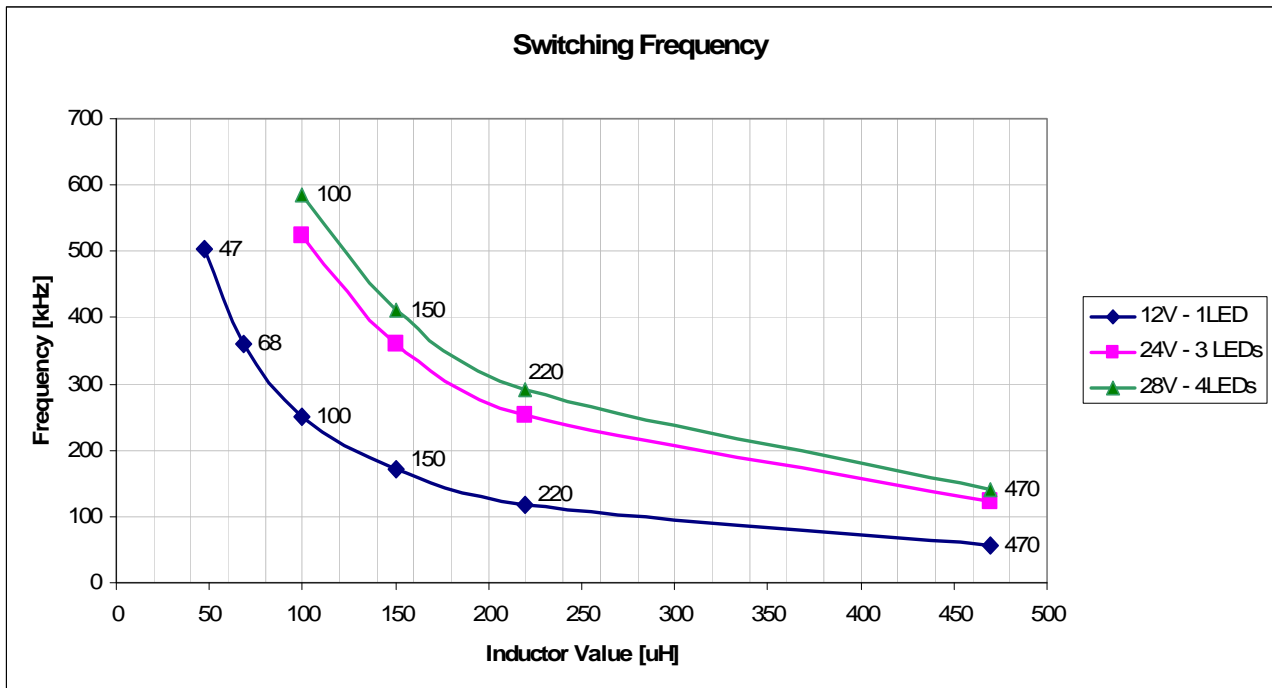
1. The overall on time starts to increase lowering the overall switching frequency.
2. The average LED current starts to increase – which may impact accuracy.

## Application Information (cont.)

### Inductor Selection

A 100 $\mu$ H inductor is recommended for most AP8800 applications with input voltage at 24V.

Figure 3 displays the resulting switching frequency varying the main circuit parameters: Supply voltage, Inductor value and number of LEDs to be driven.



**Figure 3 Switching Frequency vs. Supply Voltage, Inductor, and Number of LEDs**

### Capacitor Selection

The small size of ceramic capacitors makes them ideal for AP8800 applications. X5R and X7R types are recommended because they retain their capacitance over wider voltage and temperature ranges than other types such as Z5U. A 1 $\mu$ F input capacitor is sufficient for most intended applications of AP8800.

### Diode Selection

Schottky diode, e.g. B140, with their low forward voltage drop and fast reverse recovery, is the ideal choice for AP8800 applications.

### Miscellaneous

To ensure optimal performance, RSVD pin should be connected to the GND pin with the shortest trace length.

## Application Information (cont.)

### LED Current Dimming

The LED current can be dimmed in two ways;

1. Analog Dimming: Where a dc voltage is applied to the CTRL pin  
or
2. PWM Dimming: Where a Pulse Width Modulated (PWM) signal is applied to the CTRL pin.

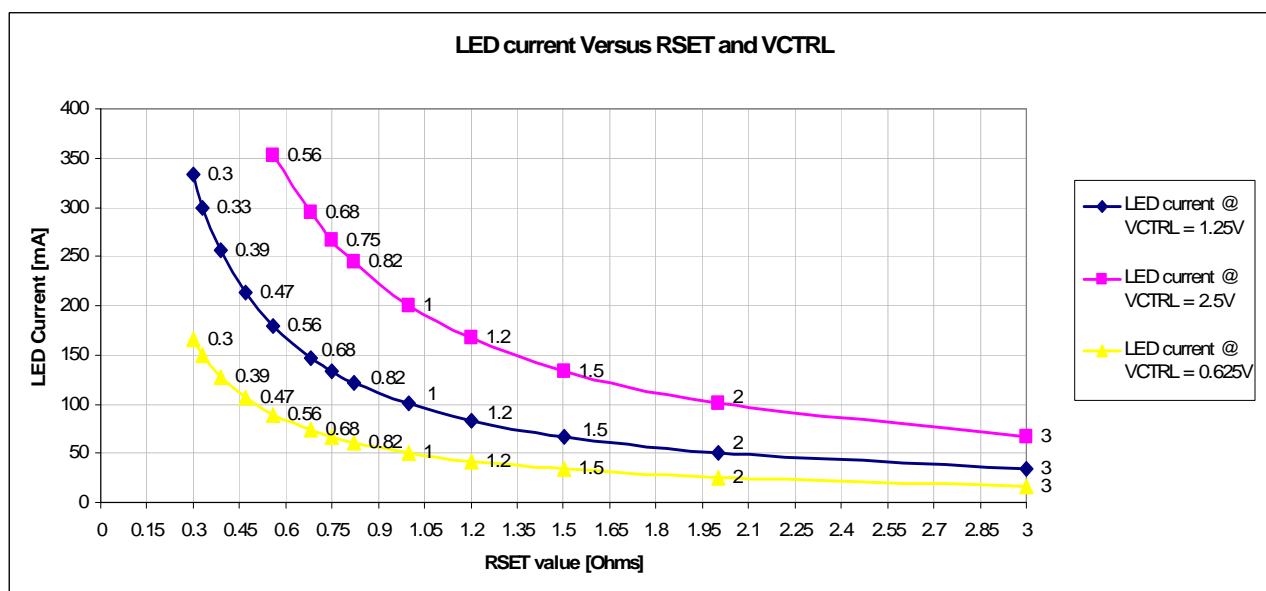
### Analog Dimming

If the CTRL pin is driven by an external voltage (lower than 2.5V), the average LED current in this case is:

$$I_{LED} = \frac{V_{CTRL}}{V_{REF}} \times \frac{V_{TH}}{R_{SET}}$$

A DC signal from 0.3V to 2.5V applied to the CTRL pin will vary the LED current from 24% to 200% of nominal LED current. This gives an approximate 8:1 dimming range; care, should be exercised when overdriving the CTRL pin to 200% of nominal LED current not to exceed the power dissipation of the package.

The graph in Figure 4 shows values of nominal average output current for 3 values of current setting resistor ( $R_{SET}$ ) in the typical application circuit shown on Figure 1, for different voltages applied on the CTRL pin.



**Figure 4 LED Current Setting vs.  $R_{SET}$  and  $V_{CTRL}$**

## Application Information (cont.)

### PWM Dimming

A PWM signal with a max resolution of 8bit can be applied to CTRL regulate the output current to a value below the nominal average value set by resistor  $R_{SET}$ . PWM dimming gives a wider average LED current variation and is more accurate at lower average LED currents than by applying DC voltage to the CTRL pin to achieve average LED current dimming.

Figure 5 shows the typical PWM response of the AP8800A. An internal filter produces a ramp.

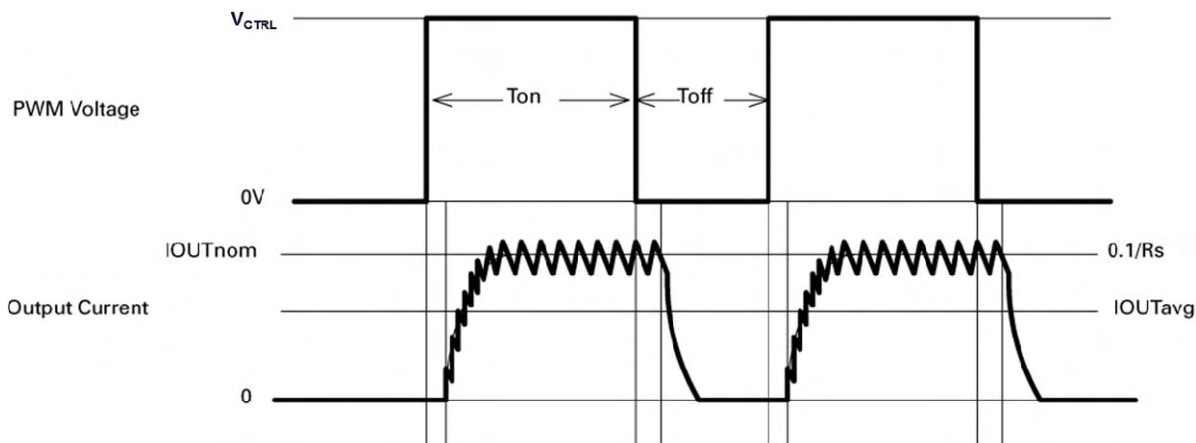


Figure 5 Typical PWM Dimming Waveform

The recommended method of driving the CTRL pin and controlling the amplitude of the PWM waveform is to use a small NPN switching transistor as shown below:

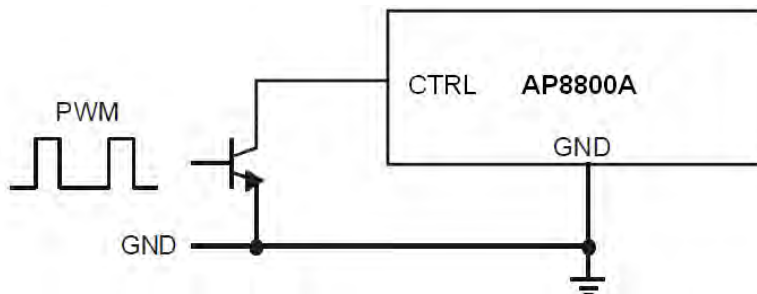


Figure 6 Open Collector PWM Dimming Circuit

This scheme uses the 200k resistor between the ADJ pin and the internal voltage reference as a pull-up resistor for the external transistor eg MMBT3904.

### Soft-Start

An external capacitor from the CTRL pin to ground will provide soft-start delay, by increasing the time taken for the voltage on this pin to rise to the turn-on threshold and by slowing down the rate of rise of the control voltage at the input of the comparator.

The soft-start time is  $0.5\text{ms/nF}$ .

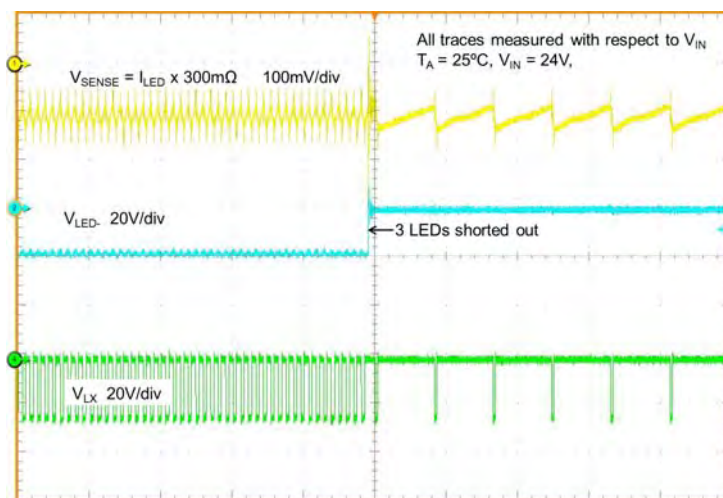
## Application Information (cont.)

### Fault conditions

The AP8800 is inherently protected against open-LED conditions. If one LED becomes open circuit the device automatically stops switching and will only restart if the open-LED fault is removed.

If one or more LEDs should become shorted together then the switching frequency and duty cycle will change. If one or more LEDs get shorted together, the ramp-up time of LED current will become shorter due to there being a larger voltage across the inductor. However, the ramp-down time of the LED current will increase due to the voltage across the inductor becoming smaller.

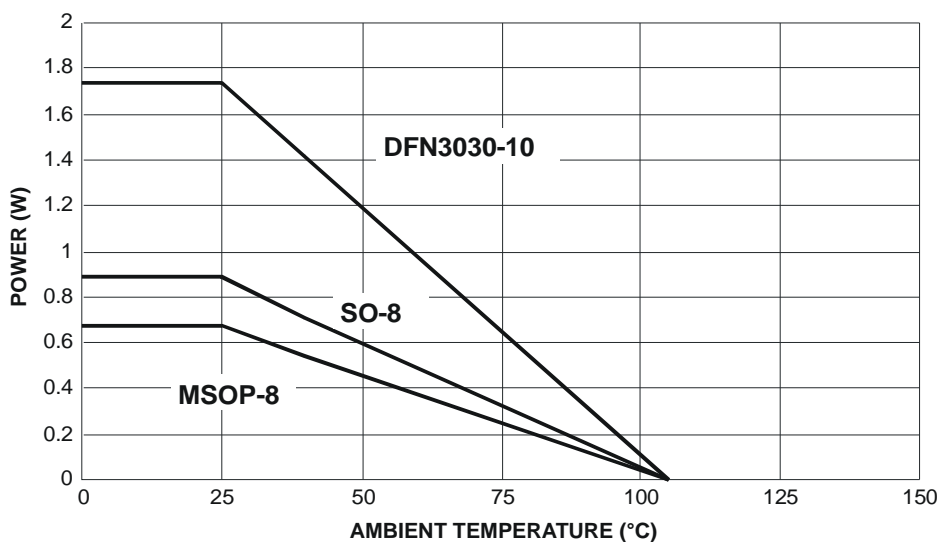
Figure 7 below shows the AP8800 driving 3 LEDs when all 3 LEDs become shorted together. Due to the large voltage change across the inductor during both LED current ramp-up and ramp-down we see a large difference in switching frequency.



**Figure 7 LED Short Fault Condition**

### Thermal Considerations

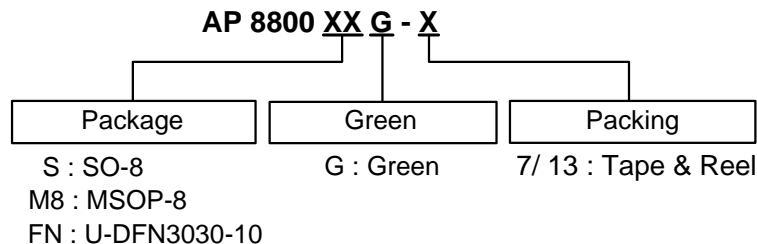
The graph below in Figure 8, gives details for power derating. This assumes the device to be mounted on a 25 x 25mm PCB with 1oz copper standing in still air.



**Figure 8 Power Dissipation Derating Curve**



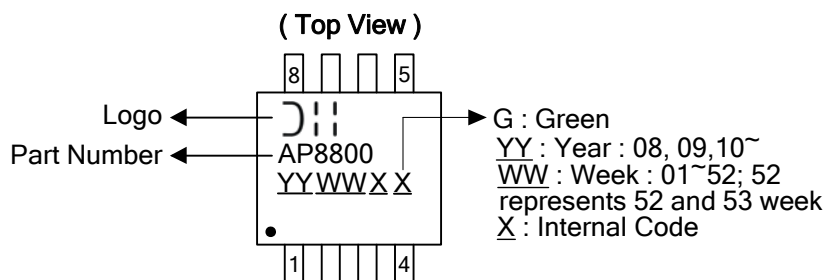
## Ordering Information



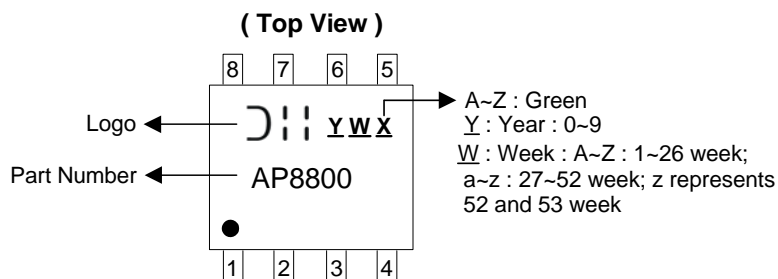
Part Number	Package Code	Packaging	7"/13" Tape and Reel	
			Quantity	Part Number Suffix
AP8800SG-13	S	SO-8	2500/Tape & Reel	-13
AP8800M8G-13	M8	MSOP-8	2500/Tape & Reel	-13
AP8800FNG-7	FN	U-DFN3030-10	3000/Tape & Reel	-7

## Marking Information

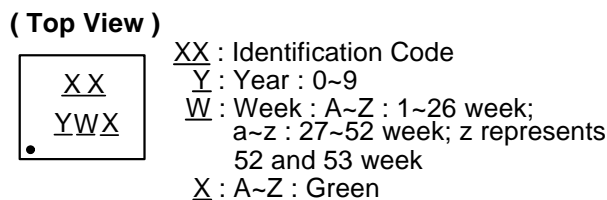
### SO-8



### MSOP-8



### U-DFN3030-10

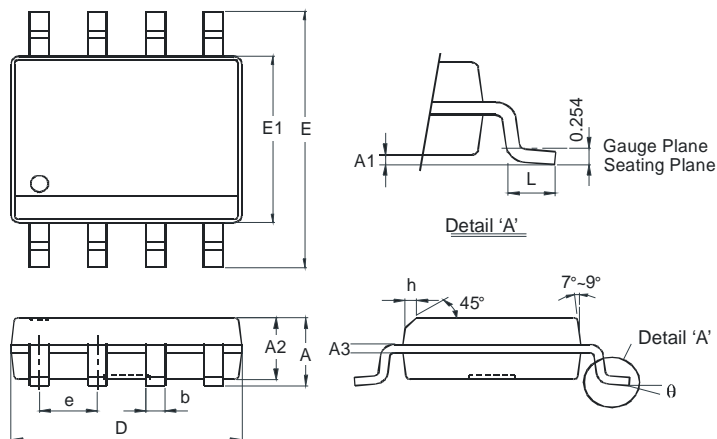


Part Number	Package	Identification Code
AP8800FNG-7	U-DFN3030-10	A4

## Package Outline Dimensions (All dimensions in mm.)

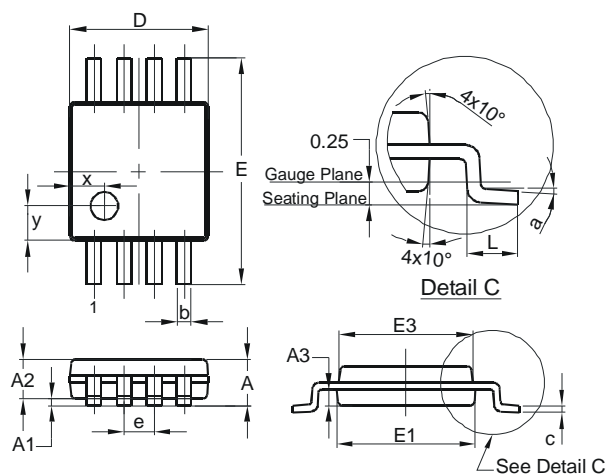
Please see AP02002 at <http://www.diodes.com/datasheets/ap02002.pdf> for latest version.

### Package Type: SO-8



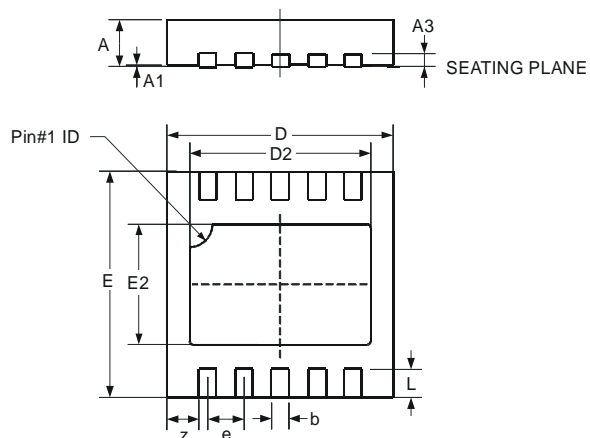
SO-8		
Dim	Min	Max
A	-	1.75
A1	0.10	0.20
A2	1.30	1.50
A3	0.15	0.25
b	0.3	0.5
D	4.85	4.95
E	5.90	6.10
E1	3.85	3.95
e	1.27 Typ	
h	-	0.35
L	0.62	0.82
θ	0°	8°
All Dimensions in mm		

### Package Type: MSOP-8



MSOP-8			
Dim	Min	Max	Typ
A	-	1.10	-
A1	0.05	0.15	0.10
A2	0.75	0.95	0.86
A3	0.29	0.49	0.39
b	0.22	0.38	0.30
c	0.08	0.23	0.15
D	2.90	3.10	3.00
E	4.70	5.10	4.90
E1	2.90	3.10	3.00
E3	2.85	3.05	2.95
e	-	-	0.65
L	0.40	0.80	0.60
a	0°	8°	4°
x	-	-	0.750
y	-	-	0.750
All Dimensions in mm			

### Package Type: U-DFN3030-10

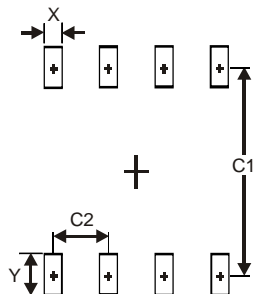


U-DFN3030-10			
Dim	Min	Max	Typ
A	0.57	0.63	0.60
A1	0	0.05	0.02
A3	—	—	0.15
b	0.20	0.30	0.25
D	2.90	3.10	3.00
D2	2.30	2.50	2.40
e	—	—	0.50
E	2.90	3.10	3.00
E2	1.50	1.70	1.60
L	0.25	0.55	0.40
z	—	—	0.375
All Dimensions in mm			

## Suggested Pad Layout

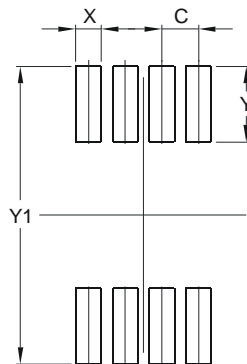
Please see AP02001 at <http://www.diodes.com/datasheets/ap02001.pdf> for the latest version.

### Package Type: SO-8



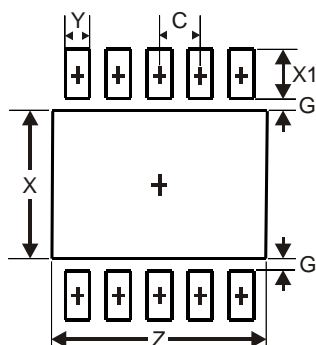
Dimensions	Value (in mm)
X	0.60
Y	1.55
C1	5.4
C2	1.27

### Package Type: MSOP-8



Dimensions	Value (in mm)
C	0.650
X	0.450
Y	1.350
Y1	5.300

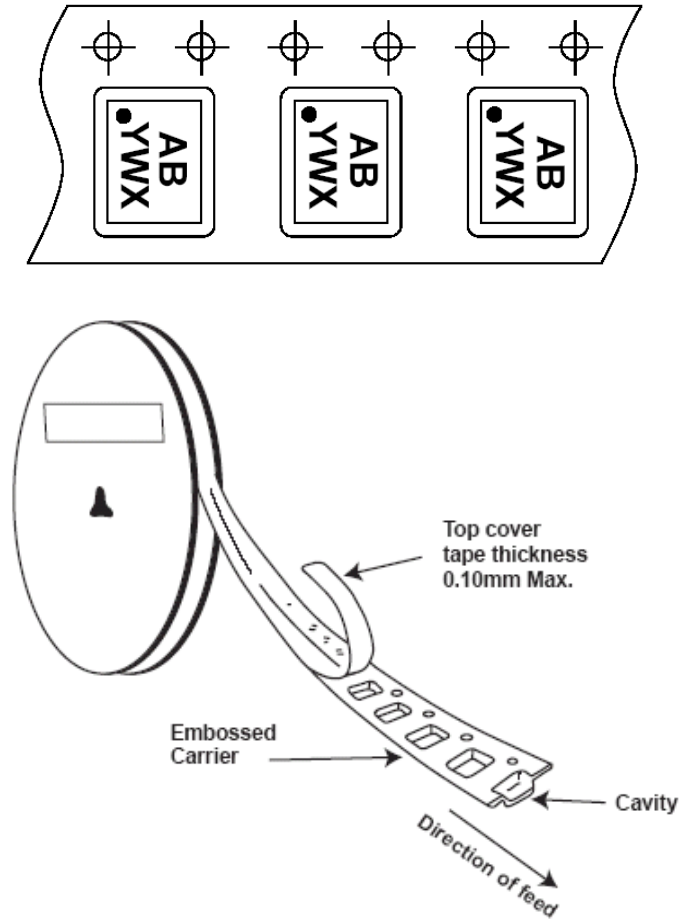
### Package Type: U-DFN3030-10



Dimensions	Value (in mm)
Z	2.60
G	0.15
X	1.80
X1	0.60
Y	0.30
C	0.50

## Tape Orientation (Note 6)

For U-DFN3030-10



Notes: 6. The taping orientation of the other package type can be found on our website at <http://www.diodes.com/datasheets/ap02007.pdf>.

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