TB9961
LED Driver

Description

The TB9961 is an average current mode control LED driver IC operating in a constant off-time mode. Unlike TB99,this control IC does not produce a peak-to-average error, and therefore greatly improves accuracy, line and load regulation of the LED current without any need for loop compensation or high-side current sensing. The output LED current accuracy is ±3%.

The IC is equipped with a current limit comparator for hiccup-mode output short circuit protection.

The TB9961 can be powered from an 8.0 - 450V supply. A PWM dimming input is provided that accepts an External control TTL compatible signal. The output current can be programmed by an internal 275mV reference, or controlled externally through a 0 - 1.5V dimming input.

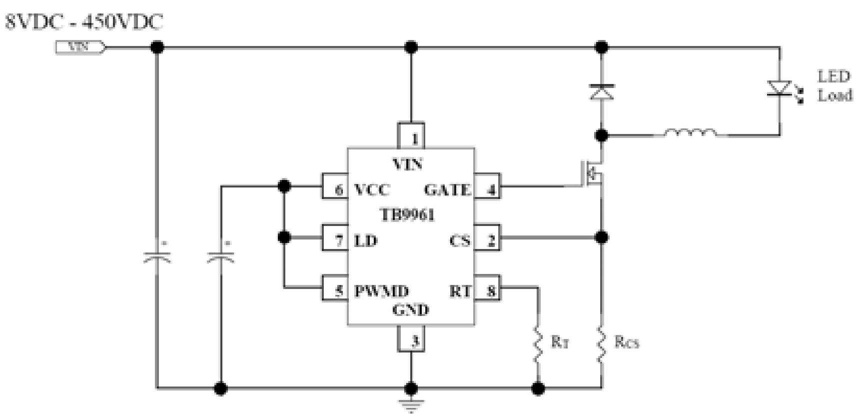
Applications

- DC/DC or AC/DC LED driver applications
- LED backlight driver for LCD displays
- General purpose constant current source
- LED signage and displays
- Architectural and decorative LED lighting
- LED street lighting

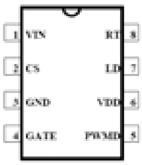
Features

- Fast average current control
- Programmable constant off-time switching
- Linear dimming input
- PWM dimming input
- Output short circuit protection with skip mode
- Ambient operating temperature -40OC to +125OC
- Pin-compatible with the TB99

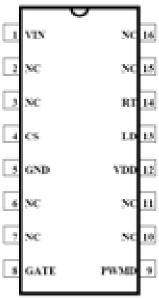
Typical Application Circuit



Pin Description



SOP-8



SOP-16

Absolute Maximum Ratings

Parameter	Value
V_{IN} to GND	-0.5V to 500V
V_{DD} to GND	12V
CS, LD, PWMD, GATE , RT to GND	-0.3V to (V_{DD} + 0.3V)
V_{DD} to GND	12V
Junction temperature range	-45°C to +150°C
Storage temperature range	-65°C to +150°C
Continuous Power Dissipation (T_A = +25°C) SOP-8 SOP-16	 650mW 1100mW

Electrical Characteristics *(Specifications are at T_A = 25 °C. V_{IN} = 12V, V_{LD} = V_{DD}, PWMD = V_{DD} unless otherwise noted)*

Sym	Description		Min	Typ	Max	Units	Conditions
Input							
V_{INDC}	Input DC supply voltage[1]	*	8.0	-	450	V	DC input voltage
I_{INSD}	Shut-down mode supply current	*	-	0.5	1.0	mA	Pin PWMD to GND

Notes:
1. Also limited by package power dissipation limit, whichever is lower.
* Denotes the specifications which apply over the full operating ambient temperature range of -40°C < T_A < +125°C.

Electrical Characteristics (Specifications are at T_A = 25°C. V_{IN} = 12V, V_{LD} = V_{DD}, PWMD = V_{DD} unless otherwise noted)

Sym	Description		Min	Typ	Max	Units	Conditions
Internal Regulator							
V_{DD}	Internally regulated voltage	-	7.25	7.5	7.75	V	V_{IN} = 8.0V, $I_{DD(ext)}$ = 0 500pF at GATE; R_T = 226KΩ
$\triangle V_{DD, line}$	Line regulation of V_{DD}	-	0	-	1.0	V	V_{IN} = 8.0V - 450V, $I_{DD(ext)}$ = 0 500pF at GATE; R_T = 226KΩ
$\triangle V_{DD, load}$	Load regulation of V_{DD}	-	0	-	100	mV	$I_{DD(ext)}$ = 0 - 1.0mA 500pF at GATE; R_T = 226KΩ
UVLO	V_{DD} undervoltage lockout threshold	*	6.45	6.70	6.95	V	V_{IN} rising
△UVLO	V_{DD} undervoltage lockout hysteresis	-	-	500	-	mV	V_{IN} falling
$I_{IN,MAX}$	Maximum input current (limited by UVLO)	#	3.5	-	-	mA	V_{IN} = 8.0V, T_A = 25℃
		#	1.5	-	-		V_{IN} = 8.0V, T_A = 25℃
PWM Dimming							
$V_{EN(lo)}$	PWMD input low voltage	*	-	-	0.8	V	V_{IN} = 8.0 – 450V
$V_{EN(hi)}$	PWMD input high voltage	*	2.2	-	-	V	V_{IN} = 8.0 – 450V
R_{EN}	Internal pull-down resistance At PWMD	-	50	100	150	KΩ	V_{PWMD} = 5.0V

Average Current Sense Logic

Sym	Description		Min	Typ	Max	Units	Conditions
V_{CS}	Current sense reference Voltage	-	268	-	286	mV	---
$A_{V(LD)}$	LD-to-CS voltage ratio	-	0.182	-	0.188	-	---
$AV_{LD(OFFSET)}$	LD-to-CS voltage offset	-	0	-	10	mV	Offset = V_{CS} - $A_{V(LD)}$*V_{LD}; V_{LD} = 1.2V
-	CS threshold temp regulation	*	-	-	5.0	mV	---
$V_{LD(OFF)}$	LD input voltage, shutdown	-	-	150	-	mV	V_{LD} falling
$\Delta V_{LD(OFF)}$	LD input voltage, enable	-	-	200	-	mV	V_{LD} rising
T_{BLANK}	Current sense blanking interval	*	150	-	320	ns	---
$T_{ON(min)}$	Minimum on-time	-	-	-	1000	ns	CS = V_{CS}+30mV
D_{MAX}	Maximum steady-state duty cycle	-	75	-	-	%	Reduction in output LED current may occur beyond this duty cyce

Short Circuit Protection

Sym	Description		Min	Typ	Max	Units	Conditions
V_{CS}	Hiccup threshold voltage	-	410	-	470	mV	---
T_{DELAY}	Current limit delay CS-to-GATE	-	-	-	150	ns	CS = V_{CS} + 30mV
T_{HICCUP}	Short circuit hiccup timp	-	350	-	550	us	---
$T_{ON(min)}$	Minimum on-time(short circuit)	-	-	-	430	ns	CS = V_{DD}

Notes:

* Denotes the specifications which apply over the full operating ambient temperature range of -40°C < T_A < +125°C.

Guaranteed by design.

Electrical Characteristics (Specifications are at T_A = 25°C. V_{IN} = 12V, V_{LD} = V_{DD}, PWMD = V_{DD} unless otherwise noted)

Sym	Description		Min	Typ	Max	Units	Conditions

T_{OFF} Timer

Sym	Description		Min	Typ	Max	Units	Conditions
T_{OFF}	Off time	-	32	40	48	us	R_T = 1.00MΩ
		-	8.0	10	12		R_T = 226KΩ

GATE Driver

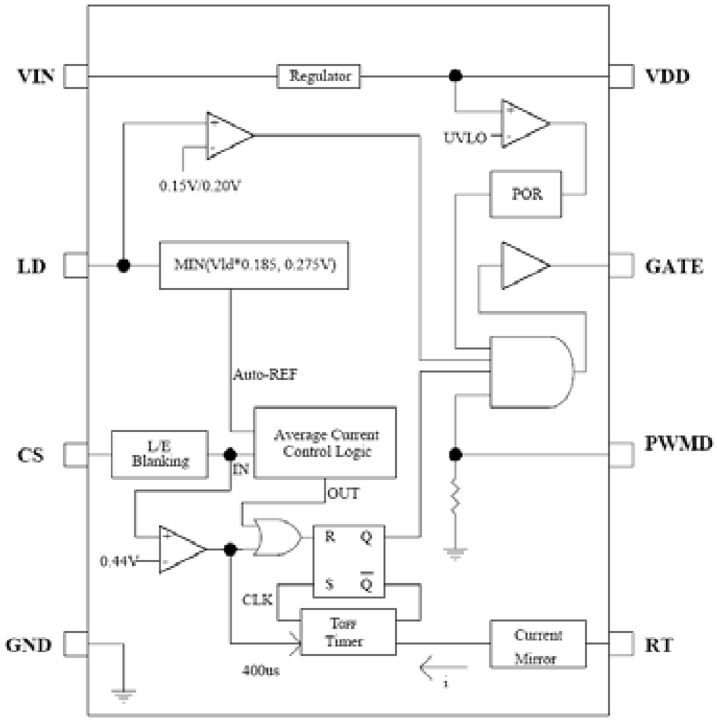
Sym	Description		Min	Typ	Max	Units	Conditions
I_{SOURCE}	GATE sourcing current	-	0.165	-	-	A	V_{GATE} = 0V, V_{DD} = 7.5V
I_{SINK}	GATE sinking current	-	0.165	-	-	A	V_{GATE} = V_{DD},V_{DD} = 7.5V
t_{RISE}	GATE output rise time	-	-	30	50	ns	C_{GATE} = 500pF,V_{DD} = 7.5V
t_{FALL}	GATE output fall time	-	-	30	50	ns	C_{GATE} = 500pF,V_{DD} = 7.5V

Notes:

* Denotes the specifications which apply over the full operating ambient temperature range of -40°C < T_A < +125°C.

Guaranteed by design.

Functional Block Diagram



Application Information

General Description

Peak-current control (as in TB99) of a buck converter is the most economical and simple way to regulate Its output current. However, it suffers accuracy and regulation problems that arise from the so-called peak-to-Average current error, contributed by the current ripple in the output inductor and the propagation delay in the current sense comparator. The full inductor current signal is unavailable for direct sensing at the ground potential in a buck converter when the control switch is referenced to the same ground potential because the control switch is only conducting for small periods. While it is very simple to detect the peak current in the switch, controlling the average inductor current is usually implemented by level translating the sense signal from $+V_{IN}$. Though this is practical for relatively low input voltage V_{IN}, this type of average-current control may become excessively complex and expensive in the offline AC or other high-voltage DC applications.

The TB9961 employs proprietary control scheme, achieving fast and very accurate control of average Current in the buck inductor through sensing the switch current only. No compensation of the current control loop is required. The LED current response to PWMD input is similar to that of the TB99. The inductor current ripple amplitude does not affect this control scheme significantly, and therefore, the LED current is independent of the variation in inductance, switching frequency or output voltage. Constant off-time control of the buck converter is used for stability and to improve the LED current regulation over a wide range of input voltages.
(Note that, unlike TB99, the TB9961 does not support the constant-frequency mode of operation.)

OFF Timer

The timing resistor connected to RT determines the off-time of the gate driver, and it must be wired to GND. (Wiring this resistor to GATE as with TB99 is no longer supported.)
The equation governing the off-time of the GATE output is given by：

$$T_{OFF}(\mu s) = \frac{R_T(k\Omega)}{25} + 0.3 \qquad (1)$$

within the range of $30k\Omega \leqq R_T \leqq 1.0M\Omega$.

Average Current Control Feedback and Output Short Circuit Protection

The current through the switching MOSFET source is averaged and used to give constant-current feedback. This current is detected using a sense resistor at the CS pin. The feedback operates in a fast open-loop mode. No compensation is required. Output current is programmed simply as:

$$I_{LED} = \frac{0.275V}{R_{CS}} \qquad (2)$$

when the voltage at the LD input $V_{LD} \geqq 1.5V$. Otherwise：

$$I_{LED} = \frac{V_{LD} \cdot 0.185}{R_{CS}} \qquad (3)$$

The above equations are only valid for continuous conduction of the output inductor. It is a good practice to design the inductor such that the switching ripple current in it is 30~40% of its average peak-to-peak, full load, DC current. Hence, the recommended inductance can be calculated as：

$$L_O = \frac{V_{O(MAX)} \cdot T_{OFF}}{0.4 \cdot I_O} \qquad (4)$$

The duty-cycle range of the current control feedback is limited to $D \leqq 0.75$. A reduction in the LED current may occur when the LED string voltage V_O is greater than 75% of the input voltage V_{IN} of the TB9961 LED driver.

Reducing the output LED voltage V_O below $V_{O(MIN)} = V_{IN} \cdot D_{MIN}$, where $D_{MIN} = 1.0\mu s/(T_{OFF} + 1.0\mu s)$, may also result in the loss of regulation of the LED current. This condition, however, causes an increase in the LED current and can potentially trip the short-circuit protection comparator.

The short circuit protection comparator trips when the voltage at CS exceeds 0.44V. When this occurs, the GATE off time $T_{HICCUP} = 400\mu s$ is generated to prevent stair-casing of the inductor current and potentially its saturation due to insufficient output voltage. The typical short-circuit current is shown in the waveform of Fig. 1.

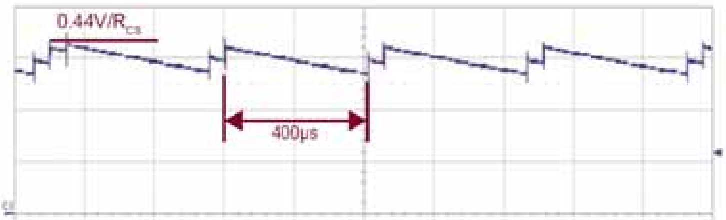


Fig.1. Short-circuit inductor current.

A leading-edge blanking delay is provided at CS to prevent false triggering of the current feedback and the short circuit protection.

Linear Dimming

When the voltage at LD falls below 1.5V, the internal 275mV reference to the constant-current feedback becomes Overridden by V_{LD} · 0.185. As long as the current in the inductor remains continuous, the LED current is given by the equation (3) above. However, when V_{LD} falls below 150mV, the GATE output becomes disabled. The GATE signal recovers, when V_{LD} exceeds 200mV. This is required in some applications to be able to shut the LED lamp off with the same signal input that controls the brightness. The typical linear dimming response is shown in Fig.2.

LD Response Characteristics

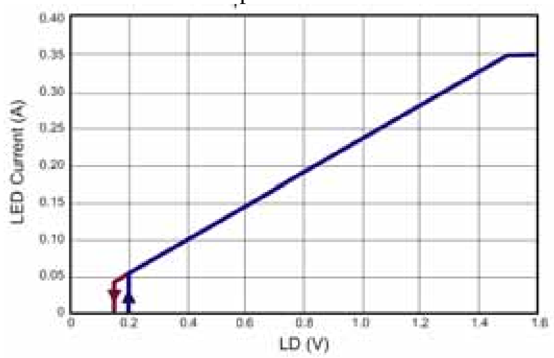


Fig.2. Typical linear dimming response of an TB9961 LED driver

The linear dimming input could also be used for "mixed-mode" dimming to expand the dimming ratio. In such case a pulse-width modulated signal of a measured amplitude below 1.5V should be applied at LD.

Input Voltage Regulator

The TB9961 can be powered directly from an 8.0 ~ 450VDC supply through its VIN input. When this voltage is applied at the VIN pin, the TB9961 maintains a constant 7.5V level at VDD. This voltage can be used to power the IC and external circuitry connected to VDD within the rated maximum current or within the thermal ratings of the package, whichever limit is lower. The VDD pin must be bypassed by a low ESR capacitor to provide a low impedance path for the high frequency current of the GATE output. The TB9961 can also be powered through the VDD pin directly with a voltage greater than the internally regulated 7.5V, but less than 12V.

Despite the instantaneous voltage rating of 450V, continuous voltage at VIN is limited by the power dissipation in The package. For example, when TB9961 draws I_{IN} = 2.0mA from the VIN input, and the 8-pin SOIC package is used, the maximum continuous voltage at VIN is limited to：

$$V_{IN(MAX)} = \frac{(T_{J(MAX)} - T_A)}{R_{\theta,J\text{-}A} \cdot I_{IN}} = 390V \qquad (5)$$

where the ambient temperature $T_A = 25^oC$, the maximum working junction temperature $T_{J(MAX)} = 125^oC$, the junctionto-ambient thermal resistance $R_{\theta,JA} = 128^oC/W$.

In such cases, when it is needed to operate the TB9961 from a higher voltage, a resistor or a Zener diode can be added in series with the VIN input to divert some of the power loss from the TB9961. In the above example, using a 100V Zener diode will allow the circuit to work up to 490V. The input current drawn from the VIN pin is represented by the following equation：

$$I_{IN} \approx 1.0mA + Q_G \cdot f_S \qquad (6)$$

In the above equation, f_S is the switching frequency, and Q_G is the GATE charge of the external FET obtained from The manufacturer's datasheet.

GATE Output

The GATE output of the TB9961 is used to drive an external MOSFET. It is recommended that the gate charge Q_G of the external MOSFET be less than 25nC for switching frequencies ≦100kHz and less than 15nC for switching frequencies >100kHz.

PWM Dimming

Due to the fast open-loop response of the average-current control loop of the TB9961, its PWM dimming performance nearly matches that of the TB99. The inductor current waveform comparison is shown in Fig. 3.

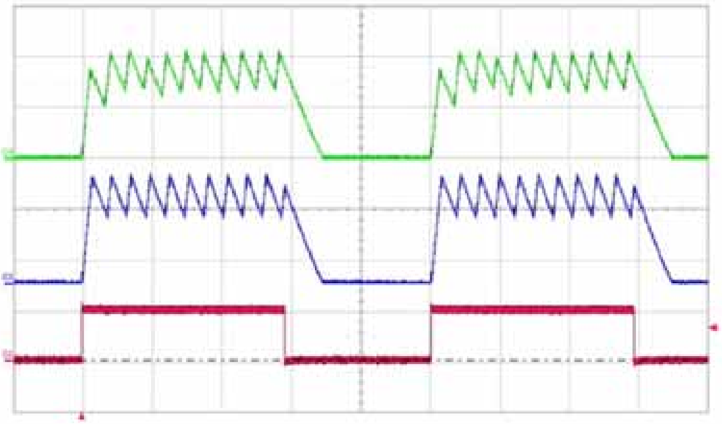


Fig.3. Typical PWM dimming response of an TB9961 LED driver.

CH2 (red)：PWMD

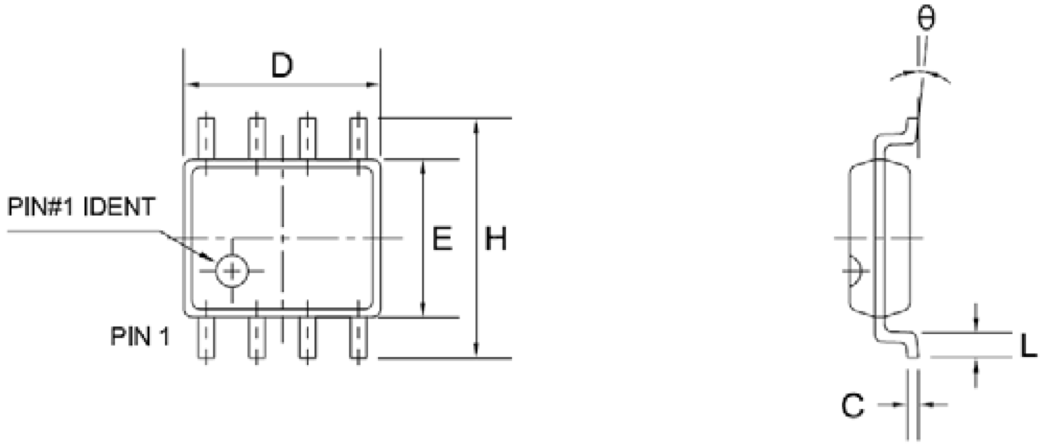
CH4 (green) ：Inductor Current

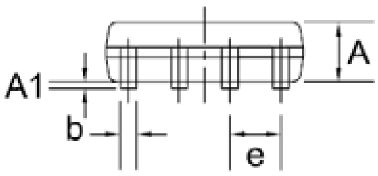
CH3 (blue) ：Same as TB99 for comparison

The rising and falling edges are limited by the current slew rate in the inductor. The first switching cycle is Terminated upon reaching the 275mV (V_{LD} • 0.185) level at CS. The circuit is further reaching its steady-state within 3~4 switching cycles regardless of the switching frequency.

Package Information

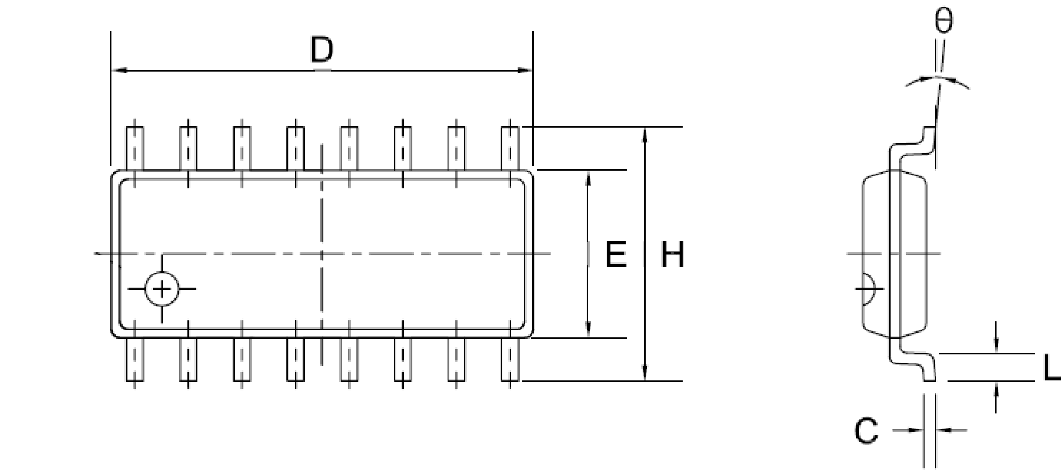
SOP-8

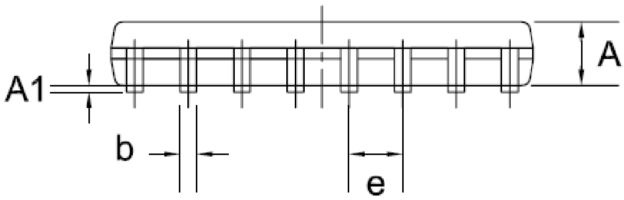




Symbol	Dimensions In Millmeters			Dimensions In Inches		
	Min	Nom	Max	Min	Nom	Max
A	——	——	4.31	——	——	0.170
A1	0.38	——	——	0.015	——	——
A2	3.15	3.40	3.65	0.124	0.134	0.144
B	——	0.46	——	——	0.018	——
B1	——	1.52	——	——	0.060	——
C	——	0.25	——	——	0.010	——
D	9.00	9.20	9.40	0.354	0.362	0.370
E	6.20	6.40	6.60	0.244	0.252	0.260
E1	——	7.62	——	——	0.300	——
e	——	2.54	——	——	0.100	——
L	3.00	3.30	3.60	0.118	0.130	0.142
θ	0°	——	15°	0°	——	15°

SOP-16





Symbol	Dimensions In Millmeters			Dimensions In Inches		
	Min	Nom	Max	Min	Nom	Max
A	1.30	1.50	1.70	0.051	0.059	0.067
A1	0.06	0.16	0.26	0.002	0.006	0.010
b	0.30	0.40	0.55	0.012	0.016	0.022
C	0.15	0.25	0.35	0.006	0.010	0.014
D	9.70	10.00	10.30	0.382	0.394	0.406
E	3.75	3.95	4.15	0.148	0.156	0.163
e	1.15	1.27	1.39	0.045	0.050	0.055
H	5.70	6.00	6.30	0.224	0.236	0.248
L	0.45	0.65	0.85	0.018	0.026	0.033
θ	0°	——	8°	0°	——	8°