Single Stage Flyback and PFC Controller With Primary Side Control LED Lighting Driver

General Description

The OCP8159 is a CRM constant current driver IC for offline LED lamps. It can accept wide input voltage range of 90V to 270VAC. It is based on a sinusoidal flyback topology and achieves very high power factor, typically 0.95.

The OCP8159 provides a primary side regulation scheme to eliminate the opto-couplers for constant output current. It achieves a total line/load regulation of +/-3.0%. The Ton value is regulated by a closed-loop. It detects the average output current. The average value is compared to a reference to generate an error voltage. The error voltage in turn, modulates the Ton (constant over a line cycle).

OCP8159 is a constant current Flyback controller with primary side regulation (PSR) and PFC function at LED lighting applications. The design operates at constant on time mode to achieve high PFC and turn on the power MOSFET at voltage valley which is known as boundray mode or CRM, Which turn on the power MOSFET at voltage valley to reduce the switching losses and impove EMI performance.

The ISEN input monitors the peak current value. The circuit design implements a compensation scheme for the current overshoot due to the turn-off delay.

The startup current of OCP8159 is rather small (20uA) to reduce the standby power loss further; the maximum switching frequency is clamped to 120Khz to reduce switching loss and EMI performance when the power stage is operated at light load or the valley point of sinusoidal AC power input.

OCP8159 provides reliable protections such as LED Short Circuit Protection (SCP), Open LED Protection (OLP), Over Temperature (OTP), and High temperature LED current compensation, etc.

The device is available in SOP-8L package and is rated over the -40°C to 85°C.

Features

- 90V to 270V input range
- Primary-side constant Ton regulation
- High power factor 0.95 (typ.)
- Valley switching with F_{SW} limit at 125kHz
- Total line/load regulation to ±3.0%
- ±3.0% Output Current Accuracy
- LED Open/Short Protection
- Over-temperature protections with restart delay
- < 20uA start-up current
- Cycle-by-Cycle Current Limit
- VIN Supply OVP and ULVO Protection
- Auto Restart Function
- Integrated LEB Circuit
- LED Current Soft Start
- Primary Over Current Protection
- Small Solution Size
- RoHS and Green Compliant
- SOP-8L Packages
- -40℃ to +85 ℃ Temperature Range

Applications

- General LED Lighting
- LED Light Tubes
- Lamp Light
- PAR Lamp
- Bulb

■ Pin Configuration

SOP-8L (Top View)

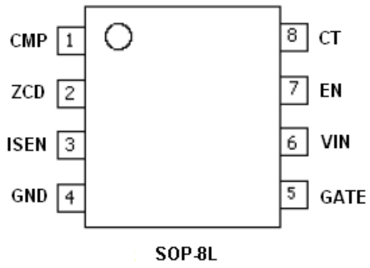


Figure 1, Pin Assignments of OCP8159

Pin Name	Pin No. SOP-8L	I/O	Pin Function
CMP	1	I/O	Compensation for the PSR regulation loop
ZCD	2	I	Zero-crossing detect (I2 current and bias-winding voltage)
ISEN	3	I/O	Primary switching current detect
GND	4	P	Ground Pin
GATE	5	O	Gate drive for external MOSFET
VIN	6	P	Chip supply voltage
EN	7	I	Enable pin
CT	8	I/O	Output Current Regulation

■ Typical Application Circuit

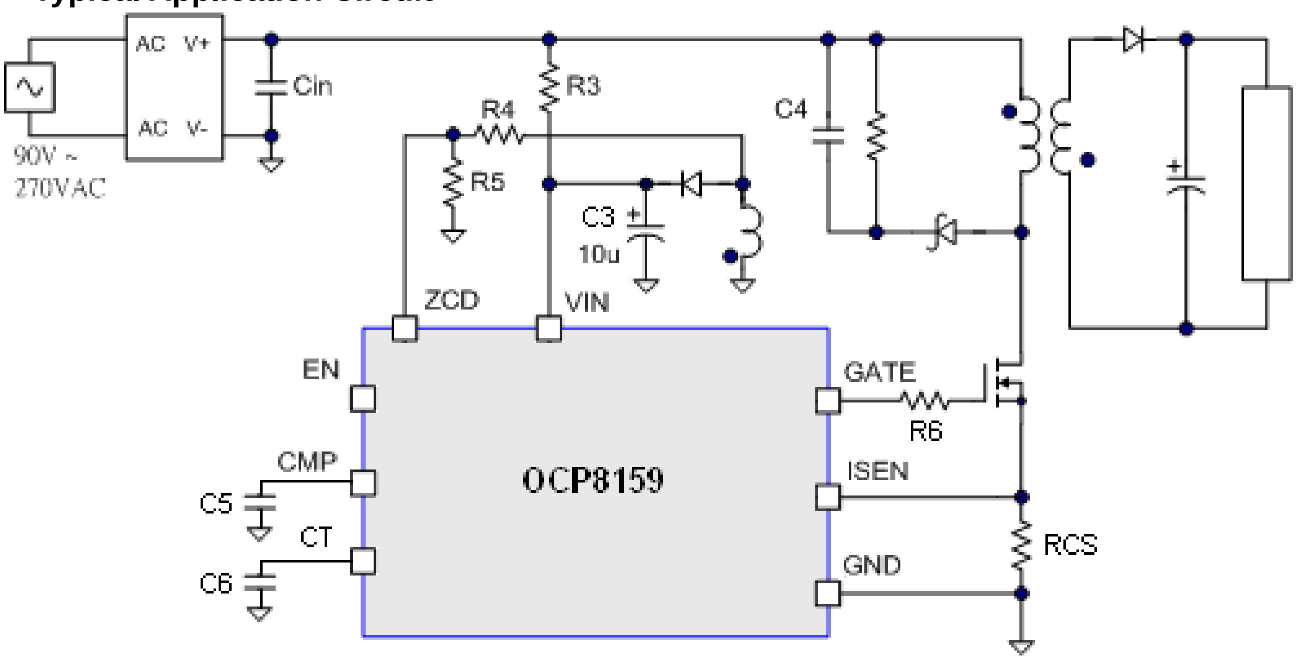


Figure 2, Typical Application Circuit of OCP8159

Block Diagram

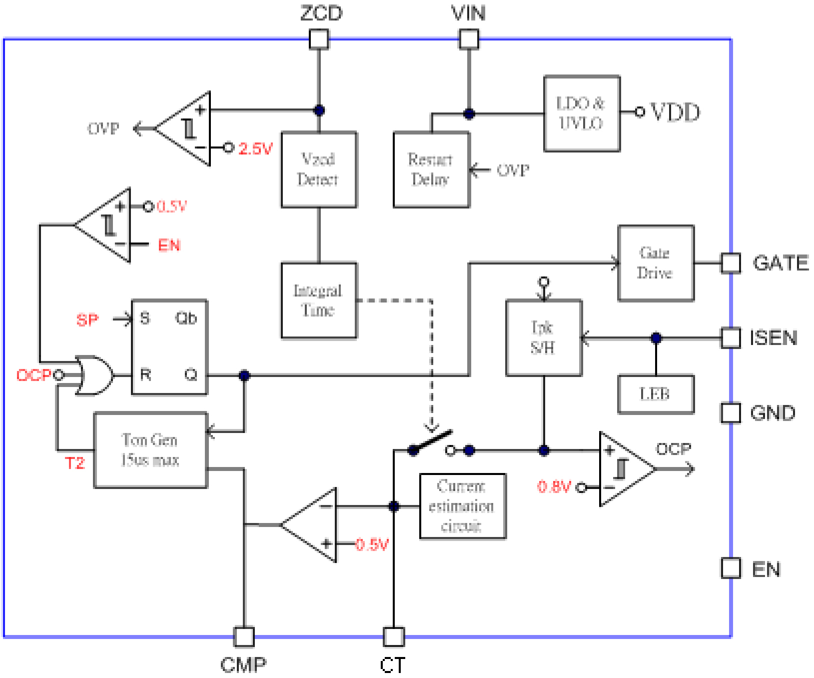


Figure 3, Block Diagram of OCP8159

Absolute Maximum Ratings[1] (TA=25°C, unless otherwise noted)

Parameter	Symbol	Rating	Unit
V_{IN} Pin to GND	V_{IN}	-0.3 to +25.0	V
V_{GATE} Pin to GND	V_{GATE}	-0.3 to +20.0	V
All Other Pins to GND	*	-0.3 to +6.0	V
Storage Temperature Range	T_S	-55 to +150	℃
Operating Junction Temperature Range	T_J	-40 to +150	℃
Maximum Soldering Temperature (at leads, 10 sec)	T_{LEAD}	300	℃

Caution: The absolute maximum ratings are rated values exceeding which the product could suffer physical damage. These values must therefore not be exceeded under any conditions.

Recommended Operating Conditions[2]

Parameter		Symbol	Rating	Unit
V_{IN} Pin Voltage to GND		V_{IN}	+9.0 to +20	V
Operating Temperature Range		T_{OP}	-40 to +85	℃
Maximum Thermal Resistance	SOP-8L	Θ_{JA}	150	℃/W
Maximum Power Dissipation	T_A<25°C	P_D	0.65	W

Note: 1: Stresses above those listed in absolute maximum ratings may cause permanent damage to the device. Functional operation at conditions other than the operating conditions specified is not implied. Only one absolute maximum rating should be applied at any one time.

2: The device is not guaranteed to function outside of its operating conditions.

■ Electrical Characteristics

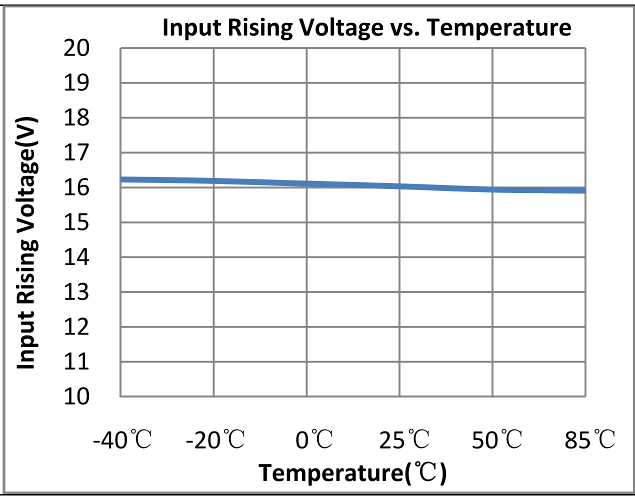
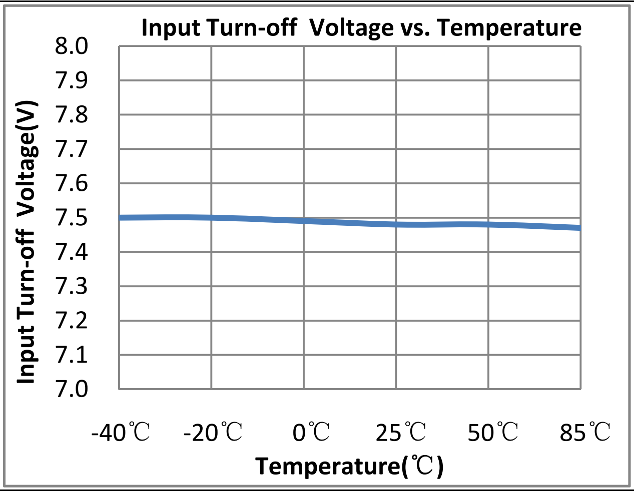
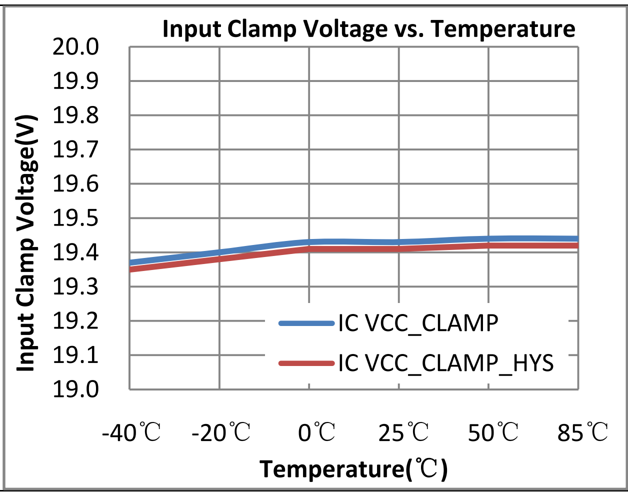
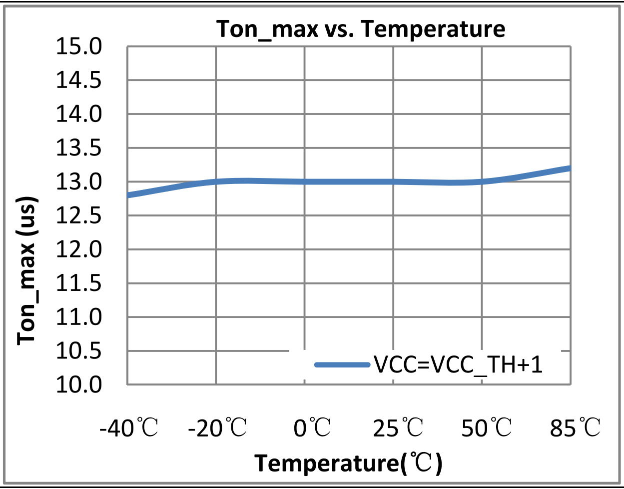
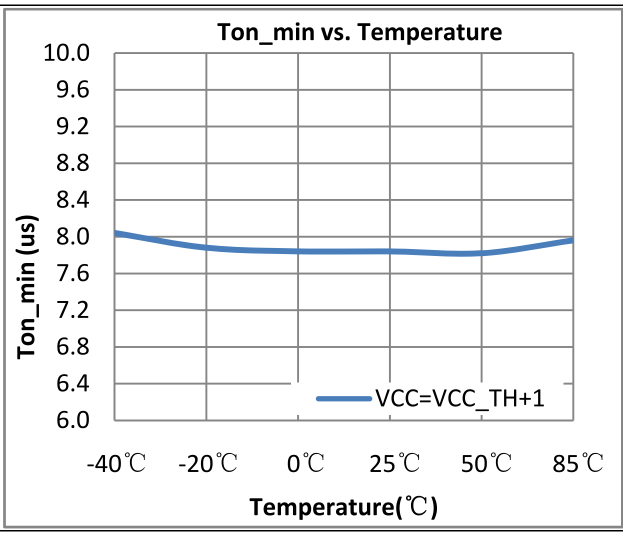
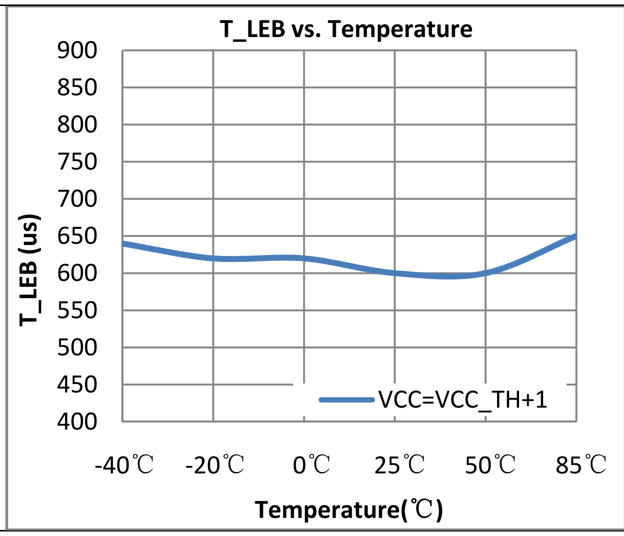
(Typical values are at T_A = +25℃, V_{IN} = 12V, unless otherwise noted.)

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
Supply						
V_{IN}	Input Voltage		9.0	12	20	V
I_Q	Operating Current (no switching)		0.2	1.0	1.5	mA
$I_{STARTUP}$	Start-up Current		1	20	30	uA
V_{IN_ON}	UVLO Cut-In Level	V_{IN} Rising	14.5	16	17.5	V
V_{IN_OFF}	UVLO Cut-Out Level	V_{IN} Falling	-	7.5	-	V
V_{IN_OVP}	VIN OVP Voltage		-	19.5	-	V
V_{OCP}	OCP Shut-Down Count	By UVLO	-	6.0	-	V
Gate Driver						
I_{SOURCE}	Source Current	PFET $R_{DS(ON)}$=80Ω	200	250	-	mA
I_{SINK}	Sink Current	NFET $R_{DS(ON)}$=50Ω	400	500	-	mA
V_{GATE_H}	Maximum Gate Voltage		V_{IN}-0.3	V_{IN}-0.2	V_{IN}	V
$T_{SW(MIN)}$	Minimum T_{SW}		-	8.0	-	uS
$T_{SW(MAX)}$	Maximum T_{SW}		-	50	-	uS
$T_{ON(MAX)}$	Maximum T_{ON}		-	13	-	uS
Current Sense						
V_{CL}	Current Limit Voltage	At fast start stage	250	300	350	mV
V_{CL}	Current Limit Voltage	At fast start-up	-	800	-	mV
T_{LEB}	Leading Edge Blanking Time		-	750	-	nS
V_{CR}	Current Regulation Reference		490	500	510	mV
EN and Dimming						
V_{EN_ON}	PWM Dimming On	100%	1.0	1.5	2.0	V
V_{EN_OFF}	PWM Dimming Off	0%	0.8	1.3	1.8	V
ZCD						
V_{ZCD_R}	ZCD Rising Threshold Voltage		1.1	1.2	1.3	V
V_{ZCD_F}	ZCD Falling Threshold Voltage		0.09	0.1	0.11	V
$T_{ZCDDELAY}$	ZCD Sense Delay Time[1]		-	2	-	uS
V_{OVP}	ZCD Protection	By OVP	-	2.5	-	V
Protection						
V_{GATE_H}	VIN Protection for Gate		-	19	-	V
T_{RESET}	Reset Delay Time		-	4	-	S
T_{SD}	Thermal Shutdown		-	150	-	℃
T_{SDHS}	Thermal Shutdown Hysteresis		-	20	-	℃
T80%	The Temperature of 80% output Current		-	140	-	℃

Note: 1, Guarantee by Design

■ Typical Characteristics—OCP8159

(Typical values are at T_A = +25℃, V_{IN} = 12V, unless otherwise noted.)

VIN_ON Voltage vs. Temperature	VIN_OFF Voltage vs. Temperature
	
VIN_OVP Voltage vs. Temperature	T_{ON_MAX} vs. Temperature
	
T_{SW_MIN} vs. Temperature	T_{LEB} vs. Temperature
	

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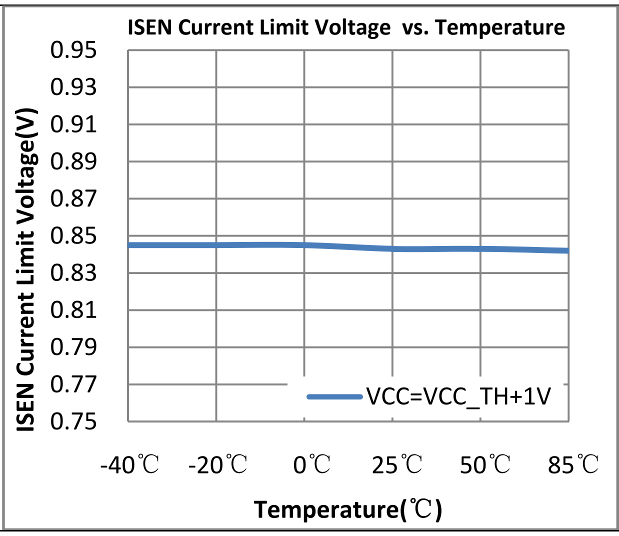
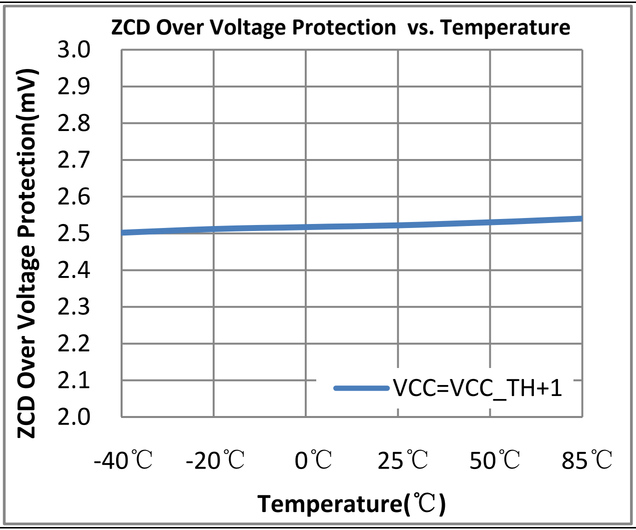
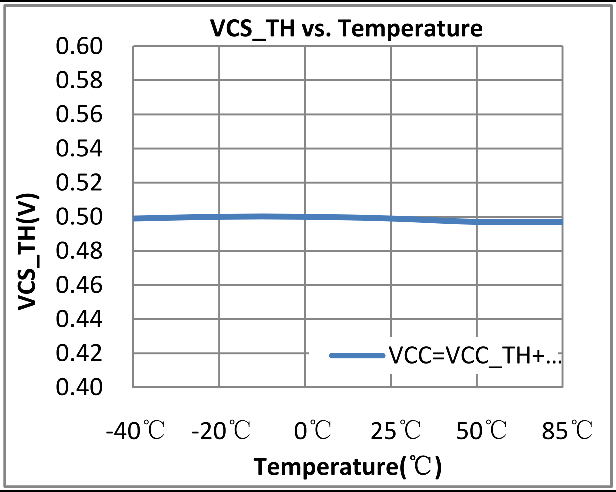
ISEN Current Limit Voltage vs. Temperature



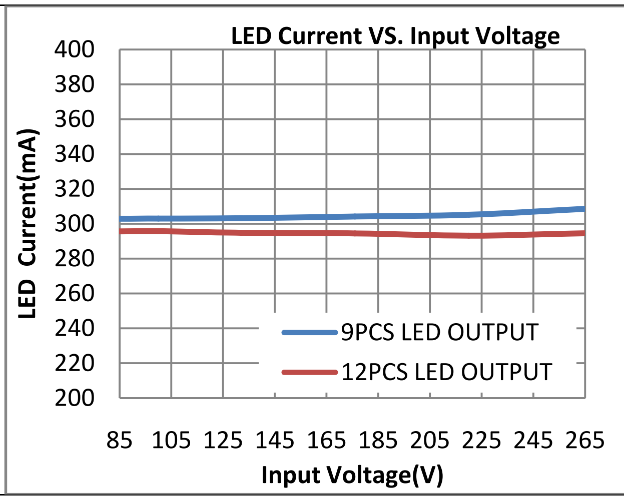
ZCD Over Voltage vs. Temperature



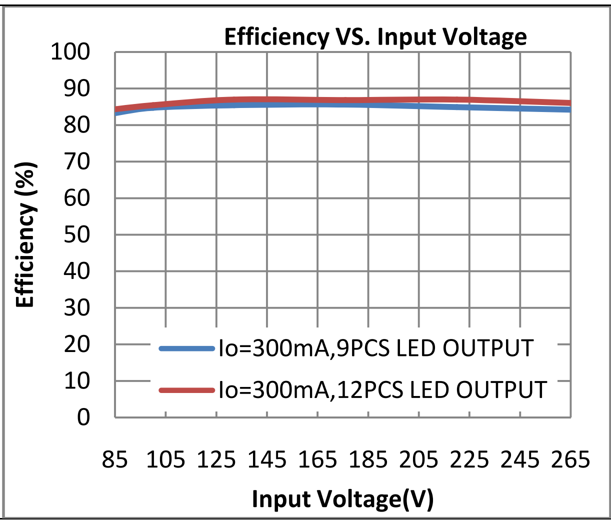
VCR_TH Voltage vs. Temperature



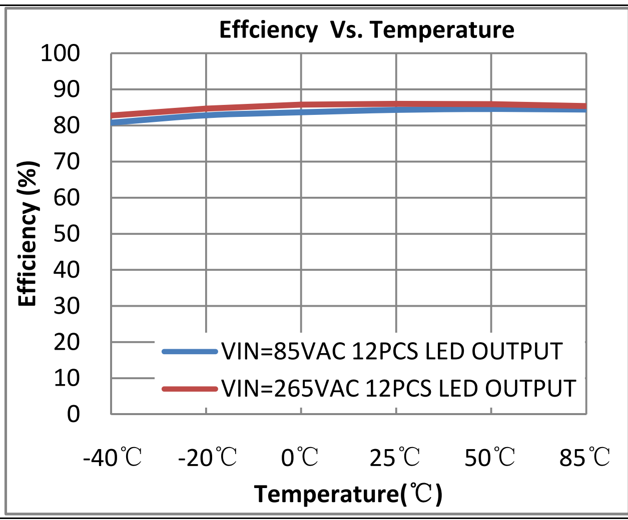
LED Current vs. Input Voltage



Efficiency vs. Input Voltage

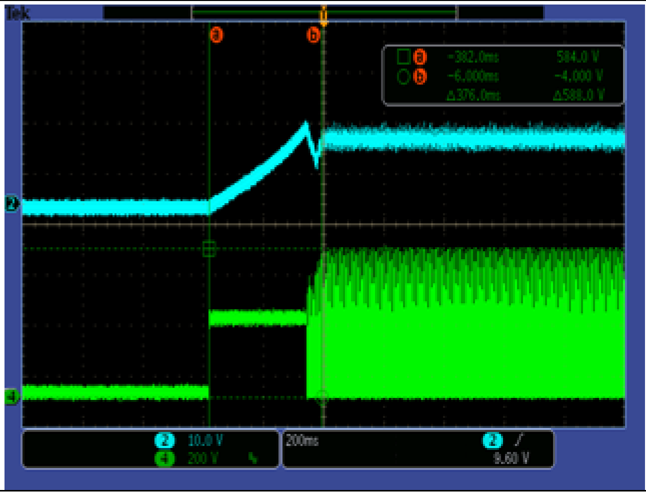
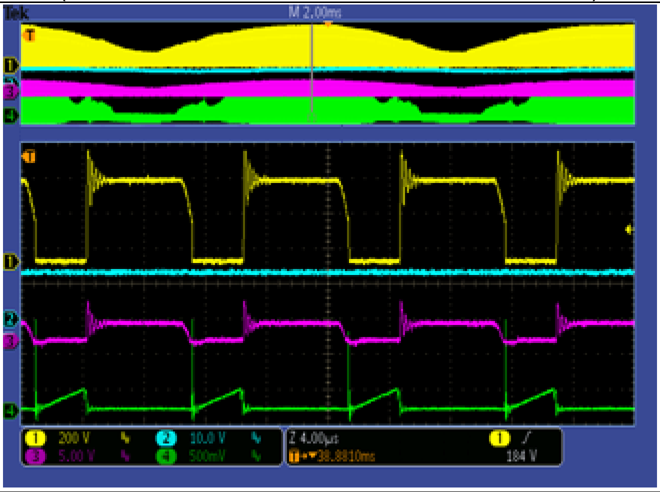
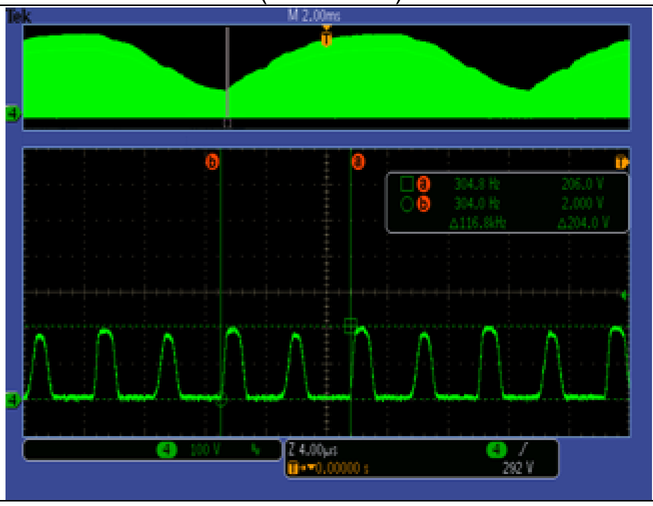
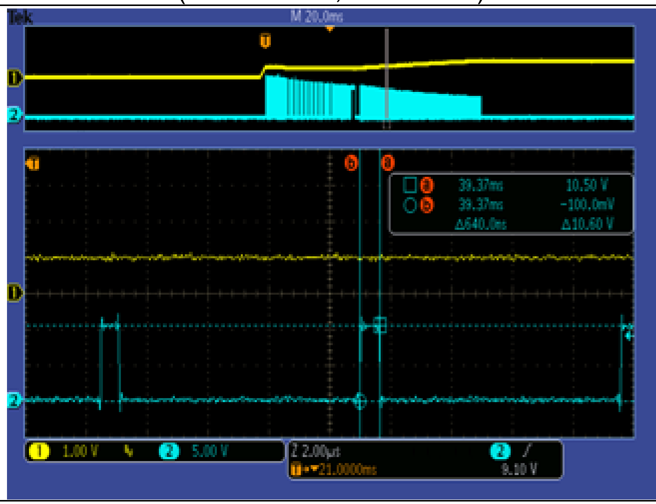
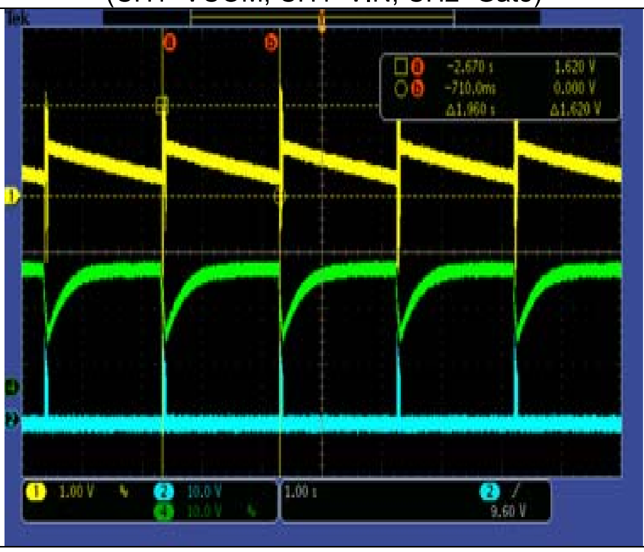
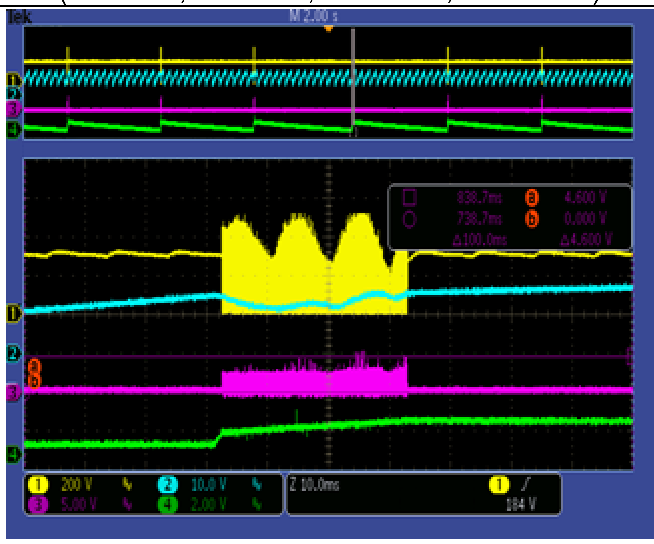


Efficiency vs. Temperature



■ Typical Characteristics—OCP8159

(Typical values are at T_A = +25℃, V_{IN} = 12V, unless otherwise noted.)

Start Up Waveform (CH1=VIN, CH2=Gate)	**Operation Waveform** (CH1=SW, CH2=VIN, CH3=ZCD, CH4=ISEN)
	
Maximum Operation Frequency (CH4=Gate)	**Minimum On Time Waveform** (CH1=VCOM, CH2=Gate)
	
LED Short Circuit Protection Waveform (CH1=VCOM, CH4=VIN, CH2=Gate)	**LED Open Protection Waveform** (CH1=SW, CH2=VIN, CH3=ZCD, CH4=ISEN)
	

Functional Description

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The OCP8159 provides a primary side regulation scheme to eliminate the opto-couplers for constant output current. It achieves a total line/load regulation of +/-3.0%. The Ton value is regulated by a closed-loop. It detects the average output current. The average value is compared to a reference to generate an error voltage. The error voltage in turn, modulates the Ton (constant over a line cycle).

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The startup current of OCP8159 is rather small (<20uA) to reduce the standby power loss further; the maximum switching frequency is clamped to 120Khz to reduce switching loss and EMI performance when the power stage is operated at light load or the valley point of sinusoidal AC power input.

OCP8159 provides reliable protections such as LED Short Circuit Protection (SCP), Open LED Protection (OLP), Over Temperature (OTP), and High temperature LED current compensation, etc.

Start Up

The input capacitor C_{IN} is charged through the start-up resistor R_{STR}, when the rectified ac input voltage HV is applied. The VIN current consumed by the OCP8159 is only 20μA (nominal). While VIN reaches the upper VIN UVLO threshold of 16V, the Internal VDDA linear regulator is enabled.

When the VDDA regulator is turned on, the external capacitor at the CMP pin begins to charge. The PWM controller, current regulation circuit, protection circuit and gate driver are enabled when the CMP voltage reaches 0.9V .The switching power supply energy is transferred from the primary to the secondary transformer winding(s). VIN will drop down by internal consumption of IC until the bias winding could supply energy to maintain VIN above 7.5V. The VDDA regulator will remain on until VIN falls to the lower UVLO threshold of 7.5V (6.5V hysteresis).

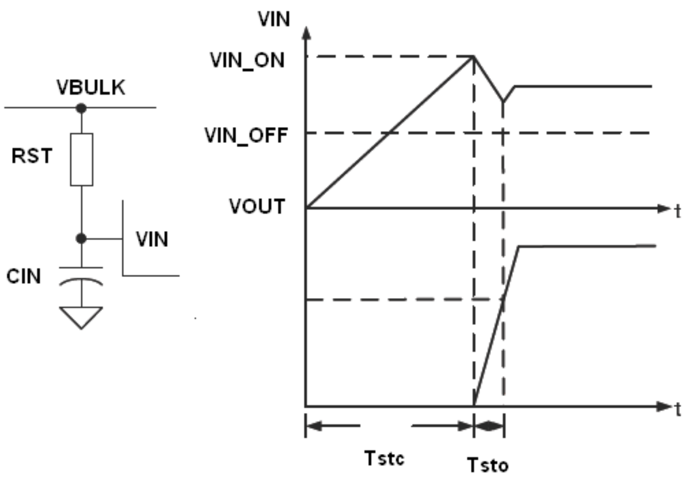


Figure 4, Start Up Waveform

The start up resistor RST and CIN are designed by rules below:

(1), Preset start up resistor RST, make sure that the current through RST is larger than $I_{STARTUP}$ and smaller than I_Q

$$\frac{V_{BULK}}{I_Q} < R_{ST} < \frac{V_{BULK}}{I_{ST}}$$

Where V_{BULK} is the BUS line Voltage.

(2), Select CIN to obtain an ideal start up timer TST, and ensure the output voltage is built up at one time.

$$C_{IN} = \frac{\left(\frac{V_{BULK}}{R_{ST}} - I_{ST}\right) * T_{ST}}{V_{IN\_ON}}$$

(3), If the CIN is not big enough to build up the output voltage at one time. Increase CIN and decease RST, go back to step (1) and redo such design flow until the ideal start up procedure is obtained.

Internal Pre-charge Design for Quick Start Up

After VIN exceeds V_{IN_ON}, V_{COMP} is pre-charged by an internal current source. The PWM block won't start to output PWM signal until V_{COMP} is over the initial voltage V_{COMP_ON}, which can be programmed by C_{COMP}. Generally, a big capacitance of C_{COMP} is necessary to achieve high power factor and stabilize the system loop (1μF~2μF recommended).

Shut Down

After AC supply or DC BUS is powered off, the energy stored in the BUS capacitor will be discharged. When the auxiliary winding of Flyback transformer can not supply enough energy to VIN pin, VIN will drop down. Once VIN is below $V_{IN\text{-}OFF}$, the IC will stop working and V_{COMP} will be discharged to zero.

PSR Control

Primary side control is applied to eliminate secondary feedback circuit or opto-coupler, which reduces the circuit cost. The switching waveforms are shown in Fig.5.

The output current I_{OUT} can be expressed as equation (1)

$$i_{out} = \frac{i_{spk}}{2} \times \frac{t_{dis}}{t_s} \quad (1)$$

$$i_{out} = N_{PS} \times \frac{i_{ppk}}{2} \times \frac{t_{dis}}{t_s} \quad (2)$$

N_{PS}: the turn ratio of Primary side to Secondary side of Flyback transformer.
I_{SPK}: peak current of secondary side.
t_{DIS}: the discharge time of Flyback transformer.
t_S: The switching period.
I_{PPK}: peak current of primary side.
L_P: Primary side inductance.

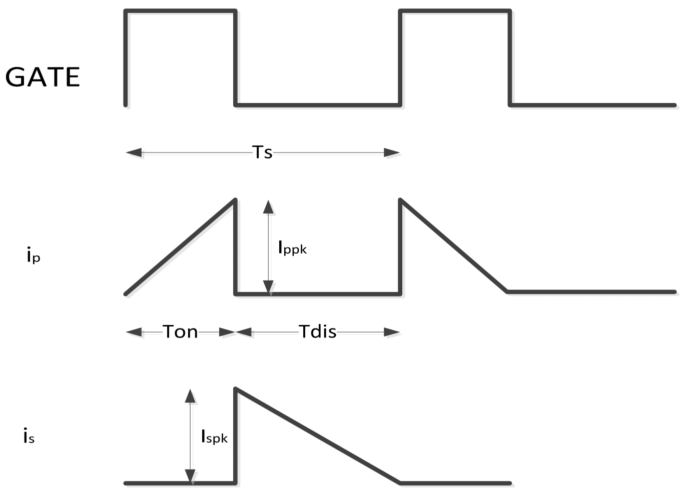


Figure 5, Switching Waveform

The average current output in a PSR power system with PFC is more complicated to estimate than a non-PFC power system.

$$I_{OUT} = \frac{1}{T}\int_0^T i_{out}(t)dt = \frac{N_{PS}}{2T}\int_0^T i_{ppk}(t) \times \frac{t_{dis}(t)}{t_s(t)}dt \quad (3)$$

The controller uses constant-on- time to achieve high PFC. Suppose on time =T_{ON}.

$$t_s(t) = t_{dis}(t) + T_{ON} \quad (4)$$

$$t_{dis}(t) = \frac{1}{N_{PS}} \times \frac{v_{ac}(t)}{V_F} \times T_{ON} \quad (5)$$

Current peak of primary side is

$$i_{ppk}(t) = \frac{v_{ac}(t)}{L_P} \times T_{ON} \quad (6)$$

Combine equation (1) to (6)

$$I_{OUT} = \frac{N_{PS}}{2T}\int_0^T i_{ppk}(t) \times \frac{t_{dis}(t)}{t_s(t)} dt = T_{ON} \times \frac{1}{L_P} \times \frac{N_{PS}}{2T}\int_0^T \frac{v_{ac}^2(t)}{N_{PS} \times V_F + v_{ac}(t)} dt \quad (7)$$

T is the half (or whole) period of 120Hz sinusoidal AC input.

The controller samples the peak voltage which represents the peak current of primary side (i_{ppk}) at I_{SENSE} pin during the turn-on period, then hold this voltage until a falling edge is detected at ZCD pin. A current estimation circuit charges and discharges a current integration capacitor synchronous with secondary side behavior. When constant current regulation is achieved, the voltage on integration capacitor is equal to 0.5V.

$$V_{REF} = 0.5 = \frac{5}{T} \times R_{SENSE} \int_0^T i_{ppk}(t) \times \frac{t_{dis}(t)}{t_s(t)} dt = \frac{T_{ON}}{L_P} \times \frac{5 \times R_{SENSE}}{T} \int_0^T \frac{v_{ac}^2(t)}{N_{PS} \times V_F + v_{ac}(t)} dt \quad (8)$$

Since it is difficult to do the calculation without computer, $\frac{1}{T}\int_0^T \frac{v_{ac}^2(t)}{N_{PS} \times V_F + v_{ac}(t)} dt$ can be simplified as $\frac{V_{AC}^2(RMS)}{N_{PS} \times V_F + V_{AC}(RMS)}$. Equation (7) is simplified as

$$I_{OUT} = T_{ON} \times \frac{1}{L_P} \times \frac{N_{PS}}{2} \times \frac{V_{AC}^2(RMS)}{N_{PS} \times V_F + V_{AC}(RMS)} \quad (9)$$

Equation (8) is simplified as

$$V_{REF} = 0.5 = 5 \times R_{SENSE} \times \frac{T_{ON}}{L_P} \times \frac{V_{AC}^2(RMS)}{N_{PS} \times V_F + V_{AC}(RMS)} \quad (10)$$

Combine equation (10) to (9)

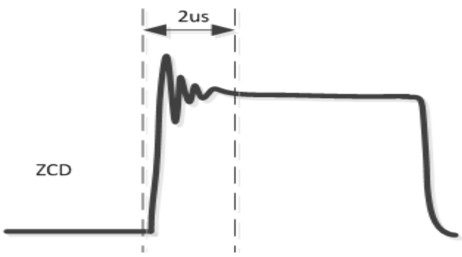
$$I_{OUT} = \frac{N_{PS}}{2} * \frac{V_{REF}}{5R_{SENSE}} \quad (11)$$

Open LED Protection / Over Voltage Protection

The controller has 2 safety valves for OLP. One is the detection of VIN; another is the detection of ZCD. When the output is opened, the output voltage increases. The voltage of the bias winding is V_{OUT} X N_A / N_S (turn ration of Bias windings to secondary side). Once VIN reaches 19V or ZCD exceeds 2.5V during the turn-off period of power MOSFET with 2us blanking, the controller will shut down power MOSFET. Due to the turn-off of the power stage, there is no energy transferred from transformer, VIN will drop down to 7.5V which triggers SCP , then the controller resume after a hiccup counter finish a cycle.

The OLP protection threshold can be expressed the following equation:

$$V_{OUT\_OVP} = 2.5V \times \frac{N_S}{N_A} \times \frac{R_{Z1} + R_{Z2}}{R_{Z2}} \quad (11)$$



When the power MOSFET is turned off, a ringing voltage spike will occur at ZCD pin which may cause mis-trigger of OVP. The controller provides a 2us blanking timer for OVP detection. If the ZCD does not maintain for more than 2us and some fetal failure occurs, other protection circuits will help to cover the safety functions.

Short Circuit Protection

When the output is shorted to ground, the output voltage is clamped to zero. The voltage of the bias winding is V_{OUT} X N_A / N_S (turn ration of Bias windings to secondary side). So VIN will drop down without bias winding supply. Once VIN drops down below 7.5V, the controller will shut down most of circuits except a hiccup counter with 150uA current consumption.

The worst case design of R_{STR} should provide 150uA charge current to maintain in hiccup mode at fault conditions. In high line condition, VIN will climb to higher voltage due to larger charge current. A 19V voltage clamping circuit will keep VIN below 19V which is a safer voltage for chip voltage rating and V_{GS} of power MOSFET. The controller is still charged by VAC through R_{STR} and operates in hiccup mode until the VAC is removed or faults are fixed.

ZCD Function

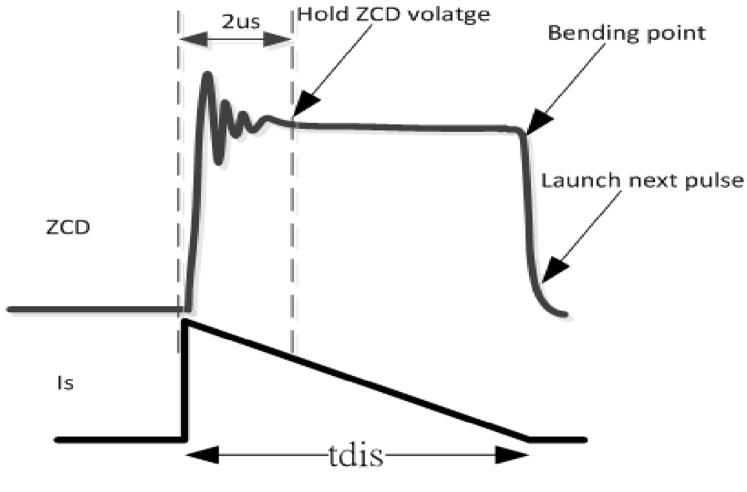
The ZCD pin is connected to the auxiliary winding through a resistor divider. The ZCD pin is used for four functions.

The first function is to detect discharge time of secondary side output which determines t_{dis}. T_{dis} is from the point at which ZCD rises above 1.2V after Gate output turned-off to the point at which the controller will detect the bending point of ZCD by comparing ZCD voltage with a pre-holding ZCD voltage to find the zero current point of the transformer.

The second function is to detect the output voltage of secondary side. The internal circuit compares ZCD with 1.2V after 2us blanking time when AC power is applied. Before ZCD > 1.2V which means output voltage is too small for auxiliary winding to establish enough voltage for VIN, the chip will launch larger Gate output width to fasten the output voltage. At this stage, current limit for I_{SEN} is 0.3V.

The third function is to detect zero-cross condition of the auxiliary winding voltage after the secondary side current decreases to zero and starts a oscillation ringing which will hit a voltage below zero, the controller starts the next turn-on when ZCD pin is less than 100mV. This function achieves the boundary conduction mode operation to minimize the switching losses and EMI.

The fourth function of ZCD pin is to implement the Open LED Protection by comparing to the internal 2.5V reference.



Current Limit of ISEN / Leading Edge Blanking of ISEN

The controller is built-in with a cycle-by-cycle current limit circuit to prevent external components from being damage under the failure conditions. When the current sense pin ISEN reaches 800mV threshold, the controller turned off the power MOSFET. It will not be turned on again until the next cycle starts.

In application circuit, when power MOSFET is turned on, a voltage spike may occur at ISEN pin due to circuit parasitic in the power stage. The controller will ignore 500ns leading-edge period at the turn-on of power MOSFET. It is to avoid power MOSFET being turned off by false detection of current-limit at ISEN pin.

Over Temperature Protection / High Temperature Compensation

The controller has two states temperature compensation when it experiences a high junction temperature.

(1) 140 $^oC < T_{JC} <150\ ^oC$, Only 80% of current will be delivered to LED.
(2) 150 $^oC < T_{JC}$, the power MOSFET is turned off. VIN will drop down below 7.5V. The restart mechanisms in hiccup mode resume the operation once the junction temperature is cooled down below 130 ^oC.

■ Ordering Information

OCP8159XXX

Package:
S: SOP-8L

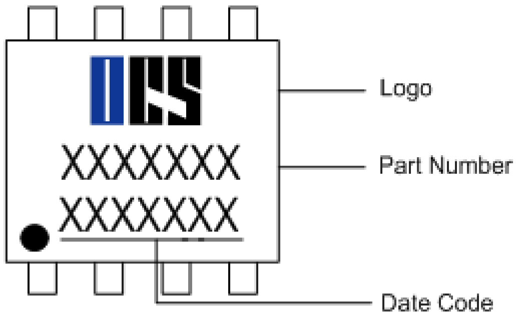
Packing:
A: Tape & Reel

Temperature Grade:
F: -40~85℃

Part Number	Driver Capability	Package Type	Package Qty	Temperature	Eco Plan	Lead
OCP8159SAD	Controller	SOP-8L	13-in reel 2500pcs/reel	-40～85℃	Green	Cu

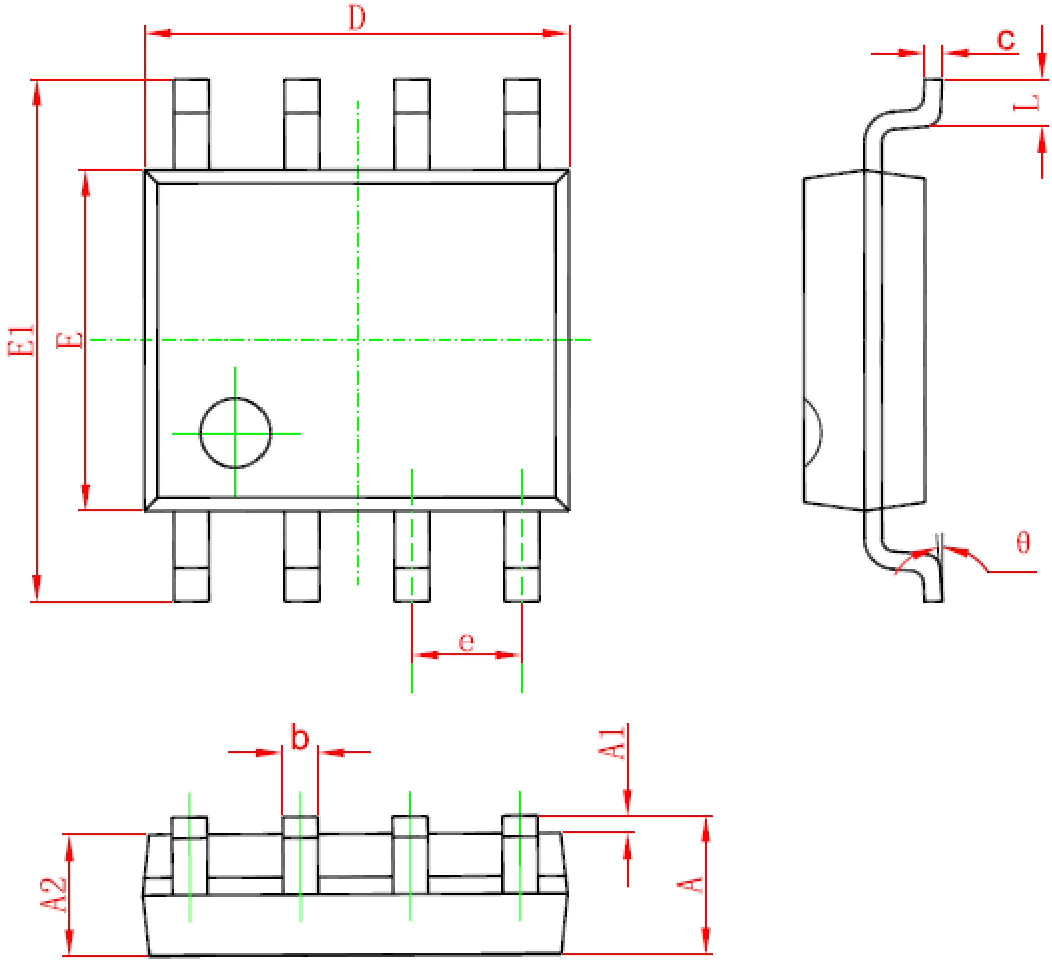
■ Marking Information

SOP-8L



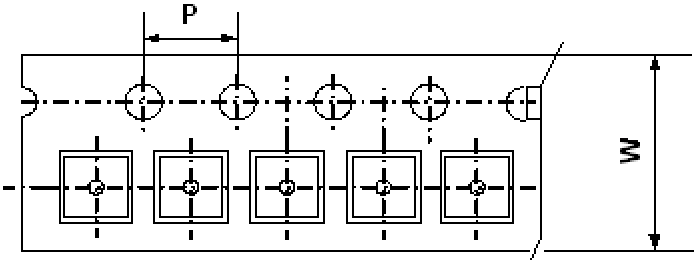
■ Package Information

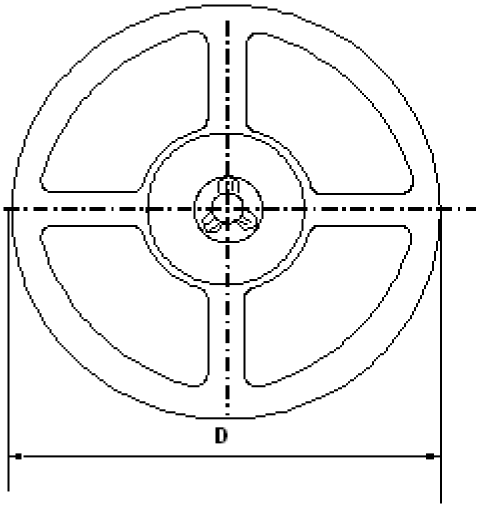
SOP-8L:



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min.	Max.	Min.	Max.
A	1.350	1.750	0.053	0.069
A1	0.100	0.250	0.004	0.010
A2	1.350	1.550	0.053	0.061
b	0.330	0.510	0.013	0.020
c	0.170	0.250	0.006	0.010
D	4.700	5.100	0.185	0.200
E	3.800	4.000	0.150	0.157
E1	5.800	6.200	0.228	0.244
e	1.270 (BSC)		0.050 (BSC)	
L	0.400	1.270	0.016	0.050
θ	0°	8°	0°	8°

■ Packing Information





Package Type	Carrier Width(W)	Pitch(P)	Reel Size(D)	Packing Minimum
SOP-8L	12.0±0.1 mm	4.0±0.1 mm	330±.1 mm	2500pcs

Note: Carrier Tape Dimension, Reel Size and Packing Minimum