

1. General description

The SSL5031TS is a highly integrated, high-precision, non-isolated MOSFET buck-boost controller. It is intended to drive LED lamps in universal mains non-dimmable lighting applications up to 25 W.

The SSL5031TS operates in Boundary Conduction Mode (BCM) with on-time regulation. Operating in BCM provides a constant output current control with high accuracy. Adaptive switching frequency gives freedom to choose the inductor, which enables the optimization of inductor size, efficiency and EMI.

The SSL5031TS starts up directly from an external resistor without dV/dt supply or auxiliary supply. It operates in switching mode. This feature simplifies the V_{CC} supply. It allows a low-cost off-the-shelf inductor to be used, providing flexibility in application design.

The SSL5031TS comes in a compact TSOP6 package.

The SSL5021BTS is suitable for low-ripple buck applications. The SSL5031BTS is suitable for high power factor/Low-THD buck applications with a high-temperature foldback function. The SSL5031CTS is best for high power factor/Low-THD buck applications without high temperature foldback function.

2. Features and benefits

- Driving LED strings from a rectified mains supply
- Small electronic Bill of Materials (BOM) enabling a compact solution and a small, single layer Printed-Circuit Board (PCB) footprint
- Excellent line regulation, load regulation and LED output current accuracy
- Efficient BCM operation with:
 - ◆ Minimum reverse recovery losses in freewheel diode
 - ◆ Zero Current Switching (ZCS) and valley switching for switch turn-on
 - ◆ Minimal inductance value and size required
 - ◆ High efficiency (up to 88 %)
 - ◆ Ultra low IC current during operation ($< 150 \mu A$)
 - ◆ Auto-recovery protections
 - ◆ UnderVoltage LockOut (UVLO)
 - ◆ Cycle-by-cycle OverCurrent Protection (OCP)
 - ◆ Internal OverTemperature Protection (OTP)
 - ◆ Output OverVoltage Protection (OVP)

- ◆ Output Short Protection (OSP)
- ◆ Thermal foldback protection via a single PTC or NTC resistor
- Compatible with wall switches with built-in standby indicator lights (Hotaru switch)
- Extended IC lifetime

3. Applications

- The SSL5031TS is intended for low-cost, non-isolated LED lighting applications with accurate fixed current output up to 25 W for single mains or universal mains voltages (90 V (AC) to 277 V (AC)).

4. Quick reference data

Table 1. Quick reference data

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{CC}	supply voltage	operating range [1]	9.5	-	16	V
R_{DSon}	drain-source on-state resistance	of internal switch				
		$T_j = 25\text{ }^{\circ}\text{C}$	-	0.75	0.90	Ω
		$T_j = 125\text{ }^{\circ}\text{C}$	-	1.20	-	Ω
$I_{I(SW)}$	input current on pin SW	triangle wave; duty cycle < 20 %	-2	-	+2	A
$V_{I(SW)}$	input voltage on pin SW	current limited at 8.8 mA; internal switch off [1]	-4	-	+22	V

[1] An internal clamp sets the supply voltage and current limits.

5. Ordering information

Table 2. Ordering information

Type number	Package		
	Name	Description	Version
SSL5031TS	TSOP6	plastic surface-mounted package; 6 leads	SOT457

6. Block diagram

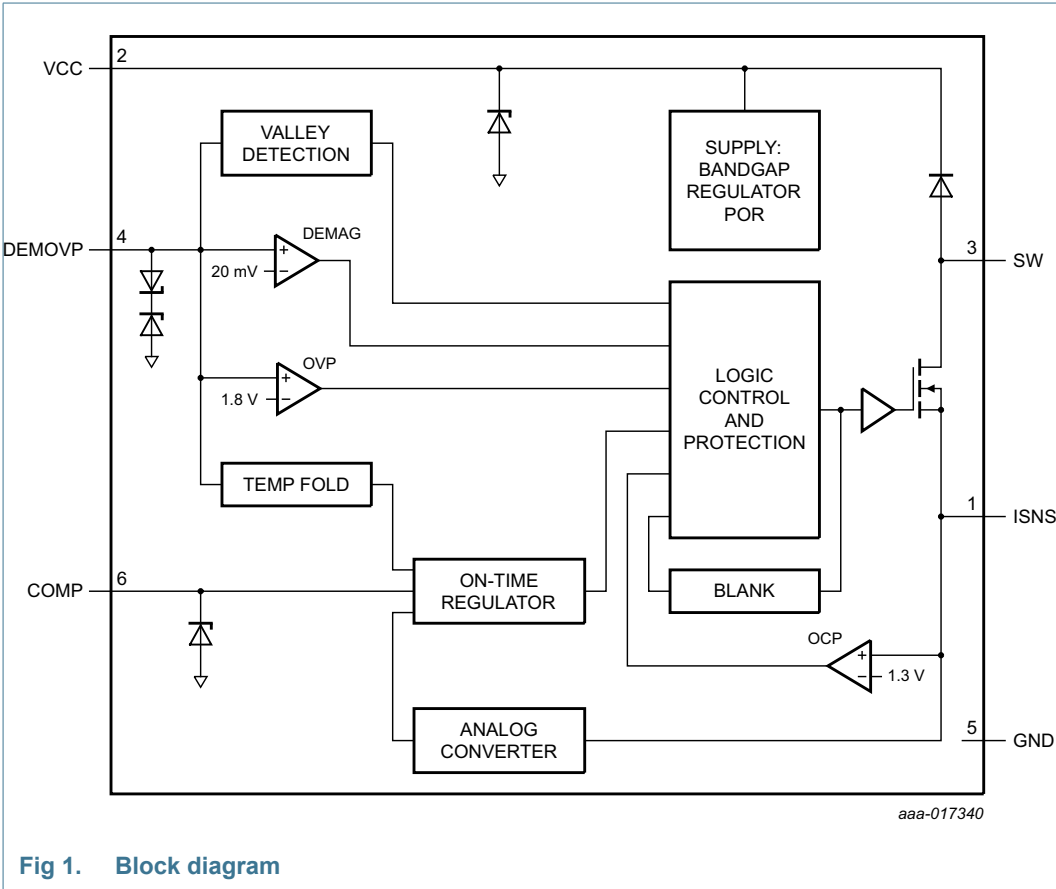


Fig 1. Block diagram

7. Pinning information

7.1 Pinning

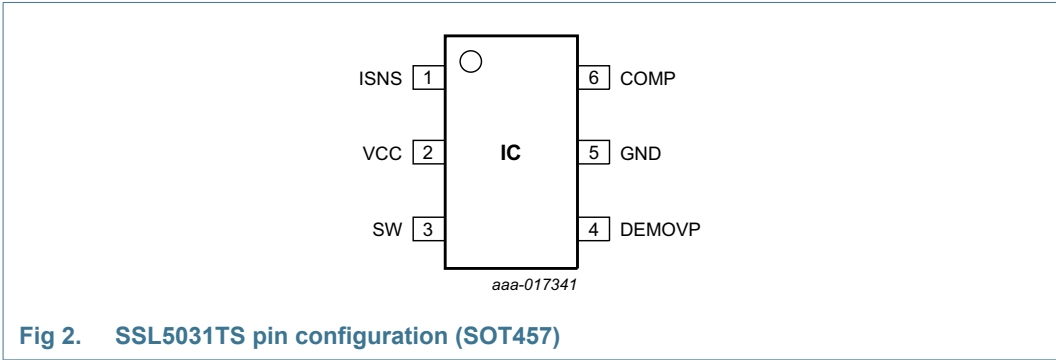


Fig 2. SSL5031TS pin configuration (SOT457)

7.2 Pin description

Table 3. Pin description

Symbol	Pin	Description
ISNS	1	current sense input
VCC	2	supply voltage
SW	3	internal switch drain
DEMOVP	4	input from LED output for demagnetization timing, valley detection, temperature foldback, and OVP
GND	5	ground
COMP	6	loop compensation to provide a stable response

8. Functional description

8.1 Converter operation

The SSL5031TS is a controller that can drive a MOSFET external switch. The switching method is source switching. It is Boundary Conduction Mode (BCM), on-time controlled system. [Figure 3](#) shows the basic application diagram for MOSFET external switch.

The integrated low-voltage switch reduces supply current $I_{CC(oper)}$ because the gate driver current is less compared to an external high-voltage switch. The reduced supply current allows the IC to be supplied by an external resistor only, even in switching mode. This converter operates at the boundary between Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). [Figure 4](#) shows the waveforms.

When the internal switch is switched on at t_0 , the inductor current I_L builds up from zero in proportional with V_{in} during the switch on-time (t_0 to t_1). Energy is stored in the inductor.

When the internal switch switches off at t_1 , I_L drops proportionally with the value of V_{out} . The current flows through the freewheeling diode and the output capacitor during the time period between t_2 and t_3 . When I_L reaches zero, after a short delay (t_3 to t_0), a new switching cycle starts.

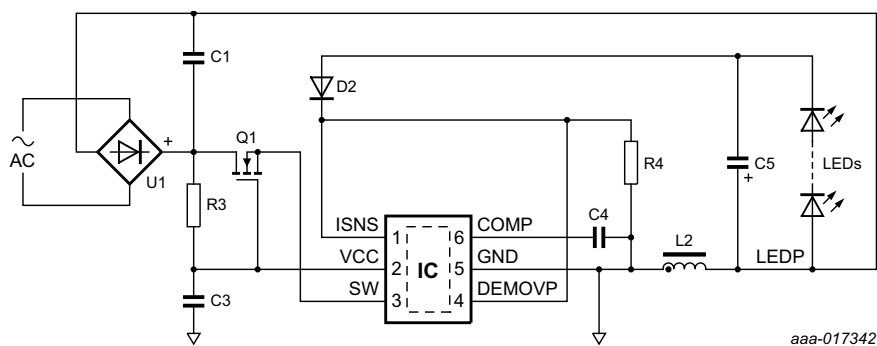


Fig 3. SSL5031TS basic application diagram for MOSFET external switch

8.2 On-time control

When measuring the inductor current I_L using sense resistor R4, the on-time is regulated so that the average regulated voltage on pin ISNS ($V_{intregd(AV)ISNS}$) equals an internal reference voltage. I_L can be calculated with [Equation 1](#):

$$I_L = \frac{V_{intregd(AV)ISNS}}{R4} \quad (1)$$

8.3 Valley detection

After I_L has decreased to zero at t_3 , the LEDP voltage starts to oscillate around the bus voltage (V_{in}) minus output voltage level (V_{out}), with amplitude output voltage (V_{OUT}) and frequency (f_{ring}). Valley detection is a special circuit that is integrated in the SSL5031TS. It senses when the LEDP voltage reaches its lowest level (valley) through the DEMOVP pin connection. If a valley is detected, the internal switch is switched on again. As a result, the switch-on switching losses are reduced.

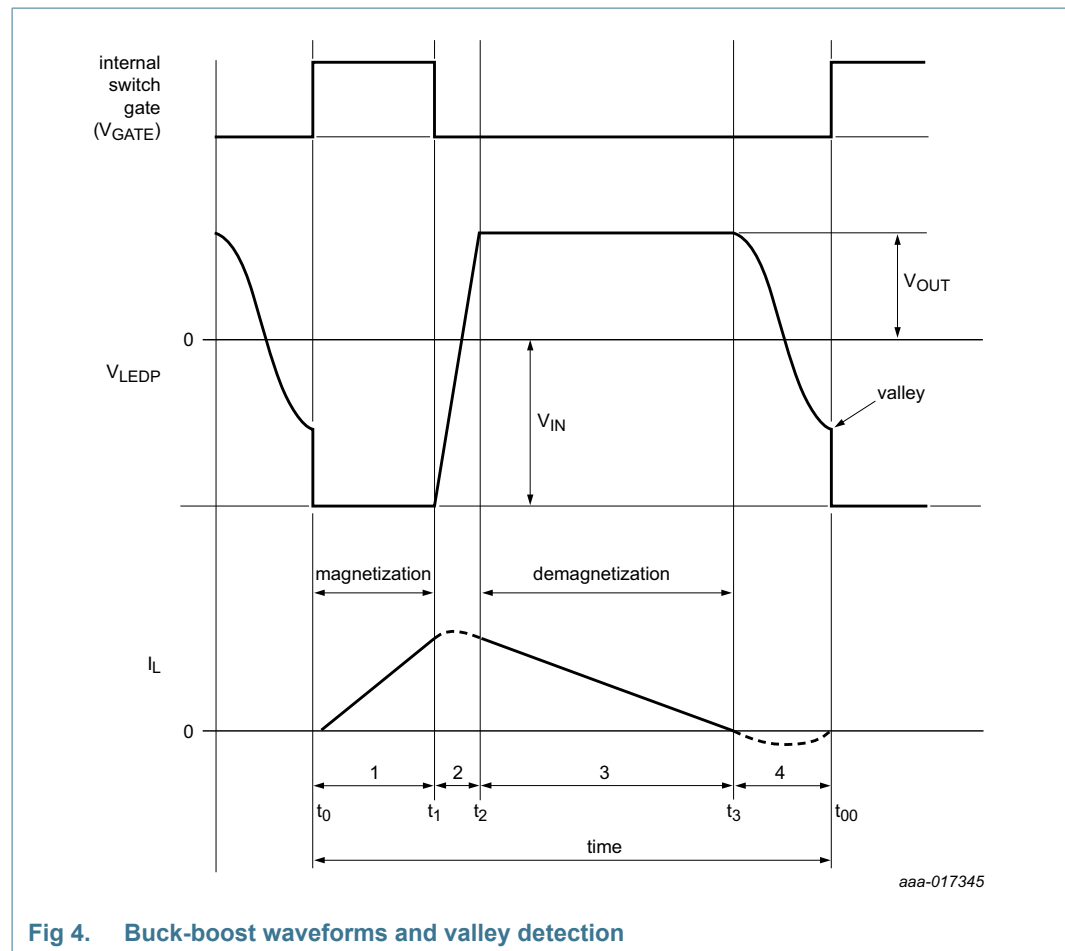


Fig 4. Buck-boost waveforms and valley detection

8.4 Start-up current

Resistor R3 supplied the supply current for the IC. The IC draws an additional start-up current ($I_{CC(startup)}$) just before V_{CC} reaches the start-up voltage level ($V_{startup}$). So the supply current in operating mode is lower than during start-up conditions, preventing lamp flicker when the mains voltage is increased or decreased slowly. Figure 5 shows the basic behavior.

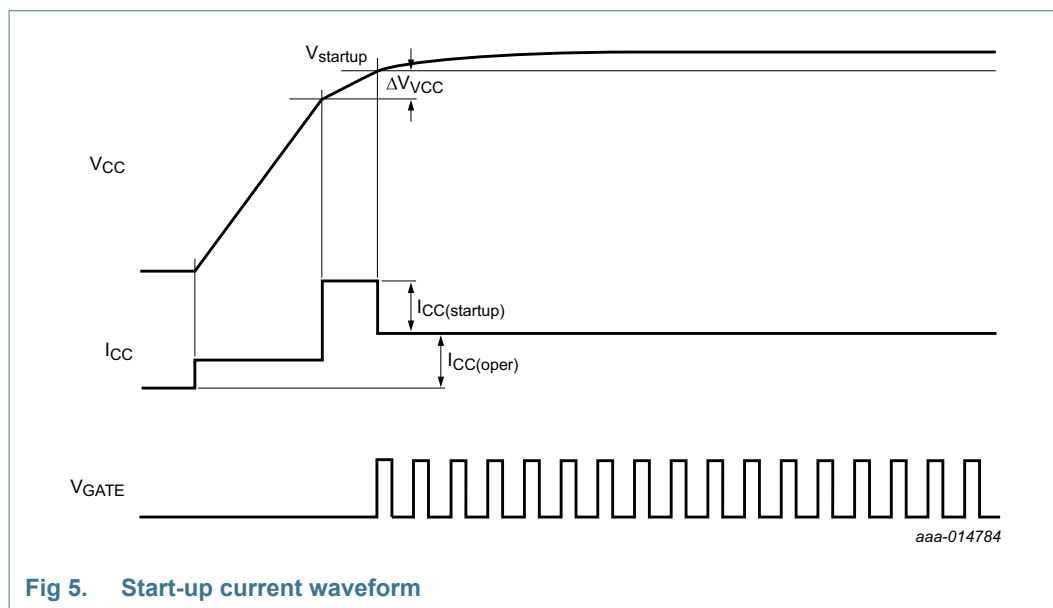


Fig 5. Start-up current waveform

8.5 Leading-Edge Blanking (LEB)

To prevent false detection of overcurrent, a blanking time (t_{leb}) following switch-on is implemented. When the internal switch turns on, a short current spike can occur because of the discharge capacitance of the MOSFET (Q1) drain/collector node.

8.6 Magnetization switching

When the mains voltage is very low, around the zero crossings of the mains, the system hardly delivers any energy to the LED. To improve the efficiency, maximum off-time ($t_{off(max)}$) switching limits the switching frequency to < 25 kHz. A peak voltage on the ISNS pin below the $V_{I(min)ISNS}$ voltage indicates a low mains voltage.

8.7 Protections

The SSL5031TS incorporates the following protections:

- UnderVoltage LockOut (UVLO)
- Cycle-by-cycle OverCurrent Protection (OCP)
- Internal OverTemperature Protection (OTP)
- Cycle-by-cycle maximum on-time protection
- Output OverVoltage Protection (OVP)
- Output Short Protection (OSP)

8.7.1 UnderVoltage LockOut (UVLO)

When voltage on VCC pin drops to below $V_{th(UVLO)}$, the IC stops switching. An attempt is made to restart IC when the voltage on the VCC pin $> V_{startup}$.

8.7.2 Cycle-by-cycle OverCurrent Protection (OCP)

The SSL5031TS incorporates a built-in peak current detector. It triggers when the voltage at the ISNS pin reaches the peak level $V_{I(max)ISNS}$. A resistor connected to ISNS pin senses the current through inductor I_L . maximum current in inductor ($I_{L(max)}$) can be calculated with [Equation 2](#):

$$I_L = \frac{V_{I(max)ISNS}}{R4 + 0.09} \quad (2)$$

Where:

- 0.09 is the ISNS bond wire resistance

The sense circuit is activated after the leading-edge blanking time (t_{leb}). The maximum LED current ($I_{LED(max)}$) can be calculated with [Equation 3](#):

$$I_{LED(max)} = \frac{I}{2} \times I_{L(max)} = \frac{I}{2} \times \frac{V_{I(max)ISNS}}{R4 + 0.09} \quad (3)$$

During operation, the sense circuit automatically provides protection for the maximum LED current.

A propagation delay (t_d) exists between the overcurrent detection and the actual switch switch-off. Due to this delay, the actual peak current is slightly higher than the OCP level set by the resistor connected in series with the ISNS pin.

8.7.3 Internal OverTemperature Protection (OTP)

The converter stops switching when the internal OTP function is triggered at the IC junction temperature $T_{pl(IC)}$. The safe-restart protection is triggered and the IC resumes switching when the IC temperature drops to below $T_{rst(IC)}$.

8.7.4 Cycle-by-cycle maximum on-time protection

Measuring the inductor current I_L using sense resistor R4 regulates the on-time. The on-time is limited to a fixed value ($t_{on(max)}$). It protects the system and the IC when the ISNS pin is shorted or when the system works at very low mains voltage.

8.7.5 Output OverVoltage Protection (OVP)

An accurate output OVP is implemented by measuring the voltage at the DEMOVP pin during the secondary stroke. The resistive divider connected between the LEDP node and the DEMOVP pin sets the maximum LED voltage.

An internal counter prevents false OVP detection because of noise on the DEMOVP pin. After three continuous cycles with a DEMOVP pin voltage above the OVP level, the OVP protection is triggered.

The overvoltage protection triggers a restart sequence: A discharge current ($I_{CC(dch)}$) is enabled and discharges the voltage on the VCC pin to below $V_{rst(latch)}$. When $V_{rst(latch)}$ is reached, the system restarts.

8.7.6 Output Short Protection (OSP)

The converter operates in Discontinuous Conduction Mode (DCM). A new cycle is only started after the previous cycle has ended. The end of the cycle is detected by measuring the voltage on the DEMOVP pin. When the DEMOVP pin voltage drops to below the demagnetization level ($V_{th(comp)DEMOVP}$) and a valley is detected, a new cycle starts. When output is shorted, the demagnetization is not finalized within the 40 μ s. The converter still regulates the adjusted output current and the on-time is reduced to a safe value by this feedback. The reduced on-time in combination with very long demagnetization time prevents that the converter is damaged or excessive dissipation occurs.

A blanking time ($t_{sup(xfmr_ring)}$) is implemented at the start of the secondary stroke to prevent false demagnetization detection.

8.8 Supply management

The IC starts up when the voltage on the VCC pin increases to exceed $V_{startup}$. The IC locks out (stops switching) when the voltage on the VCC pin drops to below $V_{th(UVLO)}$. The hysteresis between the start and stop levels allows the VCC capacitor to supply the IC during zero-crossings of the mains.

The SSL5031TS incorporates an internal clamping circuit to limit the voltage on the VCC pin. The clamp limits the voltage on the VCC pin to the maximum value, $V_{clamp(VCC)}$. If the maximum current of the external resistor minus the current consumption of the IC is lower than the limiting value of $I_{I(VCC)}$ in [Table 4](#), no external Zener diode is required.

8.9 PTC or NTC function and high-temperature foldback

The PTC function or NTC function can be used as a control method for LED thermal protection. The PTC resistor which is connected to DEMOVP pin senses the temperature. When the voltage on DEMOVP pin is higher than the foldback level $V_{th(fold)}$, the on-time is reduced with the increased DEMOVP pin voltage. Then the average LED current is reduced.

When the temperature keeps increasing, the $V_{th(ovp)}$ is exceeded. The converter stops switching. The IC restarts when OVP is triggered.

This feature is optional as shown in [Figure 6](#). PTC is normally shorted.

9. Limiting values

Table 4. Limiting values

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

Symbol	Parameter	Conditions	Min	Max	Unit
Voltages					
V_{CC}	supply voltage	current limited [1][2]	-0.4	+18	V
$V_{I(SW)}$	input voltage on pin SW	current limited to 8.8 mA; internal switch off [2]	-0.4	+22	V
$V_{I(ISNS)}$	input voltage on pin ISNS		-0.4	+5	V
$V_{IO(Comp)}$	input/output voltage on pin COMP		-0.4	+5.3	V
$V_{I(DEMOVP)}$	input voltage on pin DEMOVP		-6	+6	V
Currents					
$I_{I(VCC)}$	input current on pin VCC		-	8.8	mA
$I_{I(SW)}$	input current on pin SW	RMS current	-	380	mA
		triangle wave; duty cycle < 20 %	-2	+2	A
$I_{I(ISNS)}$	input current on pin ISNS	triangle wave; duty cycle < 20 %	-2	+2	A
General					
P_{tot}	total power dissipation	$T_{amb} < 75\text{ }^{\circ}\text{C}$	-	0.28	W
T_{stg}	storage temperature		-55	+150	$^{\circ}\text{C}$
T_j	junction temperature		-40	+160	$^{\circ}\text{C}$
ESD					
V_{ESD}	electrostatic discharge voltage	class 1			
		human body model [3]	-2000	+2000	V
		charged device model [4]	-500	+500	V

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

[2] An internal clamp sets the supply voltage and current limits.

[3] Equivalent to discharge a 100 pF capacitor through a 1.5 k Ω 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; JEDEC test board	259	K/W
$R_{th(j-c)}$	thermal resistance from junction to case	In free air; JEDEC test board	152	K/W

11. Characteristics

Table 6. Characteristics

$T_{amb} = 25\text{ }^{\circ}\text{C}$; $V_{CC} = 15\text{ V}$; all voltages are measured with respect to ground pin (pin 5); currents are positive when flowing into the IC; unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Supply (pin VCC)						
$V_{startup}$	start-up voltage		12.25	12.65	13.05	V
$V_{th(UVLO)}$	undervoltage lockout threshold voltage		9.6	9.9	10.2	V
ΔV_{VCC}	voltage difference on pin VCC		0.17	0.30	0.43	V
$V_{clamp(VCC)}$	clamp voltage on pin VCC	$I_{I(VCC)} = 2.6\text{ mA}$ [1]	15.2	15.8	16.4	V
$V_{rst(latch)}$	latched reset voltage		6.0	6.2	6.4	V
$I_{CC(oper)}$	operating supply current	switching at 100 kHz	100	125	150	μA
$I_{CC(startup)}$	start-up supply current		64	82	100	μA
$I_{CC(dch)}$	discharge supply current	$V_{CC} = V_{rst(latch)}$	3.7	4.8	5.5	mA
On-time regulation (pin COMP)						
$V_{ton(zer)COMP}$	zero on-time voltage on pin COMP		1.96	2.04	2.12	V
$V_{ton(max)COMP}$	maximum on-time voltage on pin COMP		3.8	4.0	4.2	V
$V_{clamp(COMP)}$	clamp voltage on pin COMP		4.3	4.7	5.1	V
$t_{on(max)}$	maximum on-time	$V_{IO(COMP)} = 4\text{ V}$	12.3	15.5	18.7	μs
$I_{O(COMP)}$	output current on pin COMP	$V_{I(ISNS)} = 0\text{ V}$	3.2	4.0	4.8	μA
Valley detection and overvoltage detection (pin DEMOVP)						
$I_{prot(DEMOVP)}$	protection current on pin DEMOVP	open current; $V_{I(DEMOVP)} = 0\text{ V}$	-250	-180	-50	nA
$V_{th(ovp)}$	overvoltage protection threshold voltage		1.74	1.81	1.88	V
$N_{cy(ovp)}$	number of overvoltage protection cycles		-	3	-	-
$V_{th(fold)}$	foldback threshold voltage		1.56	1.64	1.72	V
$g_m(DEMOVP)$	transconductance on pin DEMOVP	$V_{I(DEMOVP)}$ to $I_{O(COMP)}$	24	29	34	$\mu\text{A/V}$
$V_{th(comp)DEMOVP}$	comparator threshold voltage on pin DEMOVP		4	18	32	mV
$(dV/dt)_{vrec}$	valley recognition voltage change with time	[2]	-	-3.8	-	V/ μs
$t_{sup(xmfr_ring)}$	transformer ringing suppression time		1.2	1.5	1.8	μs
Current sensing (pin ISNS)						
$V_{I(min)ISNS}$	minimum input voltage on pin ISNS		30	50	70	mV
$V_{I(max)ISNS}$	maximum input voltage on pin ISNS		1.22	1.3	1.38	V
$t_{on(min)}$	minimum on-time	[3]	310	410	510	ns

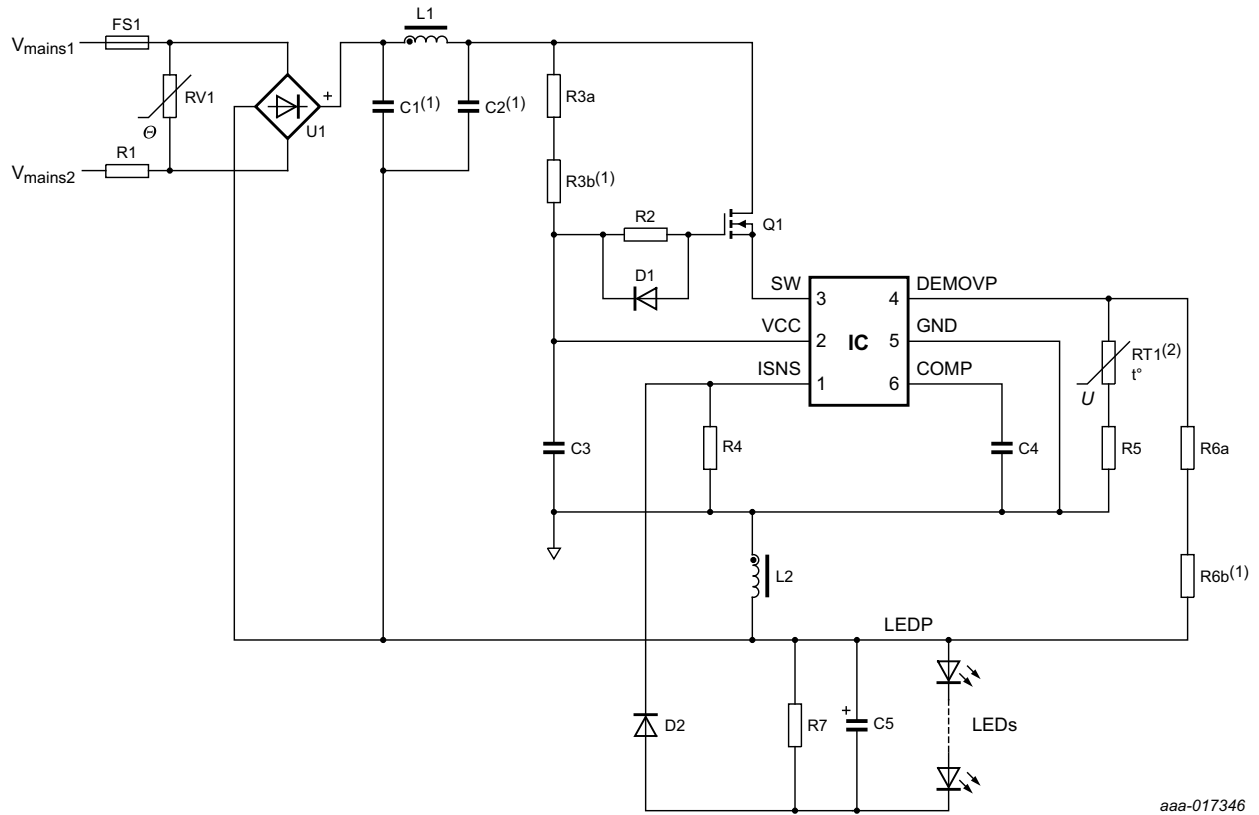
Table 6. Characteristics ...continued

$T_{amb} = 25\text{ }^{\circ}\text{C}$; $V_{CC} = 15\text{ V}$; all voltages are measured with respect to ground pin (pin 5); currents are positive when flowing into the IC; unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
t_d	delay time	[2][4]	-	100	-	ns
$g_{m(ISNS)}$	transconductance on pin ISNS	$V_{I(ISNS)}$ to $I_{O(COMP)}$	11.8	13.7	15.6	$\mu\text{A/V}$
$V_{intregd(AV)ISNS}$	average internal regulated voltage on pin ISNS		0.275	0.289	0.303	V
Driver (pin SW)						
R_{DSon}	drain-source on-state resistance	$T_j = 25\text{ }^{\circ}\text{C}$	-	0.75	0.90	Ω
		$T_j = 125\text{ }^{\circ}\text{C}$	-	1.20	-	Ω
$t_{off(max)}$	maximum off-time		30	40	50	μs
Temperature protection						
$T_{pl(IC)}$	IC protection level temperature		140	150	165	$^{\circ}\text{C}$
$T_{pl(IC)rst}$	reset IC protection level temperature		106	118	130	$^{\circ}\text{C}$

- [1] The start-up voltage and the clamp voltage are correlated.
- [2] Guaranteed by design.
- [3] The minimum on-time is only effective when overcurrent protection triggered.
- [4] $t_{leb} = t_{on(min)} - t_d$.

12. Application information



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- (1) Resistors R3b and R6b and capacitors C1 and C2 are the parts for the 230 V (AC) mains application. Short resistors R3b and R6b out; reduce the voltage rating of capacitors C1 and C2 for the 120 V (AC) mains application.
- (2) Temperature-dependent resistor RT1 is optional and can be left out. It creates thermal foldback.

Fig 6. SSL5031TS application diagram for MOSFET external switch

13. Package outline

Plastic surface-mounted package (TSOP6); 6 leads

SOT457

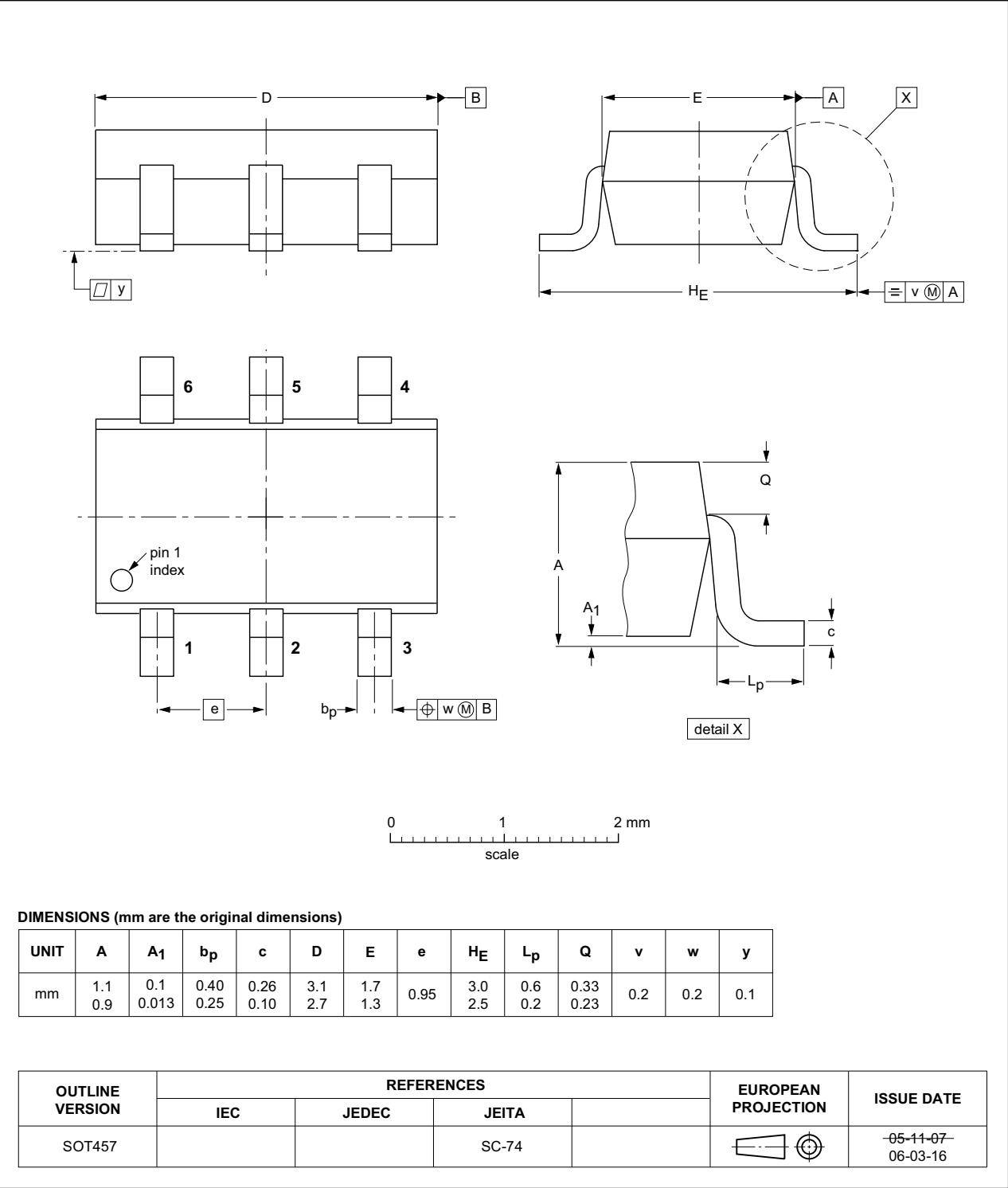


Fig 7. Package outline SOT457 (TSOP6)