SSL2129AT

Dimmable LED driver IC

Rev. 4 — 3 October 2013 Product data sheet

1. General description

The SSL2129AT is a high-voltage Integrated Circuit (IC) for driving LED lamps in general lighting applications.

The main benefits of this IC include:

- Small Printed-Circuit Board (PCB) footprint and compact solution
- High efficiency (up to 95 %) for non-dimmable high power factor solutions
- High power factor (>0.9)
- Ease of integration and many protection features
- Low electronic Bill Of Material (BOM)
- Mains phase-cut dimmable using external components
- Highly flexible IC for use in buck, buck/boost and flyback modes
- Single inductor used for non-isolated configurations because of internal demagnetization detection

The IC range has been designed to start up directly from the HV supply using an internal high-voltage current source. An internal clamp limits the supply voltage.

2. Features and benefits

- LED driver IC for driving strings of LEDs or high-voltage LED modules from a rectified mains supply
- Driver provides power-efficient boundary conduction mode of operation with:
  - No reverse recovery losses in freewheel diode
  - Zero-Current Switching (ZCS) for switch turn-on
  - Zero-voltage or valley switching for switch turn-off
  - Minimal required inductance value and size
- Fast transient response through cycle-by-cycle current control:
  - No over or undershoots in the LED current
- Simple high input power factor solution (>0.9)
- Internal Protection features:
  - UnderVoltage LockOut (UVLO)
  - Leading-Edge Blanking (LEB)
  - OverCurrent Protection (OCP)
  - Internal OverTemperature Protection (OTP)

    - Brownout protection
    - Output Short Protection (OSP)
- Mains phase cut dimmable LED driver solution:
    - Supports both leading and trailing-edge dimmers
    - Easy external temperature protection with a single NTC
    - Open output protection using external components
    - Compatible with wall switches with built-in indication light during standby
- IC lifetime easily matches or surpasses LED lamp lifetime
- Input current distributed evenly over the phase, reducing required output capacitor size and bleeder dissipation

3. Applications

The SSL2129AT is intended for mains dimmable compact LED lamps for single mains input voltages. Mains input voltages include 100 V, 120 V and 230 V (AC). The external components determine the power range.

4. Quick reference data

Table 1. Quick reference data

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{CC}	supply voltage	operating range	8	-	16	V
$I_{CC(INT)}$	internal supply current	normal operation	-	1.3	-	mA
V_{HV}	voltage on pin HV		–0.4	-	+600	V
V_{DRAIN}	voltage on pin DRAIN		–0.4	-	+600	V
f_{conv}	conversion frequency		-	100	-	kHz
$V_{o(DRIVER)max}$	maximum output voltage on pin DRIVER	$V_{CC} > V_{CC(startup)}$	9	10.5	12	V

[1] An internal clamp sets the supply voltage. The current into the VCC pin must not exceed the maximum I_{DD} value (see Table 4).

5. Ordering information

Table 2. Ordering information

Type number	Package		
	Name	Description	Version
SSL2129AT	SO8	plastic small package outline body; 8 leads; body width 3.9 mm	SOT96-1

6. Block diagram

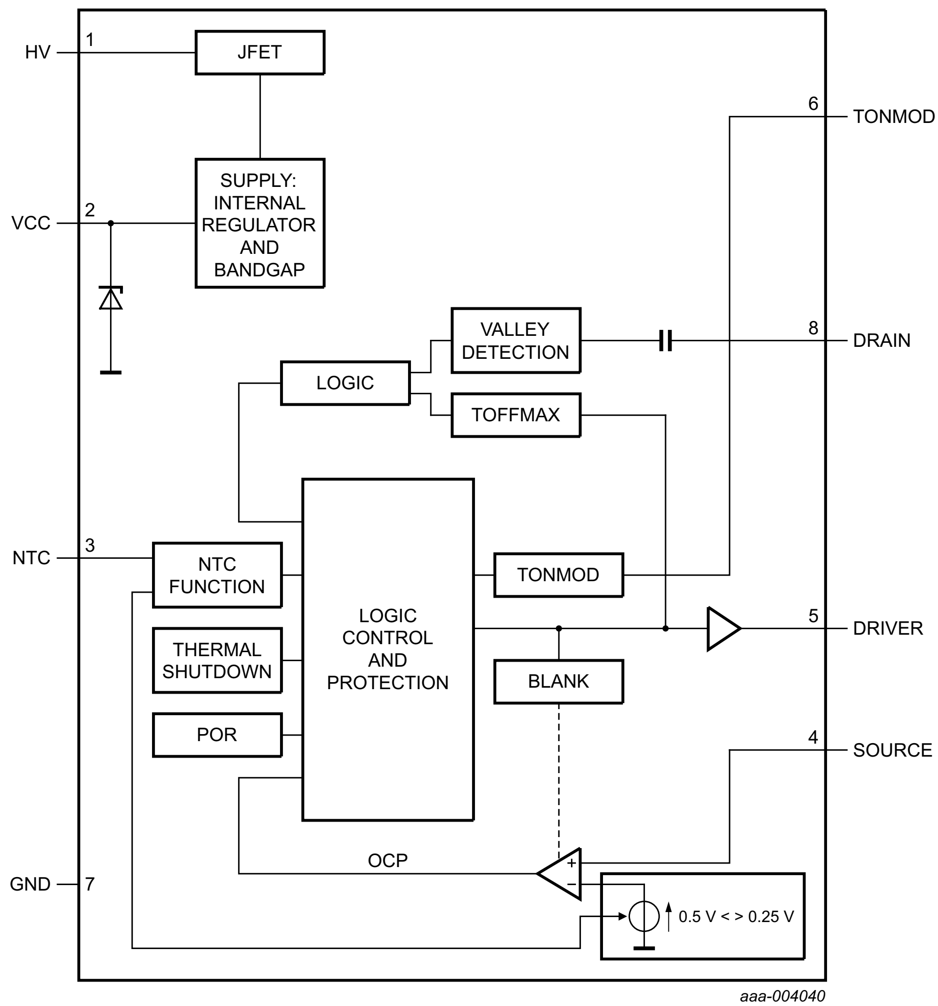


Fig 1. SSL2129AT block diagram

7. Pinning information

7.1 Pinning

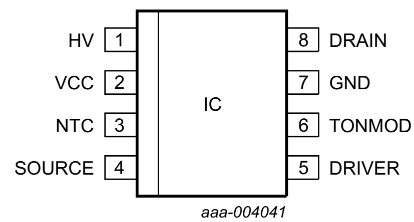


Fig 2. SSL2129AT pin configuration

7.2 Pin description

Table 3. Pin description

Symbol	Pin	Description
HV	1	high-voltage supply pin
VCC	2	supply voltage
NTC	3	temperature protection input
SOURCE	4	low-side external switch
DRIVER	5	driver output
TONMOD	6	on-time modulation input
GND	7	ground
DRAIN	8	high-side external switch

8. Functional description

8.1 Introduction

The SSL2129AT is a driver IC solution for small form factor mains phase-cut dimmable LED lamps in isolated and non-isolated applications.

8.2 Converter operation

The converter in the SSL2129AT is a Boundary Conduction Mode (BCM), peak current controlled system. See Figure 3 for the basic application diagram. See Figure 4 for the waveforms.

This converter type operates at the boundary between continuous and discontinuous mode. Energy is stored in inductor L each period that the switch is on. The inductor current I_L is zero when the MOSFET is switched on. The amplitude of the current build-up in L is proportional to the voltage drop over the inductor and the time that the MOSFET switch is on. When the MOSFET is switched off, the energy in the inductor is released towards the output. The current then falls at a rate proportional to the value of V_{OUT}. The LED current I_{LED} depends on the peak current through the inductor (SSL2129AT controlled) and on the dimmer angle while it is optimized for a high-power factor. A new cycle is started once the inductor current I_L is zero. This quasi-resonant operation results in higher efficiency.

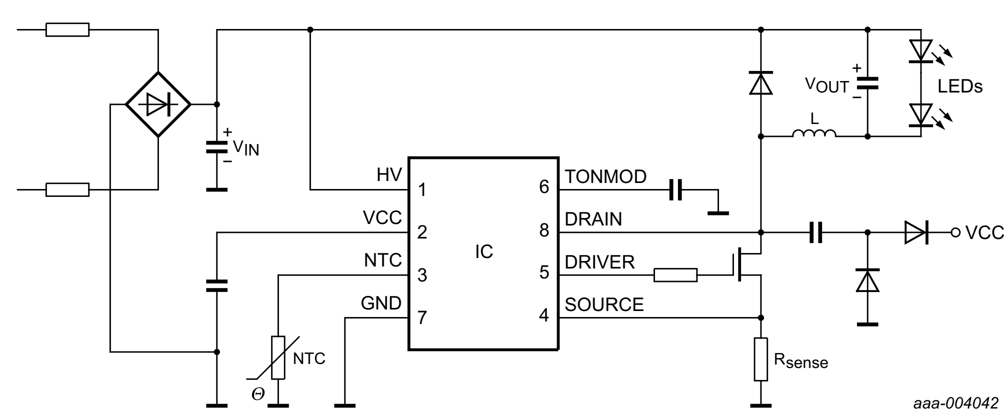


Fig 3. SSL2129AT basic application diagram

8.3 Driver pin

The SSL2129AT is equipped with a driver output for controlling an external switch. The voltage on the driver output pin is increased towards $V_{o(DRIVER)max}$ to open the switch during the first cycle (t_0 to t_1). The voltage on the driver output pin is pulled down towards a low level from the start of the secondary stroke until the next cycle starts (t_0 to t_{00}). During transition from low to high and back, there is a controlled switching slope steepness. This controlled condition limits the high-frequency radiation from the circuit to the surrounding area. The switching slope can be controlled further using an external resistor between IC and gate.

At the lowest VCC voltage ($V_{CC(stop)}$), the voltage of the driver is $V_{O(DRIVER)min}$.

8.4 Valley detection

A new cycle is started when the primary switch is switched on (see Figure 4). In the following sections, "on" represents the conductive state and off the non-conductive state.

Following time t_1, when the peak current is detected on the SOURCE pin, the switch is turned off and the secondary stroke starts at t_2. When the secondary stroke is completed with the coil current at t_3 equaling zero, the drain voltage starts to oscillate at approximately the $V_{IN} - V_{OUT}$ level. The peak to peak amplitude equals $2 \times V_{OUT}$. In a tapped buck topology, this amplitude is multiplied by the ratio of the windings.

A special feature, called valley detection is an integrated part of the SSL2129AT circuitry. Dedicated built-in circuitry connected to the DRAIN pin, senses when the voltage on the drain of the switch has reached its lowest value. The next cycle is then started at t_{00} and as a result the capacitive switching losses are reduced. A valley is detected and accepted if both the frequency of the oscillations and the voltage swing are within the range specified (f_{ring} and $\Delta V_{vrec(min)}$) for detection. If a valid valley is not detected, the secondary stroke is continued until the maximum off-time ($t_{off(high)}$) is reached. Then the next cycle is started.

A series resistance can be included at the drain sensing pin for flyback mode to remove the high-frequency ringing caused by the transformer leakage inductance.

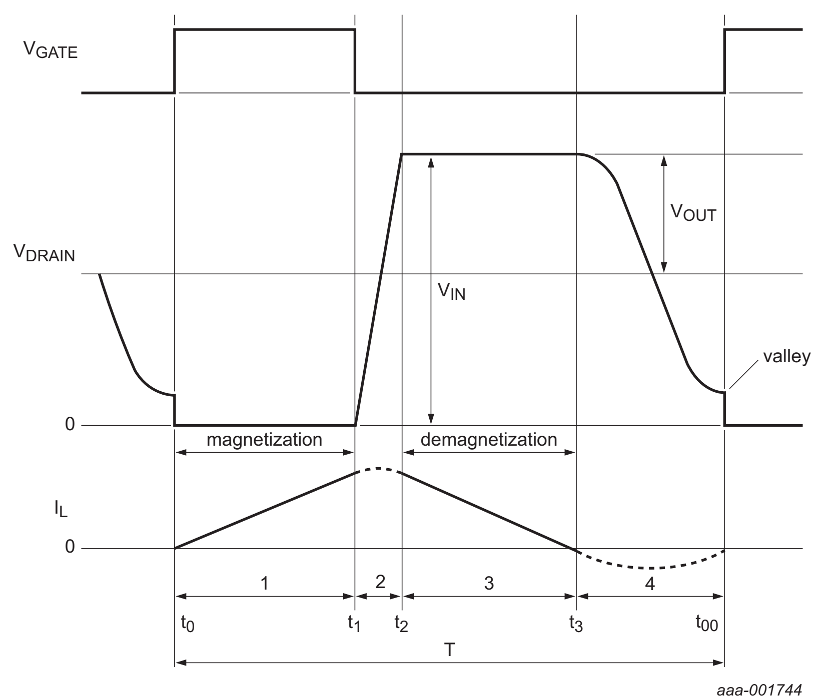


Fig 4. Waveforms and valley detection

8.5 Protective features

The IC has the following protective features:

- UnderVoltage LockOut (UVLO)
- Leading-Edge Blanking (LEB)
- OverCurrent Protection (OCP)
- Internal OverTemperature Protection (OTP)
- Brownout protection
- Output Short Protection (OSP)
- LED overtemperature control and protection
- An optional output OverVoltage Protection circuit is implemented using external components and the NTC pin.

The internal OTP and LED over temperature protections are safe-restart protections. The IC halts, causing V_{CC} to drop to below $V_{CC(stop)}$, and triggers a start-up. When V_{CC} drops to below $V_{CC(rst)}$, the IC resets the latch protection mode. Switching starts only when no fault condition exists.

8.5.1 UnderVoltage LockOut (UVLO)

When the voltage on the VCC pin < $V_{CC(stop)}$, the IC stops switching. An attempt is then made to restart by supplying V_{CC} from the HV pin voltage.

8.5.2 Leading-Edge Blanking (LEB)

To prevent false detection of the short-winding or overcurrent, a blanking time following switch-on is implemented. When the MOSFET switch switches on there can be a short current spike due to capacitive discharge of voltage over the drain and source and the charging of the gate to source capacitance. During the LEB time (t_{leb}), the spike is disregarded.

8.5.3 OverCurrent Protection (OCP)

The SSL2129AT contains a highly accurate peak current detector. It triggers when the voltage on the SOURCE pin reaches the peak level $V_{th(ocp)SOURCE}$. The current through the switch is sensed using a resistor connected to the SOURCE pin. The sense circuit is activated following LEB time t_{leb}. As the LED current is half the peak current (by design), it automatically provides protection for maximum LED current during operation. There is a propagation delay ($t_{d(ocp-swoff)}$) between the overcurrent detection and the actual switching off of the switch. Due to the delay, the actual peak current is slightly higher than the OCP level set by the resistor in series to the SOURCE pin.

8.5.4 OverTemperature Protection (OTP)

When the internal OTP function is triggered at a certain IC temperature ($T_{th(act)otp}$), the converter stops operating. The OTP safe-restart protection and the IC restarts again with switching resuming when the IC temperature drops below $T_{th(rel)otp}$.

8.5.5 Brownout protection

Brownout protection is designed to limit the lamp power when the input voltage drops close to the output voltage level. The input power has to remain constant. The input current would otherwise increase to a level that is too high for the input circuitry. In the SSL2129AT, there is a maximum limit on the on-time of switch $t_{on(high)}$.

In buck mode, the rate of current rise in the coil during the on-phase is proportional to the difference between input voltage and output voltage. Therefore, the peak current cannot be reached before $t_{on(high)}$ and as a result the average output current to the LEDs is reduced.

8.6 t_{on} control

The $t_{on(high)}$ can be lowered by connecting a capacitor to the TONMOD pin. The external capacitor is charged during the primary stroke with $I_{offset(TONMOD)}$. If the $V_{th(TONMOD)}$ level is reached before the $t_{on(high)}$ time, the switch is turned off and the secondary stroke starts. When a capacitor is not connected to the pin, $V_{th(TONMOD)}$ is reached quickly. Shorter than the minimum limit of 1 μs. In this case or when the TONMOD pin is grounded, the internal time constant, $t_{on(high)}$ determines the maximum on-time.

8.7 Output Short-circuit Protection (OSP)

During the secondary stroke (switch-off time), if a valley is not detected within the off-time limit ($t_{off(high)}$), then typically the output voltage is less than the minimum limit allowed in the application. This condition can occur either during start-up or due to a short-circuit. A timer $t_{det(sc)}$ is started when $t_{off(high)}$ is detected. Timer $t_{det(sc)}$ is reset when a valid valley detection occurs in one of the subsequent cycles or when V_{CC} drops to below $V_{CC(stop)}$.

The timer can also be reset if the maximum limit on the on-time of the switch ($t_{on(high)}$) is reached, which is usually the case at start-up (brownout protection). If no valley is detected and ($t_{on(high)}$) is not reached before $t_{det(sc)}$, then it is concluded that a real short-circuit exists. The IC enters latched protection. If V_{CC} drops to below $V_{CC(rst)}$, the IC resets the latched protection mode (see Figure 5). During PWM dimming, the OSP timer is paused during the off cycle.

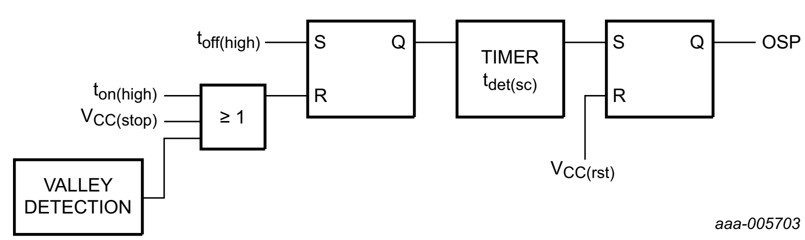


Fig 5. OSP logic diagram

The value of $t_{on(high)}$ depends on the capacitor connected to the TONMOD pin. An open or shorted TONMOD pin sets $t_{on(high)}$ to 15 μs (see Section 8.6 and Table 6).

8.8 VCC supply

The SSL2129AT can be supplied using three methods:

- Under normal operation, the voltage swing on the DRAIN pin is rectified using external components providing current towards the VCC pin
- At start-up, there is an internal current source connected to the HV pin. The current source provides internal power until an external current on the VCC pin provides the supply.
- Using an auxiliary winding, the voltage can be rectified and connected to the VCC pin via a series resistor.

The IC starts up when the voltage at the VCC pin exceeds $V_{CC(startup)}$. The IC locks out (stops switching) when the voltage at the VCC pin is lower than $V_{CC(stop)}$. The hysteresis between the start and stop levels allows the IC to be supplied by a buffer capacitor until the external supply is settled. The SSL2129AT has an internal V_{CC} clamp, which is an internal active Zener (or shunt regulator). This internal active Zener limits the voltage on the supply VCC pin to the maximum value of V_{CC}. If the maximum current of the supply minus the current consumption of the IC (determined by the load on the gate drivers), is lower than the maximum value of I_{DD} no external Zener diode is needed in the supply circuit.

8.8.1 VCC regulator

During supply dips, the input voltage can drop too low to supply the required IC current. Under these conditions, if the VCC voltage drops lower than $V_{CC(swon)reg}$ level, a second regulator is started. Its function is to fill in the required supply current which the external supply does not deliver. It prevents the IC going into UVLO. When the VCC voltage exceeds $V_{CC(swon)reg}$ level, the regulator is turned off.

8.9 NTC functionality and PWM dimming

The NTC pin can be used as a control method for LED thermal protection. Alternatively, the pin can be used as an input to disable/enable light output using a digital signal (PWM dimming). The pin has an internal current source that generates the current of $I_{offset(NTC)}$. An NTC resistor to monitor the LED temperature can be directly connected to the NTC pin. Depending on the resistance value and the corresponding voltage on the NTC pin, the converter reacts as shown in Figure 6.

During start-up, before V_{CC} reaches $V_{CC(startup)}$ the voltage on the NTC pin must be less than the minimum value of $V_{act(tmr)NTC}$. This is valid when the voltage on the NTC pin is derived from the V_{CC} using a resistive divider and a PTC in series with the resistor between pins VCC and NTC.

If an NTC resistor is connected between the NTC pin and ground, the voltage on the NTC pin is 0 V when V_{CC} reaches $V_{CC(startup)}$.

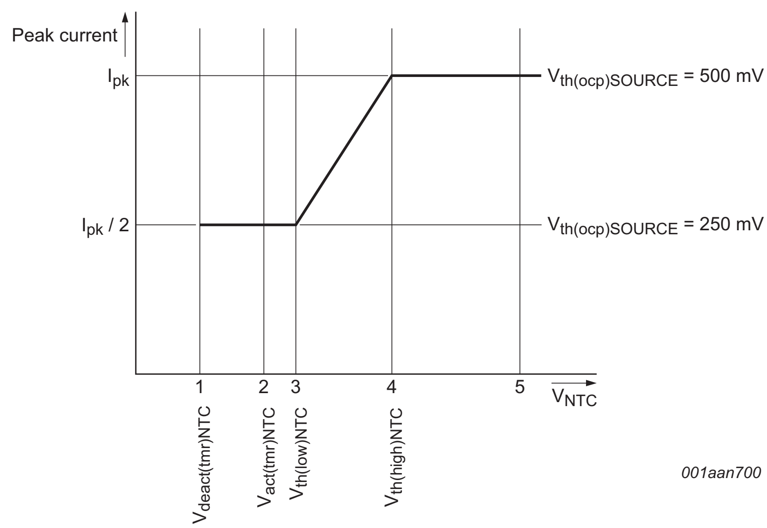


Fig 6. NTC control curve

When the voltage on the NTC pin exceeds $V_{th(high)NTC}$ (see Figure 6 (4)), the converter delivers nominal output current. When the voltage is lower than this level, the peak current is gradually reduced until $V_{th(low)NTC}$ is reached (see Figure 6 (3)). The peak current is now half the peak current of nominal operation. When $V_{act(tmr)NTC}$ is passed (see Figure 6 (2)) a timer starts to run to distinguish between the following situations:

- If the low-level $V_{deact(tmr)NTC}$ is not reached within time $t_{to(deact)NTC}$ (see Figure 6 (1)) LED overtemperature is detected. The IC stops switching and attempts to restart from the HV pin voltage. The converter restarts from an NTC protection shutdown when the voltage on the NTC pin exceeds $V_{th(high)NTC}$ (see Figure 6 (4)). It is assumed that the reduction in peak current does not result in a lower NTC temperature and LED OTP is activated.
- If the low-level $V_{deact(tmr)NTC}$ is reached within the time $t_{to(deact)NTC}$ (see Figure 6 (1)) it is assumed that the pin is pulled down externally. The restart function is not triggered. Instead, the output current is reduced to zero. PWM dimming can be implemented this way. The output current rises again when the voltage is higher than $V_{th(low)NTC}$.

8.9.1 Soft-start function

The NTC pin can be used to make a soft start function. During switch-on, the level on the NTC pin is low. By connecting a capacitor (in parallel with the NTC resistor), a time constant can be defined. The time constant causes the level on the NTC pin to increase slowly. When passing level $V_{th(low)NTC}$ (see Figure 6 (3)), the convertor starts with half of the maximum current. The output current slowly increases to maximum when $V_{th(high)NTC}$ (see Figure 6 (4)) is reached.

9. Limiting values

Table 4. Limiting values

In accordance with the Absolute Maximum Rating System (IEC 60134).

Symbol	Parameter	Conditions		Min	Max	Unit
General						
SR	slew rate	on pin DRAIN		–5	+5	V/ns
P_{tot}	total power dissipation	SO8 package		-	0.6	W
T_{amb}	ambient temperature			–40	+125	°C
T_j	junction temperature			–40	+150	°C
T_{stg}	storage temperature			–55	+150	°C
Voltages						
V_{CC}	supply voltage	continuous	[1]	–0.4	+20	V
V_{DRAIN}	voltage on pin DRAIN			–0.4	+600	V
V_{HV}	voltage on pin HV	current limited		–0.4	+600	V
V_{SOURCE}	voltage on pin SOURCE	current limited		–0.4	+5.2	V
V_{NTC}	voltage on pin NTC	current limited		–0.4	+5.2	V
Currents						
I_{DD}	supply current	on pin VCC	[2]	-	20	mA
V_{ESD}	electrostatic discharge voltage	human body model: pins DRAIN and HV		–1	+1	kV
		human body model; all other pins	[3]	–2	+2	kV
		charged device	[4]	–500	+500	V

[1] The current into the VCC pin must not exceed the maximum I_{DD} value.

[2] An internal clamp sets the supply voltage

[3] Human body model: equivalent to discharging a 100 pF capacitor through a 1.5 kΩ series resistor.

[4] Charged device model: equivalent to charging the IC up to 1 kV and the subsequent discharging of each pin down to 0 V over a 1 Ω resistor.

10. Thermal characteristics

Table 5. Thermal characteristics

Symbol	Parameter	Conditions	Typ	Unit
$R_{th(j-a)}$	thermal resistance from junction to ambient	in free air; PCB: 2 cm × 3 cm; 2-layer; 35 μm Cu per layer	159	K/W
		in free air; PCB: JEDEC 2s2p	89	K/W
Ψ_{j-top}	thermal characterization parameter from junction to top of package	top package temperature measured at the warmest point on top of the case	0.49	K/W

11. Characteristics

Table 6. Characteristics

Values specified at T_{amb} = 25 °C unless otherwise stated; all voltages are measured with respect to ground; currents are positive when flowing into the IC.

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
f_{conv}	conversion frequency			-	100	-	kHz
High-voltage							
$I_{leak(DRAIN)}$	leakage current on pin DRAIN	V_{DRAIN} = 600 V		-	-	10	μA
$I_{leak(HV)}$	leakage current on pin HV	V_{HV} = 600 V		-	-	30	μA
Supply							
V_{CC}	supply voltage	operating range	[1]	8	-	16	V
$V_{CC(startup)}$	start-up supply voltage			11	12	13	V
$V_{CC(stop)}$	stop supply voltage			8	9	10	V
$V_{CC(hys)}$	hysteresis of supply voltage	between $V_{CC(startup)}$ and $V_{CC(stop)}$		2	-	4.5	V
$V_{CC(rst)}$	reset supply voltage			4.5	5	5.5	V
$V_{CC(swon)reg}$	regulator switch-on supply voltage			8.75	9.25	9.75	V
$V_{CC(swoff)reg}$	regulator switch-off supply voltage			9.5	10	10.5	V
$V_{CC(reg)hys}$	regulator supply voltage hysteresis	$V_{CC(swoff)reg} - V_{CC(swon)reg}$		0.3	-	-	V
$V_{CC(regswon-stop)}$	supply voltage difference between regulator switch-on and stop	$V_{CC(swon)reg} - V_{CC(stop)}$		0.3	-	-	V
Consumption							
$I_{stb(HV)}$	standby current on pin HV	during start-up or in protection; V_{HV} = 100 V		300	350	400	μA
$I_{CC(INT)}$	internal supply current	normal operation		-	1.3	-	mA
Capability							
$I_{sup(high)HV}$	high supply current on pin HV	standby: V_{HV} = 40 V; $V_{CC} < V_{CC(stop)}$		1	1.3	1.6	mA
		regulator on: V_{HV} = 40 V; $V_{CC} < V_{CC(swon)reg}$ after start-up		2	2.3	2.6	mA
Current							
$V_{th(ocp)SOURCE}$	overcurrent protection threshold voltage on pin SOURCE	$\Delta V/\Delta t$ = 0.1 V/μs		480	500	520	mV
		$\Delta V/\Delta t$ = 0.1 V/μs; V_{NTC} = 0.325 V		230	250	270	mV
$t_{d(ocp-swoff)}$	delay time from overcurrent protection to switch-off	$\Delta V/\Delta t$ = 0.1 V/μs		-	75	100	ns
t_{leb}	leading edge blanking time	overcurrent protection		260	300	340	ns
Valley detection							
$(\Delta V/\Delta t)_{vrec}$	valley recognition voltage change with time	on pin DRAIN		−30	−20	−10	V/μs
f_{ring}	ringing frequency		[2]	200	550	1000	kHz
$\Delta V_{vrec(min)}$	minimum valley recognition voltage difference	voltage drop on pin DRAIN		15	20	25	V
$t_{d(vrec-swon)}$	valley recognition to switch-on delay time			-	100	-	ns

Table 6. Characteristics *...continued*

Values specified at T_{amb} = 25 °C unless otherwise stated; all voltages are measured with respect to ground; currents are positive when flowing into the IC.

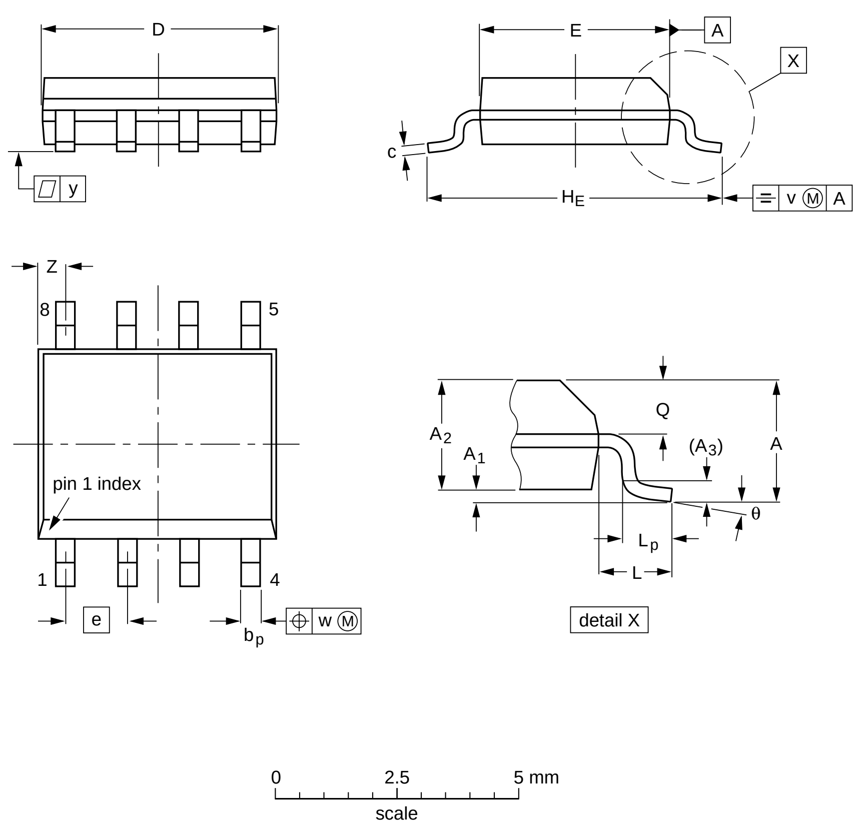
Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Brownout detection						
$V_{th(TONMOD)}$	threshold voltage on pin TONMOD		3.75	4	4.25	V
$I_{offset(TONMOD)}$	offset current on pin TONMOD		–37	–43	–48	µA
$t_{on(high)}$	high on-time		12.5	15	17.5	µs
Driver (pin DRIVER)						
$I_{source(DRIVER)}$	source current on pin DRIVER	1.5 ms maximum; V_{DRIVER} = 2 V	-	–0.195	-	A
$I_{sink(DRIVER)}$	sink current on pin DRIVER	20 µs maximum; V_{DRIVER} = 2 V	-	0.28	-	A
		20 µs maximum; V_{DRIVER} = 10 V	-	0.46	-	A
$V_{o(DRIVER)max}$	maximum output voltage on pin DRIVER	$V_{CC} > V_{CC(startup)}$	9	10.5	12	V
$V_{o(DRIVER)min}$	minimum output voltage on pin DRIVER	$V_{CC} = V_{CC(stop)}$	6.5	7.5	8.5	V
NTC functionality						
$V_{th(high)NTC}$	high threshold voltage on pin NTC		0.47	0.5	0.53	V
$V_{th(low)NTC}$	low threshold voltage on pin NTC		0.325	0.35	0.375	V
$V_{act(tmr)NTC}$	timer activation voltage on pin NTC		0.26	0.3	0.325	V
$V_{deact(tmr)NTC}$	timer deactivation voltage on pin NTC		0.17	0.2	0.23	V
$t_{to(deact)NTC}$	deactivation time-out time on pin NTC		33	46	59	µs
$I_{offset(NTC)}$	offset current on pin NTC		-	–47	-	µA
Temperature protection						
$T_{th(act)otp}$	overtemperature protection activation threshold temperature		160	170	180	°C
$T_{th(rel)otp}$	overtemperature protection release threshold temperature		90	100	110	°C

[1] An internal clamp sets the supply voltage. The current into the VCC pin must not exceed the maximum I_{DD} value (see Table 4).

[2] This parameter is not tested during production, by design it is guaranteed

12. Package outline

SO8: plastic small outline package; 8 leads; body width 3.9 mm **SOT96-1**



DIMENSIONS (inch dimensions are derived from the original mm dimensions)

UNIT	A max.	A_1	A_2	A_3	b_p	c	D(1)	E(2)	e	H_E	L	L_p	Q	v	w	y	Z(1)	θ
mm	1.75	0.25 0.10	1.45 1.25	0.25	0.49 0.36	0.25 0.19	5.0 4.8	4.0 3.8	1.27	6.2 5.8	1.05	1.0 0.4	0.7 0.6	0.25	0.25	0.1	0.7 0.3	8^{o} 0^{o}
inches	0.069	0.010 0.004	0.057 0.049	0.01	0.019 0.014	0.0100 0.0075	0.20 0.19	0.16 0.15	0.05	0.244 0.228	0.041	0.039 0.016	0.028 0.024	0.01	0.01	0.004	0.028 0.012	

Notes

1. Plastic or metal protrusions of 0.15 mm (0.006 inch) maximum per side are not included.
2. Plastic or metal protrusions of 0.25 mm (0.01 inch) maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT96-1	076E03	MS-012				~~99-12-27~~ 03-02-18

Fig 7. Package outline SOT96-1 (SOT8)