

1. General description

The SSL2109AT 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 (application dependent)
- Ease of integration and many protection features
- Low electronic Bill Of Material (BOM)
- Highly flexible IC for use in buck, buck/boost and flyback modes
- Single inductor used for non-isolated configurations because of internal demagnetization detection and dV/dt supply

The IC is supplementary to the SSL21081/SSL21083 series but without an internal switch. The IC has been designed to start up directly from the HV supply by an internal high-voltage current source. Thereafter, the dV/dt supply is used with capacitive coupling from the drain, or any other auxiliary supply. This functionality provides full flexibility in the application design. An internal clamp limits the supply voltage.

The IC provides accurate output current control to within 5 % LED current accuracy. The IC can be operated using Pulse-Width Modulation (PWM) current regulation and has many protection features including easy LED temperature feedback.

2. Features and benefits

- LED driver IC for driving strings of LEDs or high-voltage LED modules from a rectified mains supply
- Part of a high-efficiency switch mode flyback or buck product family.
 - ◆ Driver-only which can drive an external MOSFET
- Driver that has 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
- Suitable for high power factor (>0.9) applications
- Applicable in buck, buck/boost and flyback topologies

- Direct PWM current regulation possible
- Fast transient response through cycle-by-cycle current control:
 - ◆ Negligible AC mains ripple in LED current and minimal total capacitance in low ripple configurations
 - ◆ 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)
- Low component count LED driver solution (see [Figure 3](#)):
 - ◆ Easy external temperature protection with a single NTC
 - ◆ Option for soft-start function
 - ◆ Compatible with wall switches with built-in indication light during standby
- IC lifetime easily matches or surpasses LED lamp lifetime

3. Applications

The SSL2109AT is intended for compact LED lamps with accurate fixed current output for single mains input voltages. Mains input voltages include 100 V, 120 V and 230 V (AC). The output signal can be modulated using a PWM signal. 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 [1]	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 IDD value (see [Table 4](#))

5. Ordering information

Table 2. Ordering information

Type number	Package		
	Name	Description	Version
SSL2109AT	SO8	plastic small package outline body; 8 leads; body width 3.9 mm	SOT96-1

6. Block diagram

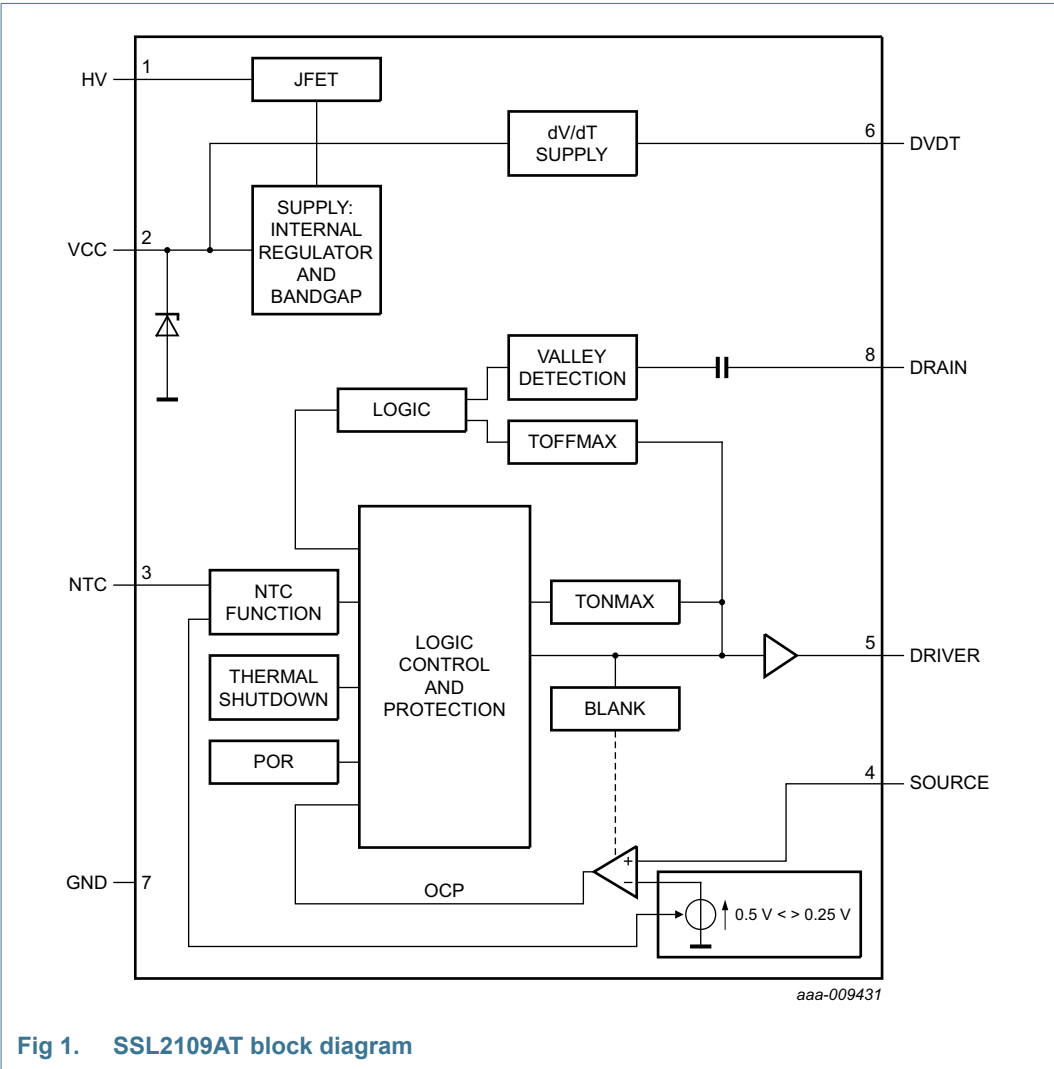
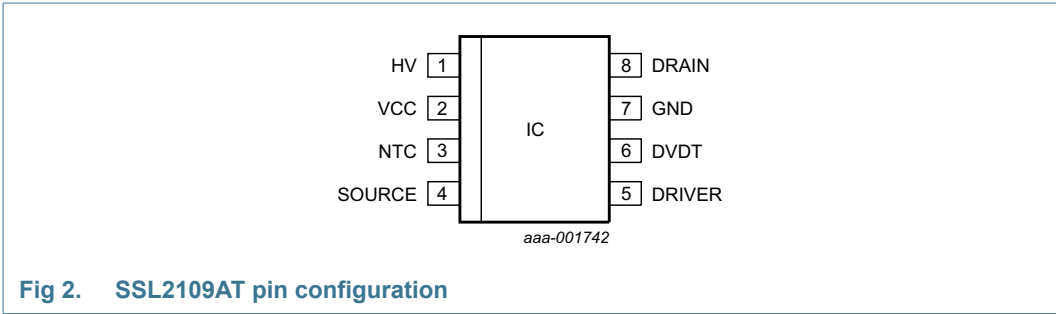


Fig 1. SSL2109AT block diagram

7. Pinning information

7.1 Pinning



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
DVDT	6	AC supply pin
GND	7	ground
DRAIN	8	high-side external switch

8. Functional description

8.1 Introduction

The SSL2109AT is a driver for small form factor retrofit SSL lamps and separate LED drivers.

8.2 Converter operation

The converter in the SSL2109AT is a Boundary Conduction Mode (BCM), peak current controlled system. [Figure 3](#) shows the basic application diagram. [Figure 4](#) shows 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 (SSL2109AT controlled) and on the HV bus voltage 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.

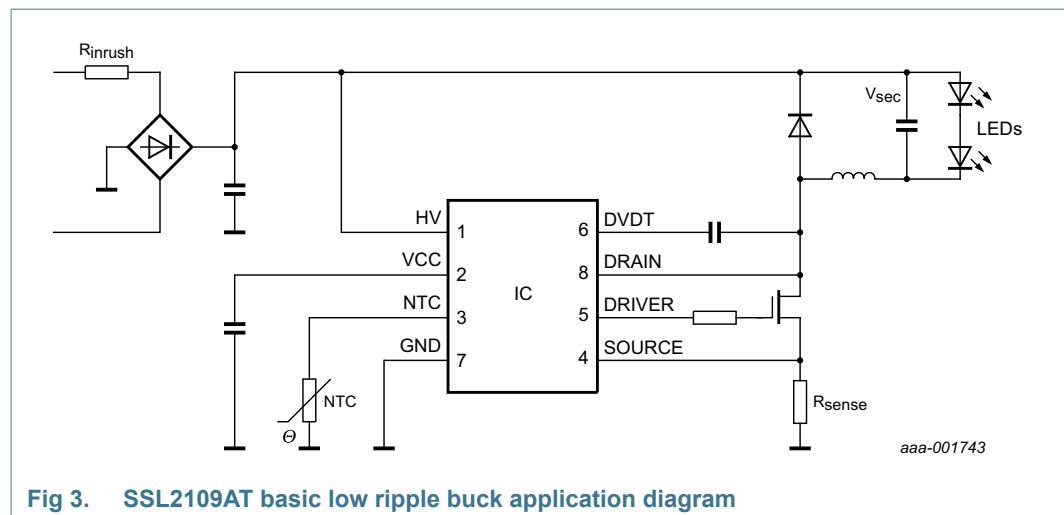


Fig 3. SSL2109AT basic low ripple buck application diagram

8.3 Driver pin

The SSL2109AT is equipped with an internal driver that can control 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.

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 $V_{IN} - V_{OUT}$ level. The peak-to-peak amplitude equals $2 \times V_{OUT}$.

A special feature, called valley detection is an integrated part of the SSL2109AT 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} . As a result the capacitive switching losses are reduced.

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, a valley is detected and accepted. 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.

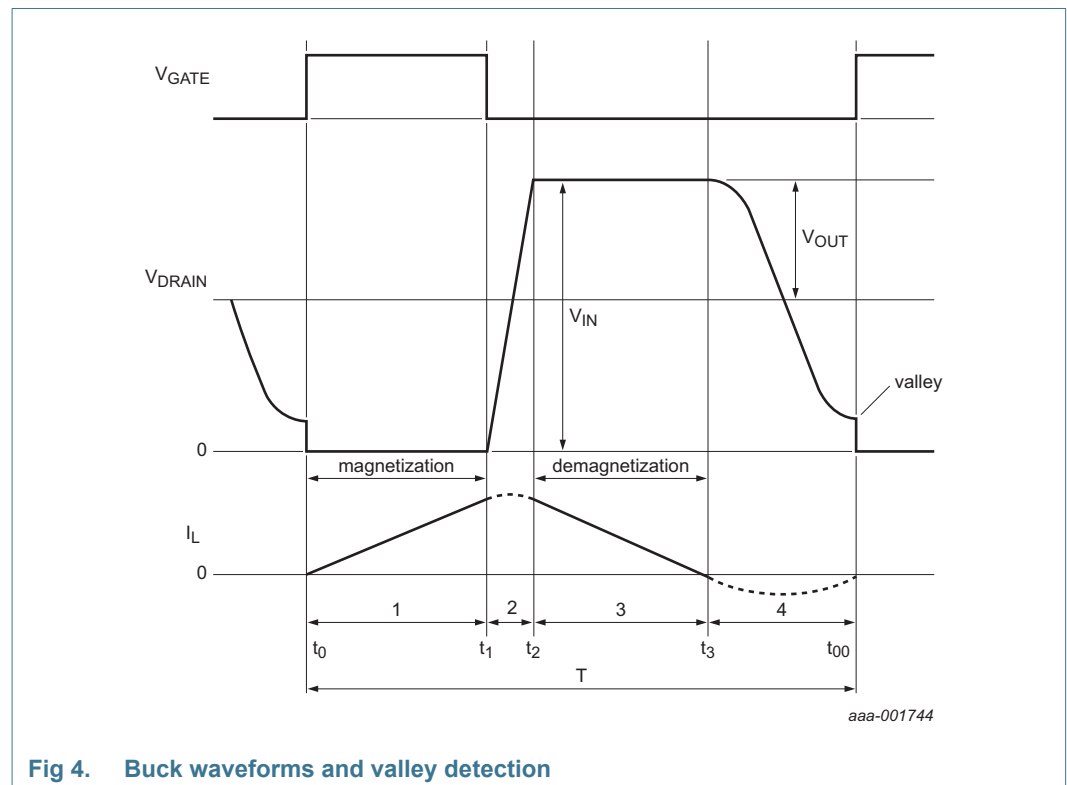


Fig 4. Buck waveforms and valley detection

8.5 Protective features

The IC has the following protections:

- 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

The OSP is a latched protection. This protection causes the IC to halt until a reset (a result of power cycling) is executed. When V_{CC} drops to below $V_{CC(rst)}$, the IC resets the latch protection mode. The internal OTP and LED over temperature protections are safe-restart protections. If V_{CC} drops to below $V_{CC(stop)}$, the IC halts. Switching starts only when a no fault condition exists.

8.5.1 UnderVoltage LockOut (UVLO)

When the voltage on the VCC pin drops lower than $V_{CC(stop)}$, the IC stops switching. An attempt is 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 SSL2109AT contains a highly accurate peak current detector. It triggers when the voltage at 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 using 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 restart with switching resuming when the IC temperature drops lower than $T_{th(rel)otp}$.

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. For the SSL2109AT, there is a maximum limit on the on-time of switch $t_{on(high)}$.

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 $t_{on(high)}$. As a result the average output current to the LEDs is reduced.

8.5.6 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).

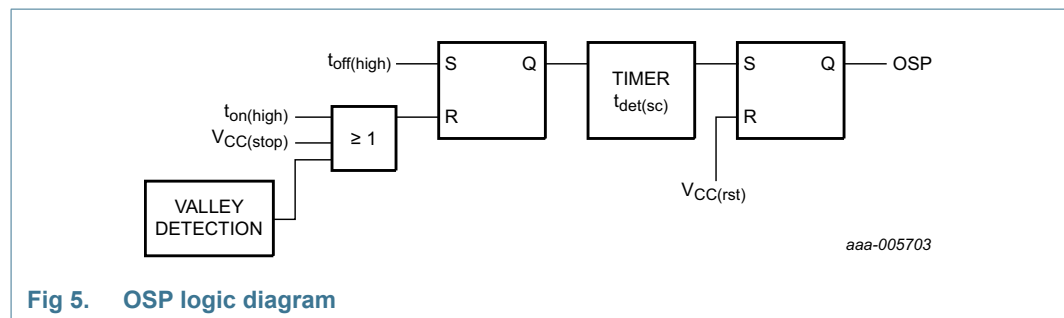


Fig 5. OSP logic diagram

8.6 VCC supply

The SSL2109AT can be supplied using three methods:

- Under normal operation, the voltage swing on the DVDT pin is rectified within the IC 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 either the dV/dt supply or an external current on the VCC pin provides the supply
- Using an auxiliary winding, the voltage is rectified and connected to the VCC pin via a series resistor.

The IC starts up before the voltage at the VCC pin exceeds $V_{CC(startup)}$. The IC locks out (stops switching) when the voltage at the VCC pin is $< V_{CC(stop)}$. The hysteresis between the start and stop levels allows the IC to be supplied by a buffer capacitor until the dV/dt supply is settled. The SSL2109AT 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 dV/dt supply minus the current consumption of the IC (determined by the load on the gate drivers) is lower than the I_{DD} maximum value, no external Zener diode is required in the supply circuit.

8.7 DVDT pin supply

The DVDT pin is connected to an internal single-sided rectification stage. When a different voltage with sufficient amplitude is supplied to the pin, the IC can be powered without any other external power connection. This provides an effective method to prevent additional high power losses, which are the result if a regulator were used for continuously powering the IC. Unlike an auxiliary supply, additional inductor windings are not required.

8.8 VCC regulator

During supply dips, the input voltage can drop so much that it can no longer supply the required IC current through the DVDT pin. Under these conditions, if the VCC voltage drops lower than $V_{CC(swon)reg}$ level, another regulator with a current capability of up to $I_{HVhigh(oper)}$ is started. The job of the regulator is to fill in the required supply current, which the dV/dt supply does not deliver, thus preventing that the IC enters UVLO. When the VCC voltage is higher than the $V_{CC(swon)reg}$ level, the regulator is turned off.

8.9 NTC functionality and PWM regulation

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 regulation). 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 connected directly 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 $V_{CC(startup)}$.

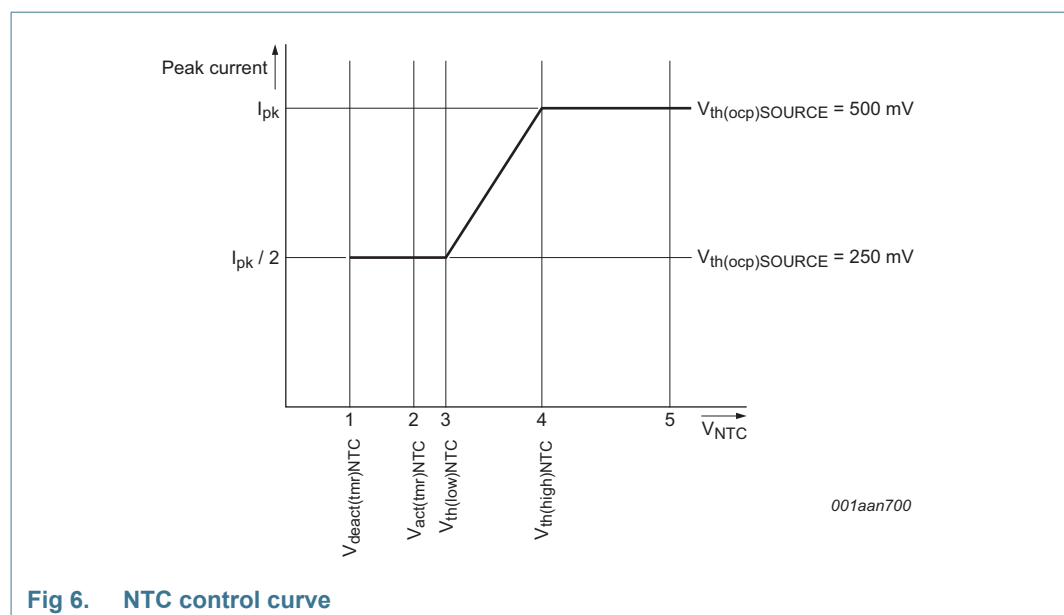


Fig 6. NTC control curve

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 regulation and consequently LED output current regulation can be implemented this way. The output current rises again when the voltage exceeds $V_{th(low)NTC}$.

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 converter 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	at pin VCC	[2] -	20	mA
I _{DVDT}	current on pin DVDT	duration 20 μs maximum	-	1.3	A
V _{ESD}	electrostatic discharge voltage	human body model; pins DRAIN and HV	[3] −1	+1	kV
		human body model; all other pins	−2	+2	kV
		charged device	[4] −500	+500	V

[1] The current flowing 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 $T_{amb} = 25\text{ }^{\circ}\text{C}$ unless otherwise specified; 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	insufficient dV/dt supply	8.75	9.25	9.75	V
V _{CC(swoff)reg}	regulator switch-off supply voltage	insufficient dV/dt supply	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 protection						
V _{th(ocp)SOURCE}	overcurrent protection threshold voltage on pin SOURCE	ΔV/Δt = 0.1 V/μs	480	500	520	mV
		ΔV/Δt = 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	ΔV/Δt = 0.1 V/μs	-	75	100	ns
t _{leb}	leading edge blanking time	overcurrent protection	260	300	340	ns

Table 6. Characteristics ...continued

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

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
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
Brownout detection						
$t_{on(high)}$	high on-time		12.5	15	17.5	μs
Driver (pin DRIVER)						
$I_{source(DRIVER)}$	source current on pin DRIVER	1.5 ms maximum; $V_{DRIVER} = 2\text{ V}$	-	-0.195	-	A
$I_{sink(DRIVER)}$	sink current on pin DRIVER	20 μs maximum; $V_{DRIVER} = 2\text{ V}$	-	0.28	-	A
		20 μs maximum; $V_{DRIVER} = 10\text{ V}$	-	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
OSP						
$t_{det(sc)}$	short-circuit detection time		16	20	24	ms
$t_{off(high)}$	high off-time		30	36	42	μs
Temperature protection						
$T_{th(act)otp}$	overtemperature protection activation threshold temperature		160	170	180	$^{\circ}\text{C}$
$T_{th(rel)otp}$	overtemperature protection release threshold temperature		90	100	110	$^{\circ}\text{C}$

[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. Application information

An LED driver with the SSL2109AT can be a buck, tapped buck or flyback converter operating in BCM. [Figure 7](#) shows a buck solution in a low ripple configuration using a minimum of components.

Capacitor C3 buffers the IC supply voltage, which is powered via the HV pin at start-up and via C5 during normal operation. Sense resistors R4 and R5 convert the current through MOSFET Q1 into a voltage on the SOURCE pin. The value of these resistors determines the maximum primary peak current on MOSFET Q1, and thus the LED current. Resistor R6 reduces the reverse current into the DRIVER pin. The DRAIN pin is connected with the drain of Q1 for valley detection.

In the example shown in [Figure 7](#), the NTC pin is used for temperature protection. Negative Temperature Coefficient (NTC) resistor R3 sets the temperature level. Capacitor C4 reduces noise on the NTC pin. See the SSL2109AT *application note* for more information.

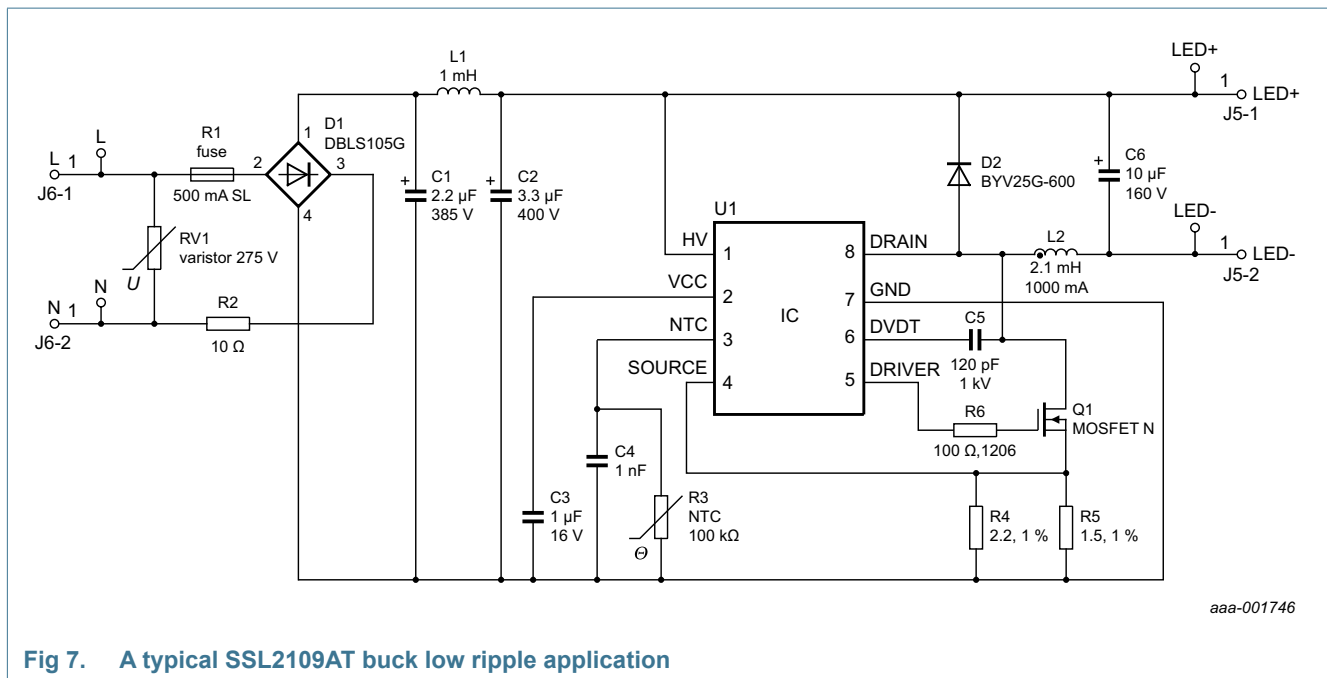


Fig 7. A typical SSL2109AT buck low ripple application

13. Package outline

SO8: plastic small outline package; 8 leads; body width 3.9 mm

SOT96-1

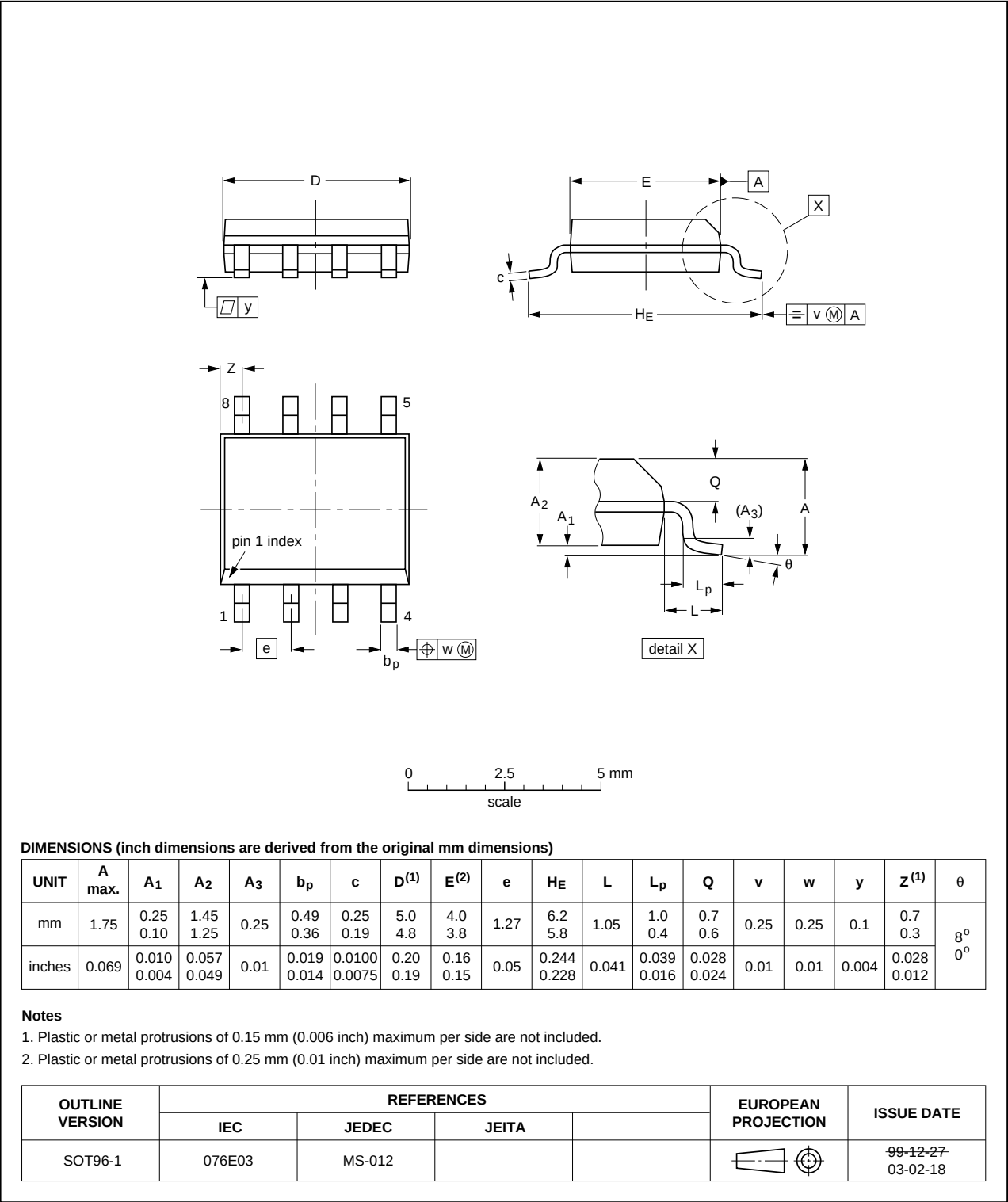


Fig 8. Package outline SOT96-1 (SOT8)