

## Automotive Boost-Buck LED Lamp Driver IC

### Features

- Constant Output Current
- Steps Output Voltage Up or Down
- Very Low Susceptibility to Input Voltage Transients
- Frequency Jitter
- Externally Programmable Fixed Switching Frequency
- Temperature Foldback with External NTC Resistor
- Internal 40V Voltage Regulator
- +/-1A MOSFET Gate Driver
- Short LED Protection
- Open LED Protection
- Input Undervoltage Lockout Protection
- Enable and PWM Dimming
- ±3% Accurate Trimmed Reference
- AEC-Q100 Compliant

### Applications

- Automobile Lighting
- Battery-Powered LED Lamps
- Other Low-Voltage AC/DC or DC/DC LED Drivers

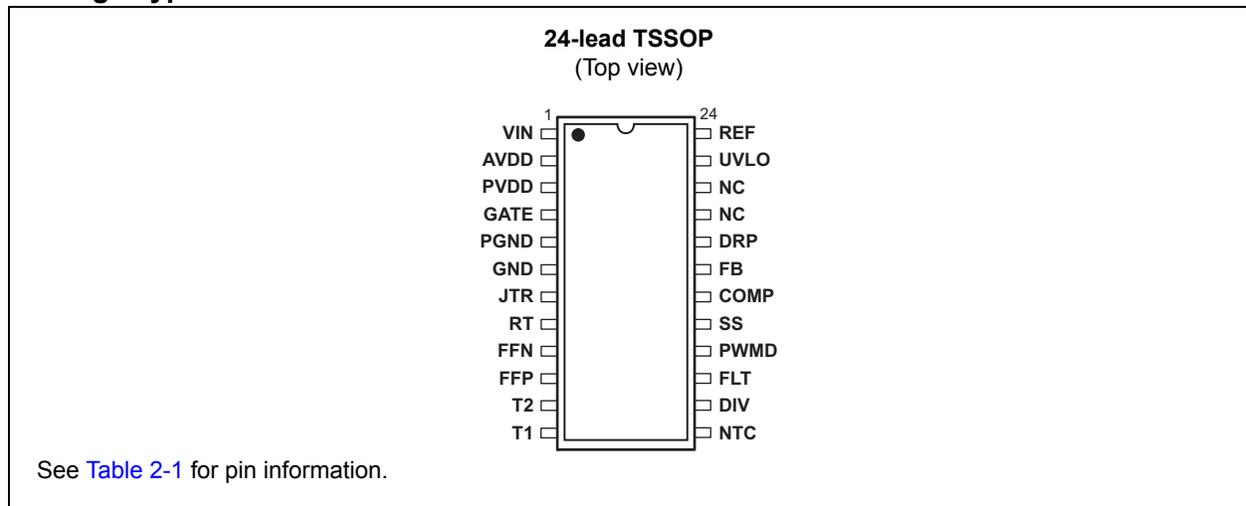
### General Description

The AT9932 is an advanced fixed-frequency PWM controller IC designed to control an LED lamp driver using a boost-buck topology that can step the input voltage up or down automatically. The IC provides fast output current transient response and very low susceptibility to input voltage transients. This allows the lamp driver to pass the rigorous electrical transient requirements of SAE J1455 or ISO 7637-2, making the AT9932 an ultimate solution for automobile lighting. Capacitive isolation protects the LED Lamp from failure of the switching MOSFET.

The AT9932 features a unique feed-forward current control scheme, differential output current sensing, soft start and protection from short or open LED load. Switching frequency can be programmed with a single external resistor.

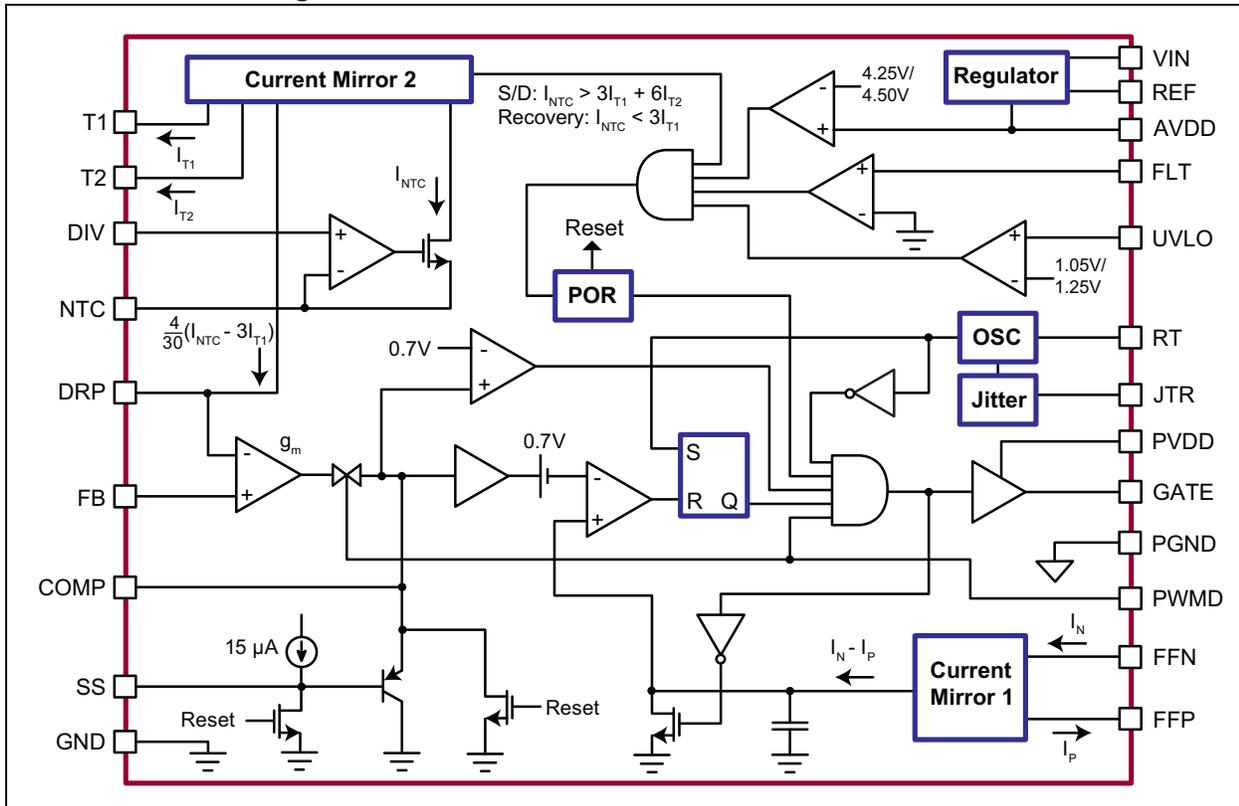
The AT9932 includes a temperature foldback of the output current using an external NTC resistor. This feature allows optimization of the light output of the LED load for safe operation over the entire operating temperature range.

### Package Type

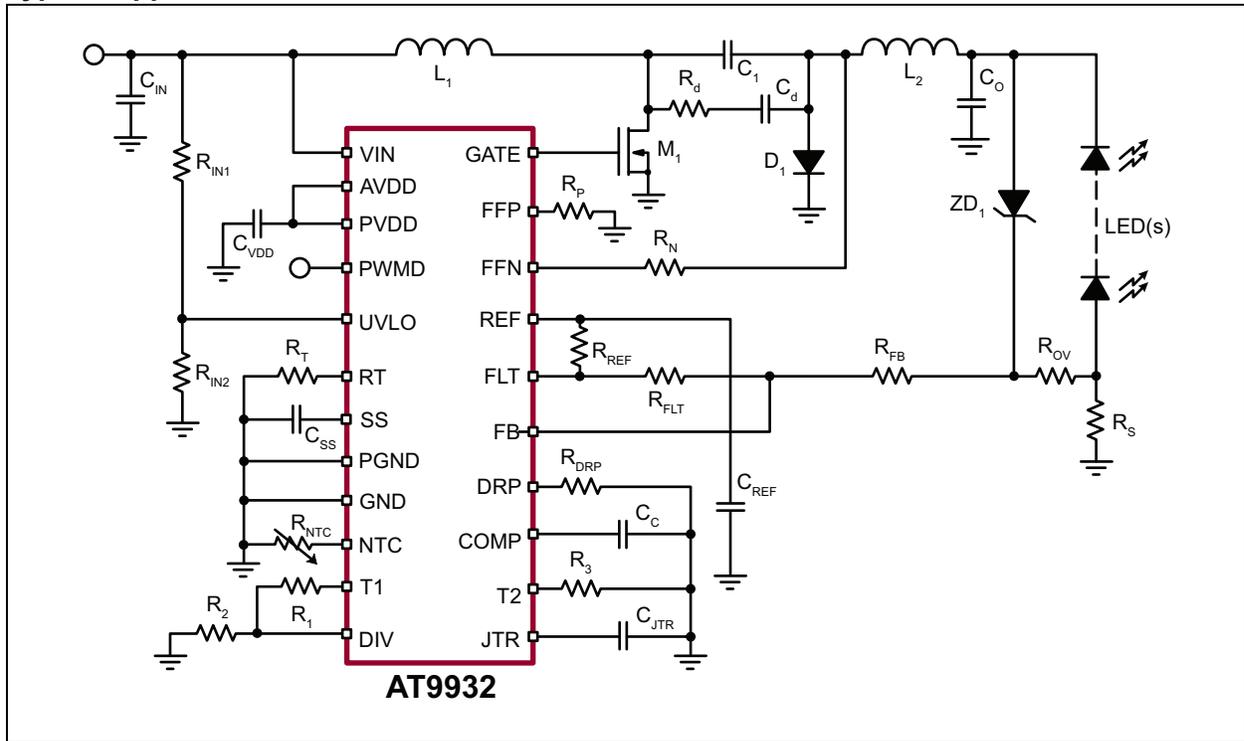


# AT9932

## Functional Block Diagram



## Typical Application Circuit



# AT9932

## 1.0 ELECTRICAL CHARACTERISTICS

### Absolute Maximum Ratings†

$V_{IN}$ to GND .....	-0.5V to +45V
PVDD and AVDD to GND .....	-0.3V to +6V
Gate to GND Voltage .....	-0.3V to (PVDD +0.3V)
All other pins to GND Voltage .....	-0.3V to (AVDD +0.3V)
FFN, FFP Current .....	2 mA
REF Current .....	5 mA
Junction Temperature, $T_J$ .....	-40°C to +150°C
Storage Temperature, $T_S$ .....	-65°C to +150°C
Continuous Power Dissipation ( $T_A = +25^\circ\text{C}$ ):	
24-lead TSSOP ( <b>Note 1</b> ) .....	1000 mW

† **Notice:** Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at those or any other conditions above those indicated in the operational sections of this specification is not intended. Exposure to maximum rating conditions for extended periods may affect device reliability.

**Note 1:**  $R_{\theta JA} = 125^\circ\text{C/W}$

### ELECTRICAL CHARACTERISTICS

**Electrical Specifications:** Specifications are at  $T_A = 25^\circ\text{C}$ ,  $V_{IN} = 12\text{V}$ ,  $V_{PWMD} = V_{UVLO} = V_{AVDD} = V_{PVDD}$ , Gate open,  $R_T = 200\text{ k}\Omega$ ,  $C_{REF} = 0.1\text{ }\mu\text{F}$ ,  $C_{AVDD} = C_{PVDD} = 1\text{ }\mu\text{F}$ ,  $I_{T1} = I_{T2} = 100\text{ }\mu\text{A}$  unless otherwise noted.

Parameter	Sym.	Min.	Typ.	Max.	Unit	Conditions
<b>INPUT</b>						
Input DC Supply Voltage Range	$V_{IN}$	5.3	—	40	V	
Input Supply Current	$I_{INEN}$	—	—	2	mA	$V_{PWMD} = V_{GND}$ ( <b>Note 1</b> )
Input Current, UVLO Mode	$I_{INDIS}$	—	—	100	$\mu\text{A}$	$V_{UVLO} = V_{PWMD} = V_{GND}$ ( <b>Note 1</b> )
<b>INTERNAL REGULATOR</b>						
Regulated Output Voltage	$V_{DD}$	4.65	5	5.35	V	$I_{DD} = 0\text{ mA} - 20\text{ mA}$ , $V_{IN} = 6\text{V} - 40\text{V}$ , $V_{PWMD} = V_{GND}$ ( <b>Note 1</b> )
$V_{DD}$ UVLO Upper Threshold	$V_{DDUV, R}$	4.25	4.5	4.85	V	$V_{DD}$ rising ( <b>Note 1</b> )
$V_{DD}$ UVLO Hysteresis	$\Delta V_{DDUV}$	—	250	—	mV	$V_{DD}$ falling
<b>REFERENCE</b>						
Reference Output Voltage	$V_{REF}$	1.21	1.25	1.29	V	$I_{REF} = 0\text{ mA}$ ( <b>Note 1</b> )
Reference Output Voltage, UVLO Mode	$V_{REF, DIS}$	—	0	—	mV	$V_{UVLO} = V_{GND}$
Load Regulation	$\Delta V_{REF}$	0	—	2	mV	$I_{REF} = 0\text{ mA} - 1\text{ mA}$
<b>GATE OUTPUT</b>						
Gate Output Rise Time	$t_r$	—	20	35	ns	$C_{GATE} = 4\text{ nF}$ , $V_{IN} = V_{AVDD} = V_{PVDD} = 5\text{V}$
Gate Output Fall Time	$t_f$	—	20	35	ns	
Maximum Duty Cycle	$D_{MAX}$	87	90	93	%	( <b>Note 1</b> )
<b>FEED-FORWARD RAMP GENERATOR</b>						
Minimum Gate On-Time	$t_{ON(MIN)}$	250	—	400	ns	$I_{FFN} = 500\text{ }\mu\text{A}$ , $I_{FFP} = 0\text{ }\mu\text{A}$ , $V_{COMP} = 3.5\text{V}$ ( <b>Note 1</b> )
Maximum Gate On-Time	$t_{ON(MAX)}$	6	—	13	$\mu\text{s}$	$I_{FFN} = 10\text{ }\mu\text{A}$ , $I_{FFP} = 0\text{ }\mu\text{A}$ , $V_{COMP} = 3.5\text{V}$ ( <b>Note 1</b> )
Gate On-Time	$t_{ON}$	1	—	2	$\mu\text{s}$	$I_{FFN} = 110\text{ }\mu\text{A}$ , $I_{FFP} = 10\text{ }\mu\text{A}$ , $V_{COMP} = 3.5\text{V}$ ( <b>Note 1</b> )
FFN/FFP Current Balancing	$\Delta t_{ON}/t_{ON}$	-3	—	3	%	$I_{FFN} = 100\text{ }\mu\text{A}$ , $I_{FFP} = 0\text{ }\mu\text{A}$ , $V_{COMP} = 3.5\text{V}$ ( <b>Note 2</b> )

**Note 1:** Specifications apply over the full operating ambient temperature range of  $-40^\circ\text{C} < T_A < +125^\circ\text{C}$ .

**Note 2:** Specifications are obtained by characterization and are not 100% tested.

## ELECTRICAL CHARACTERISTICS (CONTINUED)

**Electrical Specifications:** Specifications are at  $T_A = 25^\circ\text{C}$ ,  $V_{IN} = 12\text{V}$ ,  $V_{PWMD} = V_{UVLO} = V_{AVDD} = V_{PVDD}$ . Gate open,  $R_T = 200\text{ k}\Omega$ ,  $C_{REF} = 0.1\text{ }\mu\text{F}$ ,  $C_{AVDD} = C_{PVDD} = 1\text{ }\mu\text{F}$ ,  $I_{T1} = I_{T2} = 100\text{ }\mu\text{A}$  unless otherwise noted.

Parameter	Sym.	Min.	Typ.	Max.	Unit	Conditions
<b>TRANSCONDUCTANCE OPERATION AMPLIFIER</b>						
Input Common Mode Range	$V_{FB}, V_{DRP}$	-0.3	—	3	V	(Note 2)
Input Offset Voltage	$V_{OS}$	-9	—	9	mV	(Note 1)
Transconductance	$g_m$	—	0.95	—	mA/V	
Open-Loop Voltage Gain	$A_V$	65	—	—	dB	COMP open
Gain Bandwidth Product	GBW	1	—	—	MHz	$C_{COMP} = 150\text{ pF}$ (Note 2)
COMP Sink Current	$I_{COMP}$	0.2	—	—	mA	$V_{FB} = 0.1\text{V}$ , $V_{COMP} = V_{GND}$ (Note 2)
COMP Source Current		-0.2	—	—	mA	$V_{FB} = -0.1\text{V}$ , $V_{COMP} = V_{AVDD}$ (Note 2)
Input Bias Current	$I_{BIAS, AMP}$	—	0.5	1	nA	(Note 2)
Output Voltage Range	$V_{COMP}$	0.7	—	$V_{DD}$	V	(Note 2)
COMP Hiccup Threshold	$V_{COMP, HT}$	—	700	—	mV	
Output Leakage Current	$I_{LEAK}$	—	0.5	1	nA	$V_{PWMD} = V_{GND}$ (Note 2)
<b>OSCILLATOR</b>						
Output Frequency	$f_{OSC1}$	90	105	120	kHz	$R_T = 1\text{ M}\Omega$ (Note 1)
	$f_{OSC2}$	427	505	583	kHz	$R_T = 200\text{ k}\Omega$ (Note 1)
Output Frequency Range	$f_{OSC}$	100	—	800	kHz	Note 2
<b>JITTER</b>						
Jitter Frequency	$F_{JTR}$	—	50	—	Hz	$C_{JTR} = 0.1\text{ }\mu\text{F}$
		—	500	—	Hz	$C_{JTR} = 0.01\text{ }\mu\text{F}$
Change in Switching Frequency	$\Delta F$	$\pm 4.5$	—	—	kHz	
<b>TEMPERATURE FOLDBACK CIRCUIT</b>						
NTC Source Current Range	$I_{NTC}$	—	—	1	mA	Note 2
DRP to NTC Current Gain	$N_{NTC}$	—	0.13	—	—	$I_{NTC} = 0.5\text{ mA}$
NTC to T1 Current Gain	$N_{T1}$	—	3	—	—	$I_{NTC} = 0.5\text{ mA}$
NTC to T2 Current Gain	$N_{T2}$	—	6	—	—	$I_{NTC} = 0.5\text{ mA}$
T1 and T2 Reference Voltage	$V_{T1}, V_{T2}$	—	3.5	—	V	
<b>SOFT START</b>						
Charging Current	$I_{SS, CHG}$	10	—	25	$\mu\text{A}$	
Discharging Current	$I_{SS, DIS}$	1	—	—	mA	$V_{SS} = 5\text{V}$
Reset Voltage	$V_{SS, RST}$	—	—	100	mV	
<b>FAULT DETECT COMPARATOR</b>						
Trip Voltage	$V_{FLT}$	-20	—	20	mV	
Input Bias Current	$I_{BIAS, FLT}$	—	0.5	1	nA	Note 2
<b>INPUT UNDERVOLTAGE LOCKOUT</b>						
Undervoltage Lockout Upper Threshold	$V_{UVLO, R}$	1.15	1.25	1.4	V	$V_{UVLO}$ rising (Note 1)
Undervoltage Lockout Hysteresis	$\Delta V_{UVLO}$	—	200	—	mV	$V_{UVLO}$ falling
Input Bias Current	$I_{BIAS, UV}$	—	0.5	1	nA	Note 2
<b>PWM DIMMING</b>						
Enable Voltage Level	$V_{PWMD(HI)}$	2	—	—	V	Note 1
Disable Voltage Level	$V_{PWMD(LO)}$	—	—	0.8	V	Note 1
Pull-Down Resistor	$R_{PWMD}$	120	—	280	k $\Omega$	

**Note 1:** Specifications apply over the full operating ambient temperature range of  $-40^\circ\text{C} < T_A < +125^\circ\text{C}$ .

**Note 2:** Specifications are obtained by characterization and are not 100% tested.

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## TEMPERATURE SPECIFICATIONS

Parameter	Sym.	Min.	Typ.	Max.	Unit	Conditions
<b>TEMPERATURE RANGE</b>						
Operating Ambient Temperature	$T_A$	-40	—	+125	°C	
Maximum Junction Temperature	$T_J$	—	—	+150	°C	
Storage Temperature	$T_S$	-65	—	+150	°C	
<b>PACKAGE THERMAL RESISTANCE</b>						
24-lead TSSOP	$\theta_{JA}$	—	125	—	°C/W	<a href="#">Note 1</a>

**Note 1:** Mounted on an FR-4 board, 25 mm x 25 mm x 1.57 mm

## 2.0 PIN DESCRIPTION

The details on the pins of AT9932 are listed on [Table 2-1](#). Refer to [Package Type](#) for the location of the pins.

**TABLE 2-1: PIN FUNCTION TABLE**

Pin Number	Pin Name	Description
1	VIN	This pin is the input of a 40V high-voltage regulator.
2	AVDD	This is a power supply pin for all internal circuits. It must be bypassed with a low-ESR capacitor to GND (at least 0.1 $\mu$ F).
3	PVDD	This is the power supply pin for the gate driver. It should be connected externally to AVDD and bypassed with a low-ESR capacitor to PGND (at least 0.1 $\mu$ F).
4	GATE	This pin is the output of gate driver for driving an external logic level N-channel power MOSFET.
5	PGND	Ground return for the gate drive circuitry
6	GND	Ground return for all the low-power analog internal circuitry. This pin must be connected to the return path from the input.
7	JTR	This pin programs the jitter of the clock by a capacitor connected from this pin to GND.
8	RT	Connecting an external resistor from this pin to GND sets the frequency of the oscillator circuit.
9	FFN	Connecting a resistor between this pin and the negative terminal of the coupling capacitor in the boost-buck converter programs positive PWM ramp signal. The slew rate is proportional to the current sunk from this pin. When the ramp voltage exceeds the voltage at COMP, the gate signal is terminated.
10	FFP	Connecting a resistor between this pin and GND cancels the FFN current error due to non-zero voltage at FFN. The FFN and FFP current mirrors are internally matched.
11	T2	Connecting a resistor from this current source pin to GND programs the overtemperature shutdown threshold temperature detected by an external NTC resistor.
12	T1	Connecting a resistor from this current source pin to GND programs the temperature threshold beyond which the LED current is reduced.
13	NTC	Connect an external NTC resistor from this current source pin to GND for temperature foldback of the output current and overtemperature shutdown.
14	DIV	This is the reference input that programs the voltage at the NTC pin.
15	FLT	This pin is an input of the fault comparator. This comparator is used for open and short LED protection. The IC shuts down and restarts after a POR delay when this comparator is triggered.
16	PWMD	When this pin is pulled to GND (or left open), the gate output is disabled. The COMP pin becomes high-impedance and holds its voltage level. When this pin is logic-high, the switching of gate resumes.
17	SS	Connecting a capacitor from this pin to GND programs the soft-start time of the LED driver.
18	COMP	This pin is the output of the error amplifier. Stable closed-loop control of the output LED current can be achieved by connecting a compensation network between COMP and GND. This pin is pulled to GND internally upon a startup or detection of a Fault condition.
19	FB	This pin is the high-impedance non-inverting input of the error amplifier. The output LED current sense voltage is programmed by connecting a resistor divider between REF and the negative terminal of the current sense resistor.
20	DRP	This is the output current sense reference voltage input at the error amplifier. Connect this pin to GND when no NTC derating is used. Connect a resistor from this pin to GND to program the droop of the LED current at temperature foldback.

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**TABLE 2-1: PIN FUNCTION TABLE (CONTINUED)**

Pin Number	Pin Name	Description
21	NC	No Connection
22	NC	
23	UVLO	This pin provides input undervoltage lockout protection. When voltage at this pin falls below its lower threshold, AT9932 halts switching, and the soft-start capacitor is discharged rapidly. The voltage at the REF pin becomes 0V, and the entire IC consumes quiescent current of less than 100 $\mu$ A. The switching resumes when the UVLO pin voltage exceeds the upper threshold. Hysteresis is provided between the two thresholds.
24	REF	This pin provides accurate reference voltage. It must be bypassed with a 0.01 $\mu$ F to 0.1 $\mu$ F capacitor to GND.

## 3.0 FUNCTIONAL DESCRIPTION

### 3.1 Power Topology

The AT9932 is optimized to drive a Continuous Conduction Mode (CCM) boost-buck DC/DC converter topology commonly referred to as the Ćuk converter. (Refer to [Typical Application Circuit](#).) This power converter topology offers numerous advantages useful for driving high-brightness light-emitting diodes (HB LED). These advantages include step-up or step-down voltage conversion ratio and low input and output current ripple. The output load is decoupled from the input voltage with a capacitor, making the driver inherently failure-safe for the output load.

The AT9932 features an optimal control method for use with a boost-buck LED driver. This method achieves very low susceptibility to input voltage transients, which makes it indispensable for automotive LED lighting applications. The AT9932 can maintain constant output current even under vigorous input transient conditions. Its output current control loop is inherently stable and can be compensated using a single capacitor with the appropriate damping at the coupling capacitor.

### 3.2 Regulator ( $V_{IN}$ , AVDD) and Gate Driver (Gate, PVDD)

The AT9932 can be powered directly from its  $V_{IN}$  pin that takes a voltage up to 40V. When  $V_{IN}$  voltage is applied, the AT9932 seeks to maintain constant voltage at the AVDD pin. When the undervoltage upper threshold is exceeded at AVDD, the gate driver is enabled after a 100  $\mu$ s power-on reset (POR) delay. The output of the gate driver (GATE) controls the gate of an external N-channel power MOSFET. The maximum duty cycle of the gate signal is limited to 0.9 (typical). The undervoltage protection comparator disables the gate driver when the voltage at AVDD falls below the undervoltage lower threshold.

A separate PVDD input is provided to power the gate output to decouple the high switching currents of the gate driver from AVDD. Both pins (AVDD, PVDD) must be wired together on the printed circuit board (PCB). AVDD needs to be bypassed to GND by a low-ESR capacitor ( $\geq 0.1 \mu$ F). PVDD needs to be bypassed to PGND by a low-ESR capacitor ( $\geq 0.1 \mu$ F).

The input current drawn from the external power supply (or  $V_{IN}$  pin) is a sum of the 2 mA maximum current drawn by the all the internal circuitry and the current drawn by the gate driver which in turn depends on the switching frequency and the gate charge of the external FET. Refer to [Equation 3-1](#).

#### EQUATION 3-1:

$$I_{IN} = 2mA + Q_G \times f_S$$

In [Equation 3-1](#),  $f_S$  is the switching frequency, and  $Q_G$  is the gate charge of the external FET which can be obtained from the FET data sheet.

### 3.3 Timing Resistor ( $R_T$ )

The switching frequency  $f_S$  is programmed by selecting an external timing resistor,  $R_T$ . The resistance value can be computed as shown in [Equation 3-2](#):

#### EQUATION 3-2:

$$R_T = \frac{1}{f_S \times C_T}$$

Where  $C_T = 9.5 \text{ pF}$

### 3.4 Jitter (JTR)

Clock frequency can be modulated by an externally programmed saw-tooth wave signal to reduce conducted electro-magnetic emission (EMI) from the LED driver. The deviation of the oscillator frequency is set internally to  $\pm 5$  kHz. The modulation frequency is programmed by connecting a capacitor from JTR to GND. The value of the capacitor required for the jitter frequency is calculated with [Equation 3-3](#).

#### EQUATION 3-3:

$$C_{JTR} = \frac{5 \mu F}{f_{JTR}(\text{Hz})}$$

Note that the jitter frequency must be chosen to be significantly lower than the crossover frequency of the closed-loop control. If not, the controller will not be able to reject the jitter frequency, and the LED current will have a current ripple at the jitter frequency.

### 3.5 Reference Voltage (REF)

The AT9932 provides a 1.25V reference voltage at the REF pin. This voltage is used to derive the various internal voltages required by the IC and is also used to set the LED current externally. It should be bypassed with a low-impedance capacitor (0.01  $\mu$ F–0.1  $\mu$ F).

### 3.6 Internal 1 MHz Transconductance Amplifier

The AT9932 includes a 1 MHz transconductance amplifier, which can be used to close the LED current feedback loop. The output state of the amplifier is controlled by the signal applied to the PWMD pin. When PWMD is high, the output of the amplifier is connected to the COMP pin and the gate drive is enabled. When PWMD is low, COMP is left open and the gate drive is disabled. This enables the integrating capacitor at the COMP pin to hold its charge when the PWMD signal has turned off the gate drive. When the

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gate drive is resumed, the voltage at COMP will be positioned for the converter to return to its Steady State condition.

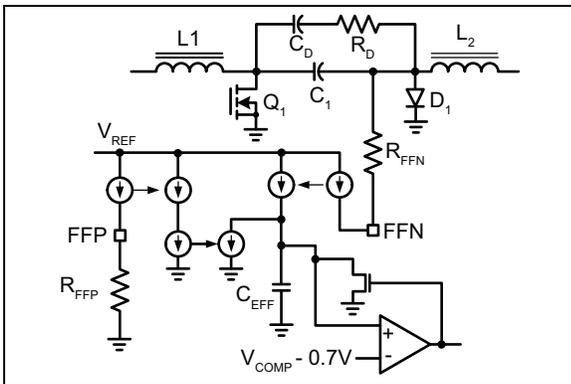
When the voltage at COMP falls below 700 mV, the gate output is disabled. This feature reduces power dissipation in the Zener diode ZD<sub>1</sub> during Open LED string condition.

## 3.7 Soft Start (SS)

The soft-start feature can determine the initial ramp-up of the error voltage at the COMP pin. Connecting a single capacitor between SS to GND can program the soft-start time. Upon the first application of voltage to the AVDD pin, a current of 15 μA is supplied from the SS pin, gradually charging the soft-start capacitor. The COMP voltage tracks the voltage at the SS pin until regulation of the output current is reached. When the voltage at AVDD pin (V<sub>DD</sub>) falls below the undervoltage lower threshold, the soft-start capacitor is discharged rapidly.

## 3.8 Feed-Forward Ramp Generator (FFP, FFN) and PWM Comparator

The heart of the AT9932 is the feed-forward circuit having two inputs: FFN and FFP. This circuit generates a voltage ramp proportional to the difference between the FFN and FFP currents.



**FIGURE 3-1:** Feed-Forward Ramp Generator.

As shown in [Figure 3-1](#), the resistor R<sub>FFN</sub> is connected between FFN and the negative terminal of the coupling capacitor C<sub>1</sub>. The resistor R<sub>FFP</sub> of the same value (R<sub>FFP</sub> = R<sub>FFN</sub>) is connected between FFP and GND. The on-time of the gate output can be computed as shown in [Equation 3-4](#).

### EQUATION 3-4:

$$t_{ON} = \frac{R_{FFN} \times C_{EFF} \times (V_{COMP} - 0.7V)}{V_{C1}}$$

Where C<sub>EFF</sub> = 50 pF ±40%, V<sub>COMP</sub> is the COMP voltage, and V<sub>C1</sub> is the voltage across the coupling capacitor C<sub>1</sub>.

The duty cycle of a Continuous Conduction mode boost-buck converter is given as illustrated in [Equation 3-5](#).

### EQUATION 3-5:

$$D = t_{ON} \times f_S = \frac{V_{OUT}}{V_{C1}} = \frac{V_{OUT}}{V_{OUT} + V_{IN}}$$

Where V<sub>IN</sub> is the input supply voltage, and V<sub>OUT</sub> is the forward voltage of the LED string.

Since the output voltage at COMP is limited to V<sub>COMP</sub> = V<sub>DD</sub>, the feed-forward resistors must be selected in accordance with [Equation 3-6](#).

### EQUATION 3-6:

$$R_{FFN} = R_{FFP} \geq \frac{V_{OUT}}{C_{EFF} \times f_S \times (V_{DD} - 0.7V)}$$

Otherwise, the steady-state Duty Cycle D will not be reached, and the LED driver will be unable to develop the desired current.

The feed-forward loop provides instantaneous response to any transient at C<sub>1</sub> and therefore achieves excellent rejection of the input voltage transients along the supply line. It is inherently stable with proper selection of the damping network R<sub>d</sub> and C<sub>d</sub>. Optimal selection of R<sub>d</sub> and C<sub>d</sub> is complex. However, the worst case design of the damping circuit can be performed under the assumption that V<sub>OUT(MAX)</sub> >> V<sub>IN(MIN)</sub> for most automotive applications of the AT9932. The simplified equations given below produce excellent results under this assumption. See [Equation 3-7](#) and [Equation 3-8](#).

### EQUATION 3-7:

$$C_d = \frac{9D_{MAX}}{(1 - D_{MAX})} \times \frac{L_1 \times I_O^2}{V_{IN(MIN)}}$$

### EQUATION 3-8:

$$R_d = \frac{V_{IN(MIN)}}{3D_{MAX}I_O}$$

In cases where the above assumption is not valid, the equations for  $R_d$  and  $C_d$  could still be used. However, they may produce conservative results. Power dissipation in the damping resistor  $R_d$  can be computed as shown in Equation 3-9.

### EQUATION 3-9:

$$P_{Rd} = \frac{\Delta V_{C1}^2}{12 \times R_d}$$

Where:

$$\Delta V_{C1} = \frac{I_{OUT} \times D}{f_s \times C_1}$$

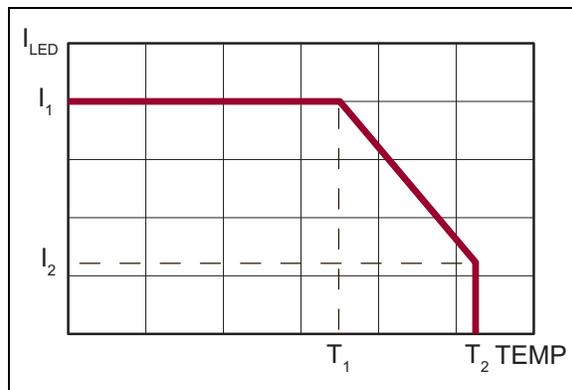
is the peak-to-peak voltage ripple at the coupling capacitor.

### 3.9 Output Overvoltage Protection

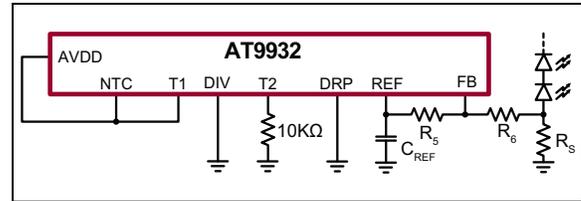
The AT9932 LED lamp driver supplies constant current to the load. Therefore, an output circuit protection is needed to prevent dramatic failures when the output load fails to open. A simple addition of a Zener diode ( $ZD_1$  in the [Typical Application Circuit](#)) will limit the output voltage when the output LED connection is lost.

### 3.10 Programming LED Current and Temperature Foldback

The AT9932 offers a temperature foldback feature that allows the programming of output current in accordance with the temperature derating characteristics provided by the LED manufacturers. A typical derating curve is shown in [Figure 3-2](#).



**FIGURE 3-2:** Temperature Derating Curve of LED Current.



**FIGURE 3-3:** Output Current Feedback without Temperature Foldback.

When no temperature foldback is required, NTC and T1 should be connected to AVDD. In addition, DIV and DRP should be connected to GND. T2 still requires a resistor to GND (10 kΩ–100 kΩ). No pins should be left floating as shown in [Figure 3-3](#). In this case, the output current of the AT9932 LED driver is programmed using Equation 3-10:

### EQUATION 3-10:

$$I_1 = \frac{V_{REF}}{R_S} \times \frac{R_6}{R_5}$$

Where  $V_{REF}$  is voltage at the REF pin ( $V_{REF} = 1.25V$ ).

When temperature foldback is required, the Equation 3-10 is also used to calculate LED current  $I_1$  at temperature below  $T_1$ .

When an external NTC resistor is connected (See [Figure 3-4](#)), both temperatures  $T_1$  and  $T_2$ , as well as the current  $I_2$  can be accurately programmed to safely regulate the light output of the LED lamp at the higher temperature range between  $T_1$  and  $T_2$ .

The ratio of the resistor divider  $R_2 / (R_1 + R_2)$  programs the voltage at the NTC pin. The voltage at T1 is approximately 3.5V. The currents sourced by NTC and T1 pins are mirrored into DRP in accordance with Equation 3-11.

### EQUATION 3-11:

$$I_{DRP} = \frac{4}{30} (I_{NTC} - 3I_{T1}) > 0$$

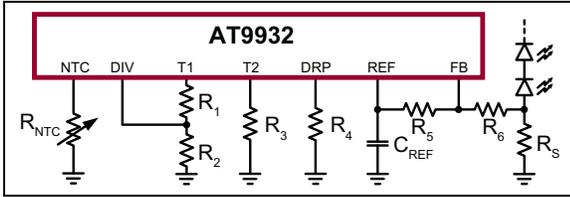
No current is sourced from DRP when  $I_{NTC} < 3 \times I_{T1}$ .

Temperature  $T_1$  is programmed by selecting  $R_2$  such that (See Equation 3-12.):

### EQUATION 3-12:

$$R_2 = 3R_{NTC(T1)}$$

Where  $R_{NTC(T1)}$  is the resistance of the NTC resistor at temperature  $T_1$ .



**FIGURE 3-4:** Output Current Feedback with Temperature Foldback.

At temperature higher than  $T_1$ , further reduction of the NTC resistance  $R_{NTC}$  will create a proportional offset of the current feedback reference voltage at DRP, and will therefore decrease the LED current. To program the desired LED current  $I_2$  at the temperature  $T_2$ , the resistor  $R_4$  at DRP can be calculated as shown in Equation 3-13.

**EQUATION 3-13:**

$$R_4 = (I_1 - I_2) \times R_S \times \frac{30R_{NTC(T_2)}(R_1 + R_2)}{4V_{T1}(R_2 - 3R_{NTC(T_2)})} \times \frac{R_5}{R_5 + R_6}$$

Where  $R_{NTC(T_2)}$  is the resistance of the NTC resistor at the temperature  $T_2$ , and  $V_{T1}$  is the voltage at the T1 pin ( $V_{T1} \approx 3.5V$ ).

When the current from the NTC pin exceeds  $3 \times I_{T1} + 6 \times I_{T2}$ , overtemperature shutdown is triggered. The voltage at T2 is approximately equal to the voltage at T1. Selecting resistance of  $R_3$  at the T2 pin programs the desired shutdown temperature  $T_2$ . Refer to Equation 3-14.

**EQUATION 3-14:**

$$R_3 = \frac{6R_{NTC(T_2)} \times (R_1 + R_2)}{R_2 - 3R_{NTC(T_2)}}$$

The overtemperature recovery threshold is independent of the current at T2 pin. The AT9932 recovers from thermal shutdown at the break temperature  $T_1$ , where  $I_{NTC} < 3 \times I_{T1}$ .

### 3.11 Input Undervoltage Lockout (UVLO) Protection

To protect the AT9932 against excessive input current at low input supply voltage, the undervoltage lockout protection comparator input is provided. Connecting a resistor divider between  $V_{IN}$  and GND programs the  $V_{IN}$  start and  $V_{IN}$  stop thresholds as indicated in Equation 3-15 and Equation 3-16.

**EQUATION 3-15:**

$$V_{IN(START)} = \frac{(R_{IN1} + R_{IN2}) \times 1.25V}{R_{IN2}}$$

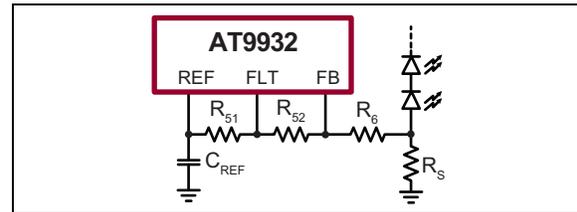
**EQUATION 3-16:**

$$V_{IN(STOP)} = 0.84 \times V_{IN(START)}$$

The hysteresis is provided to prevent oscillation.

The AT9932 becomes disabled and draws less than  $100 \mu A$  of current from  $V_{IN}$  or  $V_{DD}$  when the UVLO pin voltage falls below the UVLO lower threshold. The 1.25V reference at the REF pin becomes 0V at this condition. Hence, the UVLO input can also be used as a low stand-by power disable input.

### 3.12 Fault Comparator (FLT)



**FIGURE 3-5:** Output Short-circuit Protection.

The AT9932 also provides an internal protection comparator that can be used for protection against short and open LED string conditions. When the voltage at the FLT input falls below the GND potential, the AT9932 shuts down. The soft-start capacitor at SS is discharged. Switching resumes automatically after a POR delay.

Configuring the FLT input to protect against a short LED string is illustrated in Figure 3-5. The short-circuit current can be calculated as shown in Equation 3-17.

**EQUATION 3-17:**

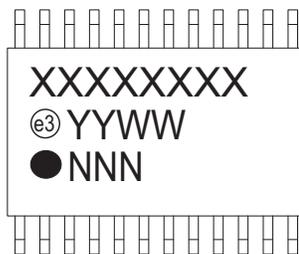
$$I_{SHORT} = \frac{V_{REF}}{R_S} \times \frac{R_6 + R_{52}}{R_{51}}$$

The same resistor divider can be used to protect the LED driver from the open LED string condition, as shown in the **Typical Application Circuit**. The addition of a Zener diode  $ZD_1$  causes the FLT comparator to trip when  $V_{OUT} > V_Z$ .

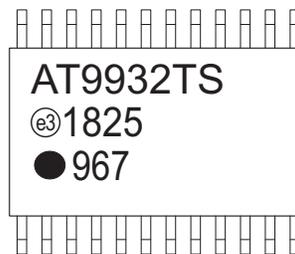
## 4.0 PACKAGING INFORMATION

### 4.1 Package Marking Information

24-lead TSSOP

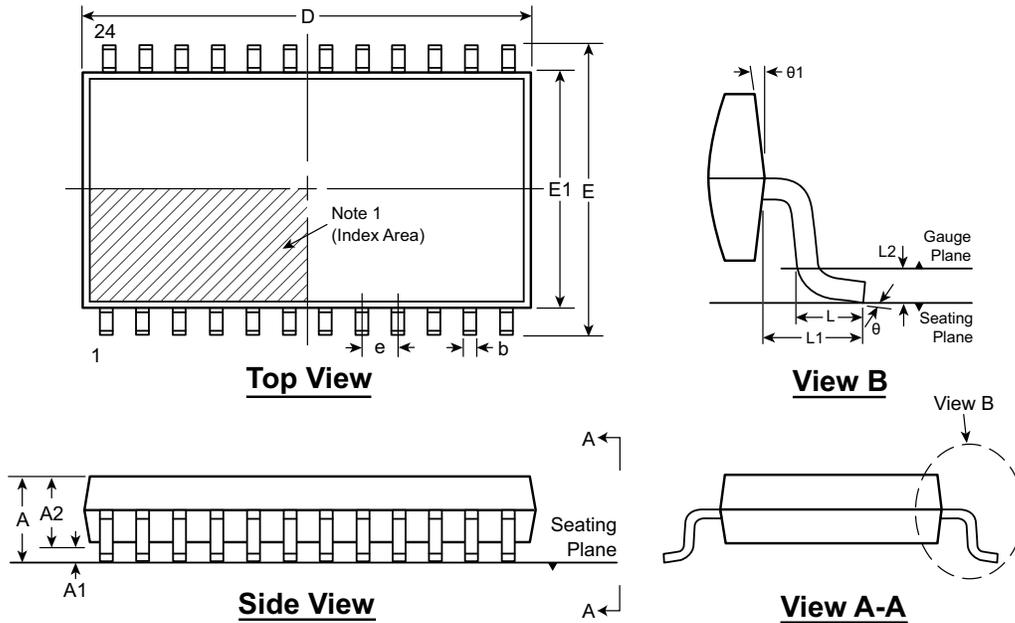


Example



<b>Legend:</b>	XX...X	Product Code or Customer-specific information
	Y	Year code (last digit of calendar year)
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week '01')
	NNN	Alphanumeric traceability code
	(e3)	Pb-free JEDEC® designator for Matte Tin (Sn)
	*	This package is Pb-free. The Pb-free JEDEC designator (e3) can be found on the outer packaging for this package.
<b>Note:</b>	In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line, thus limiting the number of available characters for product code or customer-specific information. Package may or not include the corporate logo.	

## 24-Lead TSSOP Package Outline (TS) 7.80x4.40mm body, 1.20mm height (max), 0.65mm pitch



Note: For the most current package drawings, see the Microchip Packaging Specification at [www.microchip.com/packaging](http://www.microchip.com/packaging).

**Note:**

1. A Pin 1 identifier must be located in the index area indicated. The Pin 1 identifier can be: a molded mark/identifier; an embedded metal marker; or a printed indicator.

Symbol	A	A1	A2	b	D	E	E1	e	L	L1	L2	$\theta$	$\theta_1$
Dimension (mm)	MIN	0.85*	0.05	0.80	0.19	7.70	6.20*	4.30	0.45	1.00 REF	0.25 BSC	0°	12° REF
	NOM	-	-	1.00	-	7.80	6.40	4.40	0.60			8°	
	MAX	1.20	0.15	1.15†	0.30	7.90	6.60*	4.50	0.75				

JEDEC Registration MS-153, Variation AD, Issue F, May 2001.

\* This dimension is not specified in the JEDEC drawing.

† This dimension differs from the JEDEC drawing.

**Drawings are not to scale.**

## APPENDIX A: REVISION HISTORY

### Revision A (May 2018)

- Converted Supertex Doc# DSFP-AT9932 to Microchip DS20005789A
- Changed the package marking format
- Changed the quantity of the 24-lead TSSOP TS package from 3000/Reel to 2500/Reel
- Made minor text changes throughout the document

# AT9932

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To order or obtain information, e.g., on pricing or delivery, contact your local Microchip representative or sales office.

<u>PART NO.</u>	<u>XX</u>	-	<u>X</u>	-	<u>X</u>
Device	Package Options		Environmental		Media Type
Device:	AT9932	=	Automotive Boost-Buck LED Lamp Driver IC		
Package:	TS	=	24-lead TSSOP		
Environmental:	G	=	Lead (Pb)-free/RoHS-compliant Package		
Media Type:	(blank)	=	2500/Reel for a TS Package		

**Example:**

a) AT9932TS-G: Automotive Boost-Buck LED Lamp Driver IC, 24-lead TSSOP, 2500/Reel

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