TB921/22
3-Pin Switch-Mode LED Lamp Driver ICs

General Description

The TB921/22 are pulse width modulated (PWM) high-efficiency LED driver control ICs. They allow efficient operation of LED strings from voltage sources ranging up to 400VDC. The TB921/22 include an internal high voltage switching MOSFET controlled with fi xed off-time T_{OFF} of approximately 10μs. The LED string is driven at constant current, thus providing constant light output and enhanced reliability. The output current is internally fi xed at 20/50mA for TB921/22. The peak current control scheme provides good regulation of the output current throughout the universal AC line voltage range of 85 to 264VAC or DC input voltage of 20 to 400V.
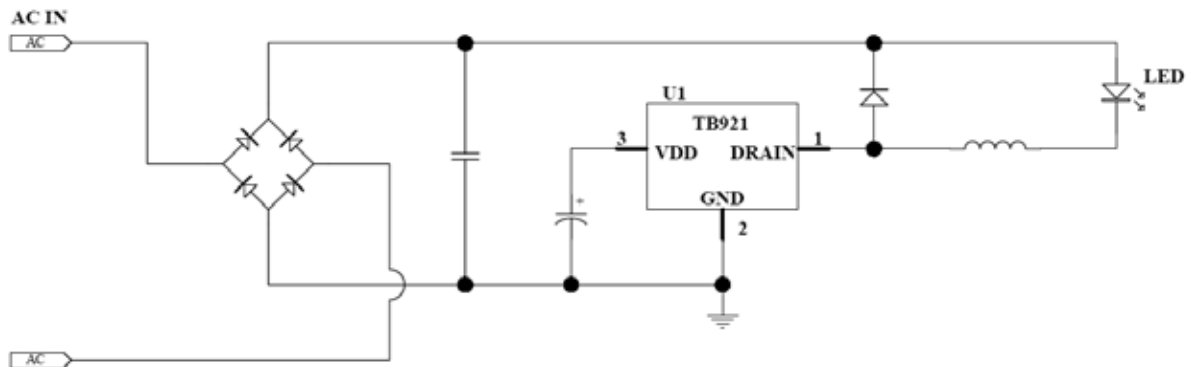
Features

Constant Output Current:
    TB921 – 20mA
    TB922 – 50mA
Universal 85-264VAC Operation
Fixed OFF-Time Buck Converter
Internal 500V Power MOSFET

Applications

Decorative Lighting
Low Power Lighting Fixtures

Typical Application Circuit

Absolute Maximum Ratings

Supply Voltage, V_{DD}	-0.3 to +10V
Supply Current, I_{DD}	+5mA
Operating Ambient Temperature Range	-40°C to +85°C
Operating Junction Temperature Range	-40° to +125°C
Storage Temperature Range	-65° to +150°C
Power Dissipation @ 25°C, SOT-89	1600mW†

+ Mounted on FR4 board, 25mm x 25mm x 1.57mm. Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifi cations is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Regulator (V_{DD})

Symbol	Paramefer	Min	Typ	Max	Units	Conditions
V_{DD}	V_{DD} Regulator Output	-	7.5	-	V	---
V_{DRAIN}	V_{DRAIN} Supply Voltage	20	-	-	V	---
V_{UVLO}	V_{DD} Undervoltage Threshold	5.0		-	V	---
ΔV_{UVLO}	V_{DD} Undervoltage Lockout Hysteresis	-	200	-	mV	---
I_{DD}	Operating Supply Current	-	200	350	uA	$V_{DD(EXT)}$ = 8.5V, V_{DRAIN} = 40V

Output (DRAIN)

Symbol	Paramefer	Min	Typ	Max	Units	Conditions
V_{BR}	Breakdown Voltage	500	-	-	V	---
R_{ON}	ON Resistance – TB921/22	-	-	210	Ω	I_{DRAIN} = 20mA I_{DRAIN} = 50mA I_{DRAIN} = 30mA
C_{DRAIN}	Output Capacitance	-	1	5	pF	V_{DRAIN} = 400V
I_{SAT}	MOSFET Saturation Current	100	150	-	mA	---

Current Sense Comparator

Symbol	Paramefer	Min	Typ	Max	Units	Conditions
I_{TH}	Threshold Current – TB921	20.5	-	25.5	mA	*
I_{TH}	Threshold Current – TB922	52	-	63	mA	*
T_{BLANK}	Leading Edge Blanking Delay	200	300	400	ns	*
$T_{ON(MIN)}$	Minimum ON Time	-	-	650	ns	---

OFF-Time Generator

Symbol	Paramefer	Min	Typ	Max	Units	Conditions
T_{OFF}	OFF Time	8	10.5	13	us	---

Functional Block Diagram
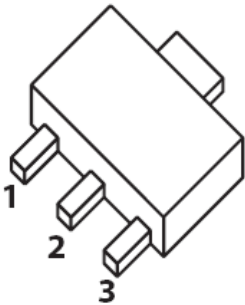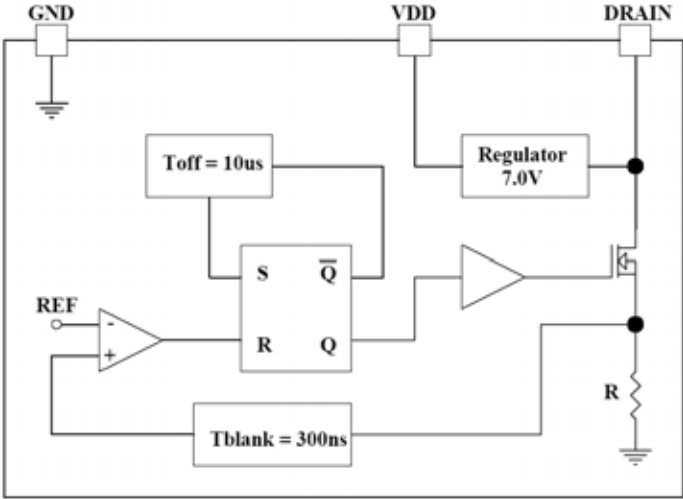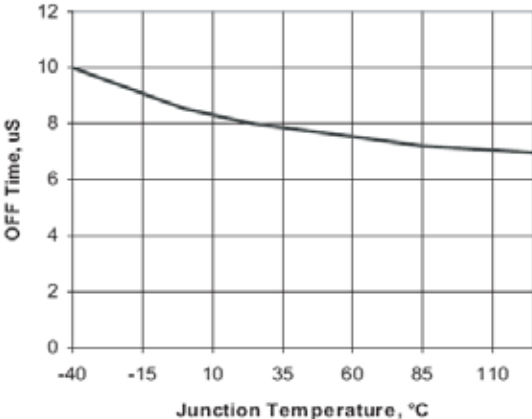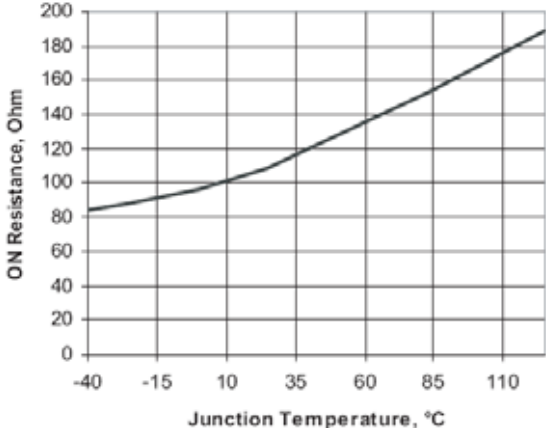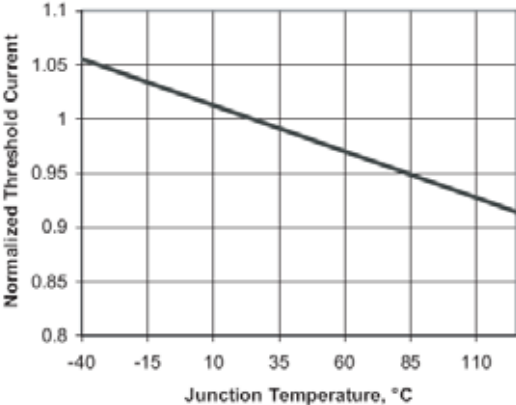

Drain – This is a drain terminal of the output switching
MOSFET and a linear regulator input.

GND – This is a common connection for all circuits.

VDD – This is a power supply pin for all control circuits.
Bypass this pin with a 0.1uF low impedance
capacitor.

Typical Performance Characteristics (T$_J$ = 25 °C unless otherwise noted)
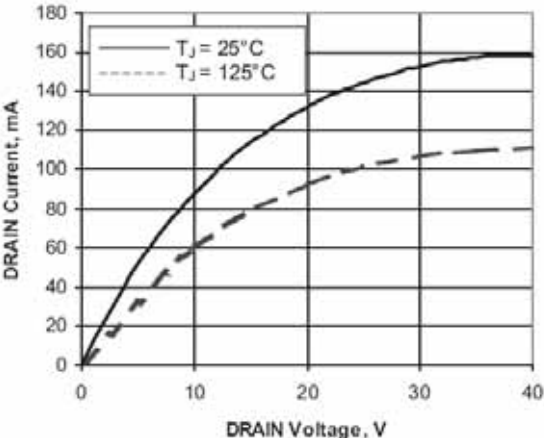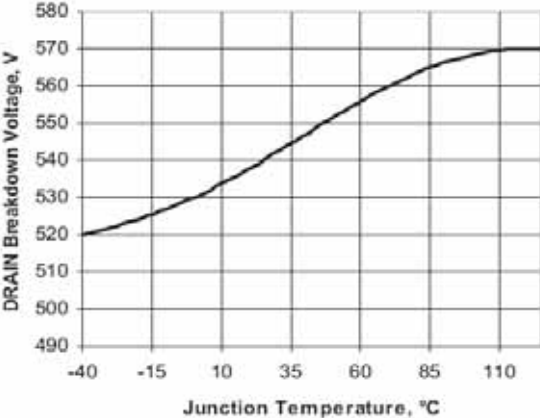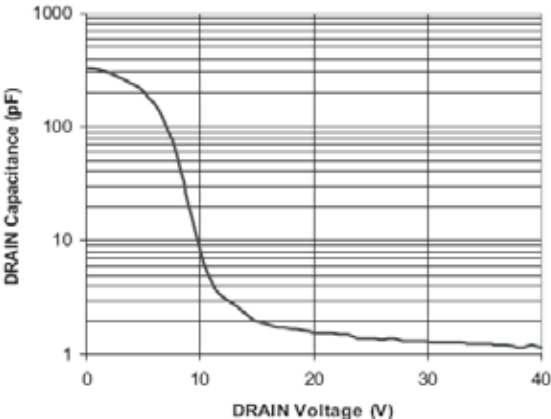
Functional Description

The TB921/22 are PWM peak current controllers for controlling a buck converter topology in Continuous conduction mode (CCM). The output current is internally preset at 20mA (TB921), 50mA (TB922).

When the input voltage of 20 to 400V appears at the DRAIN pin, the internal high-voltage linear regulator seeks to maintain a voltage of 7VDC at the V_{DD} pin. Until this voltage exceeds the internally programmed under-voltage threshold, the output switching MOSFET is non-conductive. When the threshold is exceeded, the MOSFET turns on. The input current begins to fl ow into the DRAIN pin. Hysteresis is provided in the under-voltage comparator to prevent oscillation.

When the input current exceeds the internal preset level, a current sense comparator resets an RS flip-flop, and the MOSFET turns off. At the same time, a one-shot circuit is activated that determines the duration of the off-state (10.5 μ S typ.). As soon as this time is over, the fl ip-fl op sets again. The new switching cycle begins.

A "blanking" delay of 300nS is provided that prevents false triggering of the current sense Comparator due to the leading edge spike caused by circuit parasitics.

Application Information

The TB921/22/23 is a low-cost off-line buck converter IC specifi cally designed for driving multi-LED strings. It can be operated from either universal AC line range of 85 to 264VAC, or 20 to 400VDC, and drives up to tens of high brightness LEDs. All LEDs can be run in series, and the TB921/22 regulates at constant current, yielding uniform illumination. The TB921/22 is compatible with triac dimmers. The output current is internally fi xed at 20mA for the TB921, 50mA for the TB922. These parts are available in space saving TO-92 and SOT-89 packages.

Selecting L1 and D1

There is a certain trade-off to be considered between optimal sizing of the output inductor L1 and the Tolerated output current ripple. The required value of L1 is inversely proportional to the ripple current $\triangle I_O$ in it.

$$L1 = \frac{V_O \cdot T_{OFF}}{\Delta I_O} \qquad (1)$$

V_O is the forward voltage of the LED string. T_{OFF} is the off-time of the TB921/22. The output current in the LED string (I_O) is calculated then as:

$$I_O = I_{TH} - \frac{1}{2} \cdot \Delta I_O \qquad (2)$$

where I_{TH} is the current sense comparator threshold. The ripple current introduces a peak-to-average error in the output current setting that needs to be accounted for. Due to the constant off-time control technique used in the TB921/22, the ripple current is independent of the input AC or DC line voltage variation. Therefore, the output Current will remain unaffected by the varying input voltage.

Adding a filter capacitor across the LED string can reduce the output current ripple even further, thus permitting a reduced value of L1. However, one must keep in mind that the peak-to-average current error is affected by the variation of T_{OFF}. Therefore, the initial output current accuracy might be sacrificed at large ripple current in L1.

Another important aspect of designing an LED driver with the TB921/22 is related to certain parasitic elements of the circuit, including distributed coil capacitance of L1, junction capacitance and reverse recovery of the rectifier diode D1, capacitance of the printed circuit board traces C_{PCB} and output capacitance C_{DRAIN} of the controller itself. These parasitic elements affect the efficiency of the switching converter and could potentially cause false triggering of the current sense comparator if not properly managed. Minimizing these parasitics is essential for efficient and reliable operation of the HV9921/22.

Coil capacitance of inductors is typically provided in the manufacturer's data books either directly or in terms of the self-resonant frequency (SRF).

$$SRF = 1/(2\pi\sqrt{L \cdot C_L})$$

where L is the inductance value, and C_L is the coil capacitance. Charging and discharging this capacitance every switching cycle causes high-current spikes in the LED string. Therefore, connecting a small capacitor C_O (~10nF) is recommended to bypass these spikes.

Using an ultra-fast rectifier diode for D1 is recommended to achieve high efficiency and reduce the risk of Alse triggering of the current sense comparator. Using diodes with shorter reverse recovery time t_{rr} and lower junction capacitance C_J achieves better performance. The reverse voltage rating V_R of the diode must be greater than the maximum input voltage of the LED lamp.

The total parasitic capacitance present at the DRAIN pin of the TB921/22 can be calculated as:

$$C_P = C_{DRAIN} + C_{PCB} + C_L + C_J \qquad (3)$$

When the switching MOSFET turns on, the capacitance C_P is discharged into the DRAIN pin of the IC. The Discharge current is limited to about 150mA typically. However, it may become lower at increased junction temperature. The duration of the leading edge current spike can be estimated as:

$$T_{SPIKE} = \frac{V_{IN} \cdot C_P}{I_{SAT}} + t_{rr} \qquad (4)$$

In order to avoid false triggering of the current sense comparator, C_P must be minimized in accordance with the following expression:

$$C_P < \frac{I_{SAT} \cdot (T_{BLANK(MIN)} - t_{rr})}{V_{IN(MAX)}} \qquad (5)$$

where $T_{BLANK(MIN)}$ is the minimum blanking time of 200ns, and $V_{IN(MAX)}$ is the maximum instantaneous input voltage.

Estimating Power Loss

Discharging the parasitic capacitance C_P into the DRAIN pin of the HV9921/22 is responsible for the bulk of the switching power loss. It can be estimated using the following equation:

$$P_{SWITCH} = \left(\frac{V_{IN}^2 C_P}{2} + V_{IN} I_{SAT} \cdot t_{rr} \right) \cdot F_S \qquad (6)$$

where F_S is the switching frequency, I_{SAT} is the saturated DRAIN current of the TB921/22. The switching loss is the greatest at the maximum input voltage.

The switching frequency is given by the following:

$$F_S = \frac{V_{IN} - \eta^{-1} \cdot V_O}{V_{IN} \cdot T_{OFF}} \qquad (7)$$

where η is the effi ciency of the power converter.

When the TB921/22 LED driver is powered from the full-wave rectifi ed AC input, the switching power loss can be estimated as:

$$P_{SWITCH} \approx \frac{1}{2 \cdot T_{OFF}} (V_{AC} \cdot C_P + 2 \cdot I_{SAT} \cdot t_{rr})(V_{AC} - \eta^{-1} \cdot V_O) \qquad (8)$$

V_{AC} is the input AC line voltage.

The switching power loss associated with turn-off transitions of the DRAIN pin can be disregarded. Due to the large amount of parasitic capacitance connected to this switching node, the turn-off transition occurs essentially at zero-voltage.

Conduction power loss in the TB921/22 can be calculated as:

$$P_{COND} = D \cdot I_O^2 \cdot R_{ON} + I_{DD} \cdot V_{IN} \cdot (1 - D) \qquad (9)$$

where $D = V_O / \eta \, V_{IN}$ is the duty ratio, R_{ON} is the ON resistance, I_{DD} is the internal linear regulator current. When the LED driver is powered from the full-wave rectifi ed AC line input, the exact equation for calculating The conduction loss is more cumbersome. However, it can be estimated using the following equation:

$$P_{COND} = K_c \cdot I_O^2 \cdot R_{ON} + K_d \cdot I_{DD} \cdot V_{AC} \qquad (10)$$

where V_{AC} is the input AC line voltage. The coeffi cients K_C and K_d can be determined from the minimum duty ratio of the TB921/22
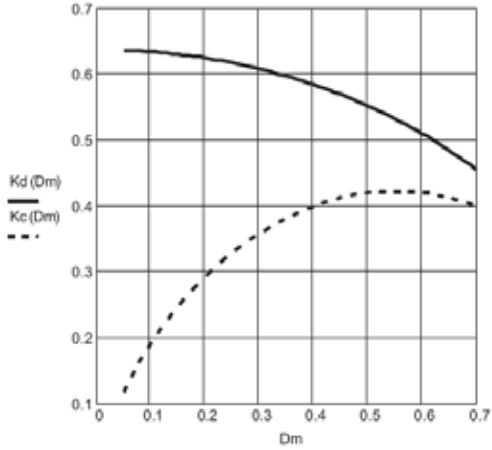

Fig. 1. Conduction Loss Coeffi cients K_C and K_d

EMI Filter

As with all off-line converters, selecting an input fi lter is critical to obtaining good EMI. A switching side capacitor, albeit of small value, is necessary in order to ensure low impedance to the high frequency switching currents of the converter. As a rule of thumb, this capacitor should be approximately 0.1- 0.2 μ F/W of LED output power. A recommended input fi lter is shown in Figure 2 for the following design example.

Design Example 1

Let us design an TB921 LED lamp driver meeting the following specifi cations:

Input: Universal AC, 85-264VAC
Output Current: 20mA
Load: String of 10 LED (LW541C by OSRAM $V_F = 4.1V$ max. each)

Step 1. Calculating L1.

The output voltage $V_O = 10 \times V_F \approx 41V$ (max.). Use equation
(1) assuming a 30% peak-to-peak ripple.

$$L1 = \frac{41V \cdot 10.5 \mu s}{0.3 \cdot 20mA} = 72mH$$

Select L1 68mH, I=30mA. Typical SRF=170KHz. Calculate the coil capacitance.

$$C_L = \frac{1}{L1 \cdot (2\pi \cdot SRF)^2} = \frac{1}{68mH \cdot (2\pi \cdot 170KHz)^2} \approx 13pF$$

Step 2. Selecting D1

Usually, the reverse recovery characteristics of ultrafast rectifi ers at I_F=20~50mA are not provided in the Manufacturer's data books. The designer may want to experiment with different diodes to achieve the best result.

Select D1 MUR160 with V_R = 600V, $t_{rr} \approx$ 20ns (I_F=20mA, I_{RR}=100mA) and $C_J \approx$ 8pF (V_F>50V).

Step 3. Calculating total parasitic capacitance using (3)

$$C_p = 5pF + 5pF + 13pF + 8pF = 31pF$$

Step 4. Calculating the leading edge spike duration using (4), (5)

$$T_{SPIKE} = \frac{264V \cdot \sqrt{2} \cdot 31pF}{100mA} + 20ns \approx 136ns < T_{BLANK(MIN)}$$

Step 5. Estimating power dissipation in TB921 at 264VAC using (8) and (10)

Let us assume that the overall effi ciency η = 0.7.

Switching power loss:

$$P_{SWITCH} \approx \frac{1}{2 \cdot 10.5\mu s}(264V \cdot 31pF + 2 \cdot 100mA \cdot 20ns)\left(264V - \frac{41V}{0.7}\right)$$

$$P_{SWITCH} \approx 120mW$$

Minimum duty ratio:

$$D_m = 41V / (0.7 \cdot 264V \cdot \sqrt{2}) \approx 0.16$$

Conduction power loss:

$$P_{COND} = 0.25 \cdot (20mA)^2 \cdot 210\Omega + 0.63 \cdot 200\mu A \cdot 264V \approx 55mW$$

Total power dissipation in TB921:

$$P_{TOTAL} = 120mW + 55mW = 175mW$$

Step 6. Selecting input capacitor C_{IN}

$$\text{Output Power} = 41V \cdot 20mA = 820mW$$

Select C_{IN} ECQ-E4104KF by Panasonic (0.1 μF, 400V, Metalized Polyester Film).

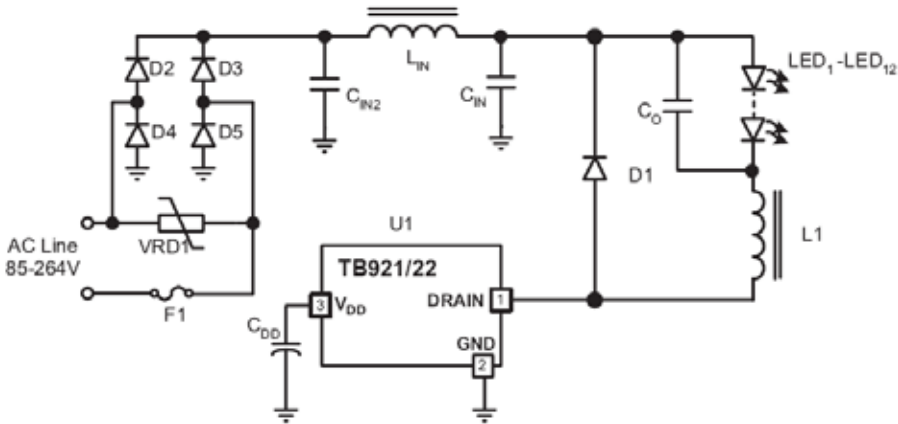# Figure 2. Universal 85-264VAC LED Lamp Driver
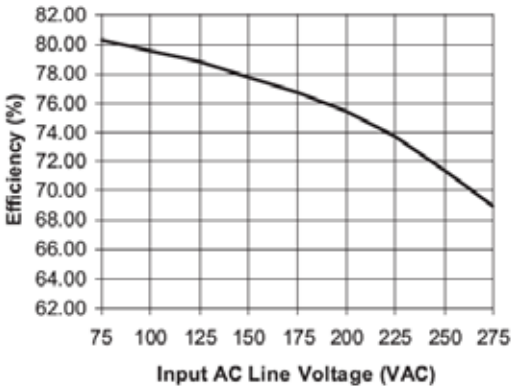

Figure 3. Typical Efficiency

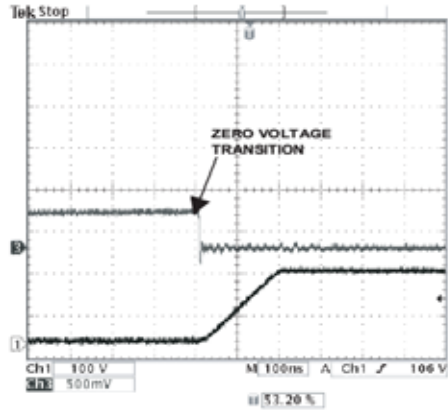Figure 4. Switch-Off Transition. Ch1: V_DRAIN, Ch3: I_DRAIN
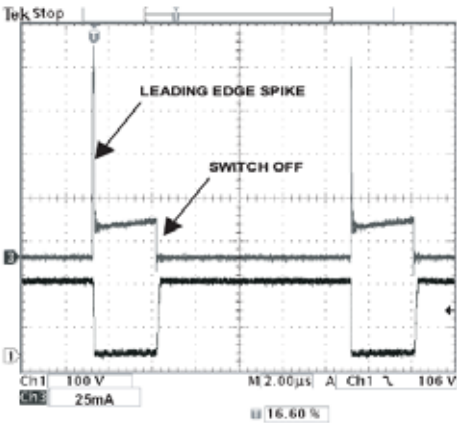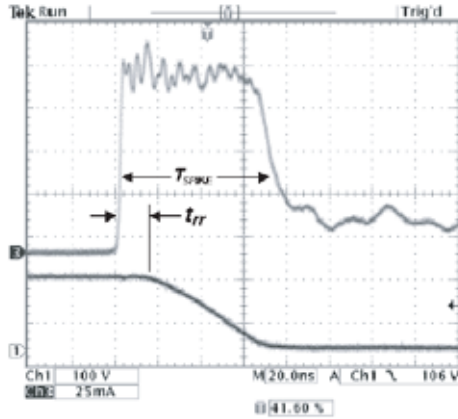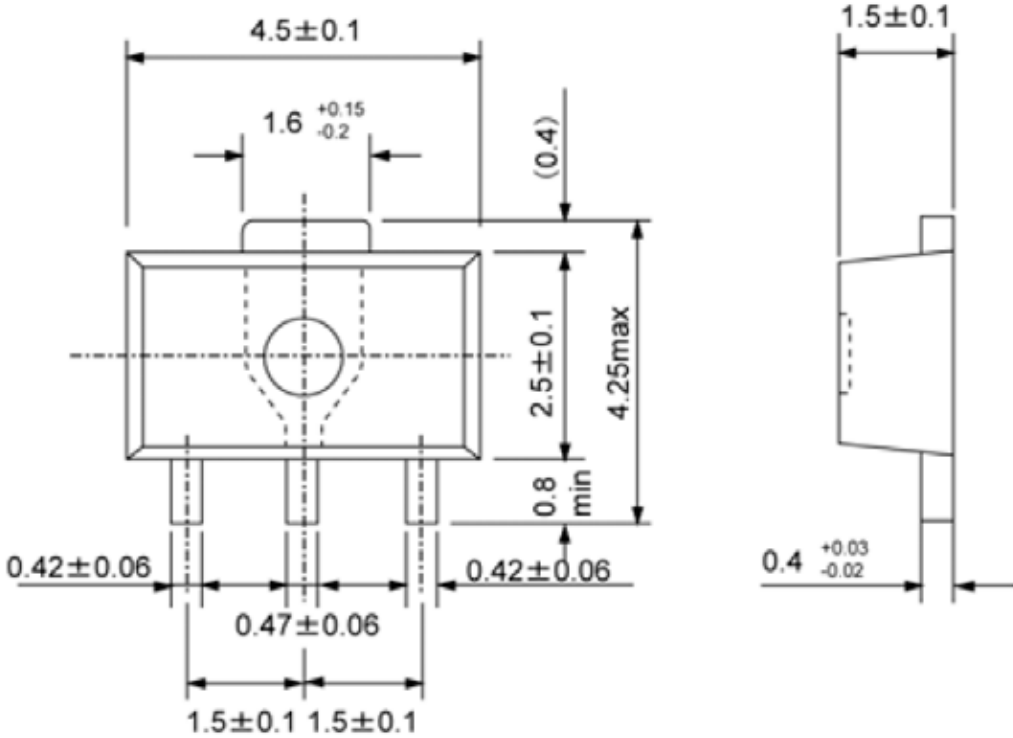

Figure 5. Typical Efficiency

Figure 6. Switch-Off Transition. Ch1: V_DRAIN, Ch3: I_DRAIN

Package Information
SOT-89 (unit mm)

TO-92 （unit mm）

$4.65^{+0.35}_{-0.45}$

3.7 ± 0.3

$4.8^{+0.4}_{-0.5}$

13.5 ± 0.5

0.45 ± 0.1

0.4 ± 0.05

（1.27）