XC9404

Application Notes

1. General Description

The XC9404 series are LED lighting offline controllers that use PFM(Pulse Frequency Modulation) control and have a Power Factor improvement function. The operating input voltage range is 85VAC to 270VAC, and the current is controlled on the primary side without using a Opto-coupler or secondary side control circuit. Because LED current fluctuations caused by input voltage fluctuations and LED voltage fluctuations can be suppressed, a stable LED lighting power supply is obtained.

A high Power Factor and low THD are attained by synchronizing the input current with the input voltage, and operation in DCM(Discontinuous Current Mode) makes it possible to achieve high efficiency. An internal acceleration startup circuit enables the LED lighting to illuminate quickly.

Over-voltage protection, over-current protection, and UVLO are provided as internal protective functions, and can suppress smoke and fire even when an LED short-circuits or is open.

2. Product Features

Unlike methods that combine a PFC IC with a constant-current IC, the XC9404 series improves the Power Factor and performs constant-current control using a single IC.

This enables simplification of the circuit and fewer components for a significant reduction of cost.

In addition, the optimum solution for the application can be selected from either an isolated flyback circuit that emphasizes safety, or a non-isolated buck-boost circuit that emphasizes cost.

This enables optimal use in a wide range of applications, from LED light bulbs under 10W to commercial/industrial lighting that requires a high Power Factor / low THD.

- **Operating Voltage** **:85VAC ~ 270VAC**
- **Output Wattage** **:up to 50W**
- **Power Factor / THD** **:Power Factor 0.95 or more / THD up to 10% attainable**
- **Harmonics regulations** **:IEC61000-3-2 class C compliance possible**
- **Control Method** **:PFM Control**
- **Function** **:Opto-coupler free due to primary control**
  :Built-in acceleration Start
  :Low Start up Current 20μA
- **Protection Function** **:LED Open/Short protection**
  :Over Voltage Protection
  :Over Current Protection
  :UVLO
- **Package** **:SOP-8D**
- **Operation Ambient Temperature** **:-40℃ ~ +105℃**

3. Pin Assignments and Pin Functions

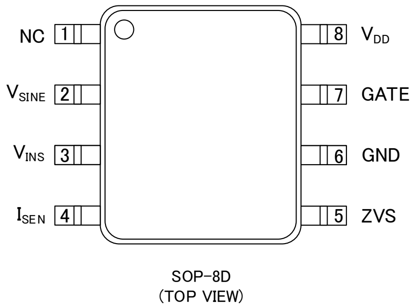


Fig. 1: Package shape and pin assignments

PIN NUMBER	PIN NAME	FUNCTION
1	NC	No connection.
2	V_{SINE}	V_{SINE} pin to detect the rectified sine waveform of input voltage.
3	V_{INS}	V_{INS} pin to detect the rectified sine waveform peak value of input voltage.
4	I_{SEN}	I_{SEN} pin monitors the primary current.
5	ZVS	Monitors the auxiliary coil voltage to detect secondary current conduction time and switch the operation state.
6	GND	Ground pin.
7	GATE	External power MOSFET drive pin.
8	V_{DD}	Power Input pin.

4. Block Diagram

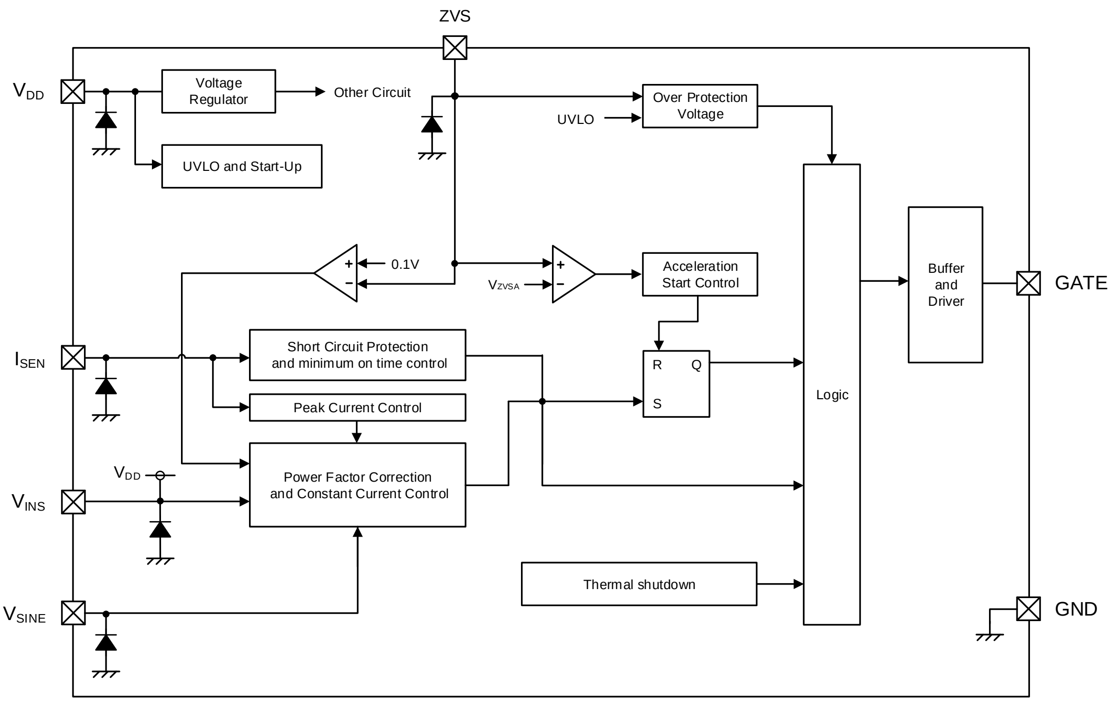


図.2Block Diagram

5. Explanation of operation

This section describes detailed control methods. 5-1 describes startup, 5-2 and 5-3 describe normal operation, and 5-4 describes protective functions. For peripheral component constant settings and selection methods, refer to Sections 6 and 7.

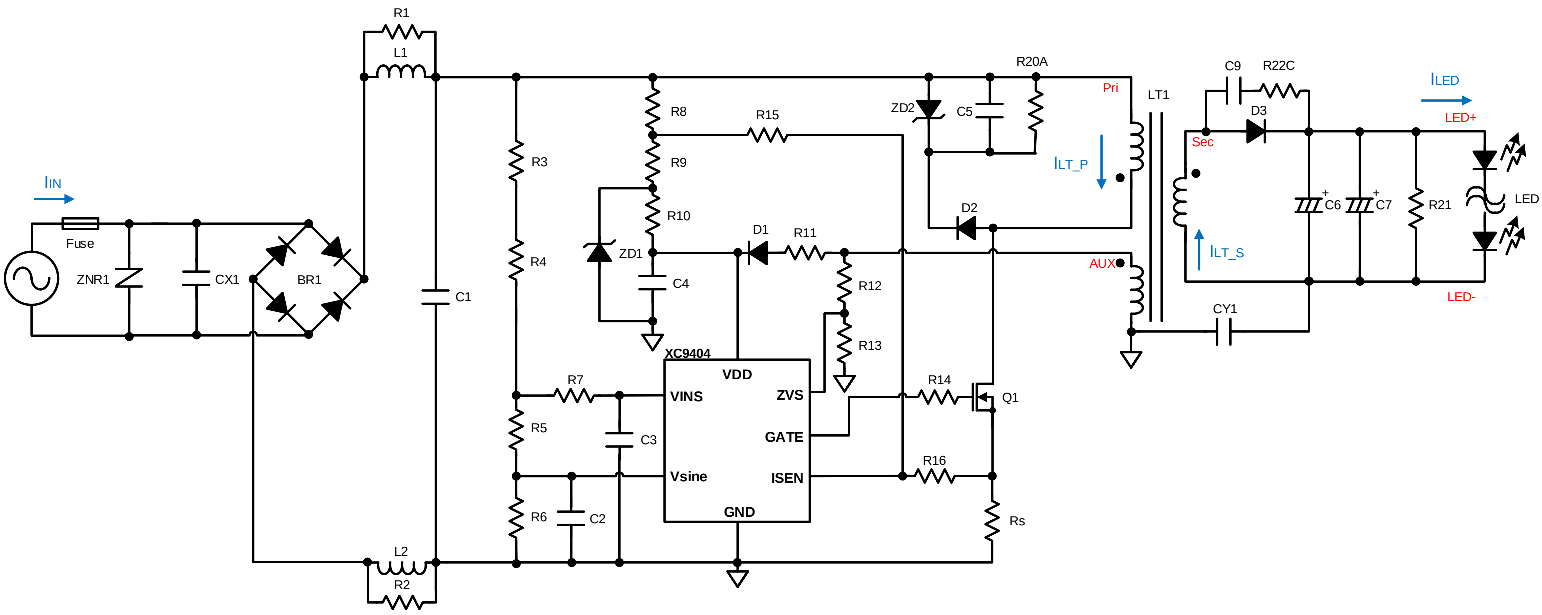


Fig 3: Isolated flyback circuit example

5-1. Startup and operation modes

The operation modes of the XC9404 series consist of CC Mode which performs normal operation, Acceleration Mode which performs startup operation, CV mode which prevents the output voltage from exceeding the specified voltage, and Over Voltage Protection which prevents peripheral component destruction due to over-voltage. Operation mode switching is accomplished by means of the ZVS pin voltage, which divides the transformer auxiliary coil voltage. Please see below for the details about the each operation mode.

<< Acceleration Mode>>

Acceleration Mode is used for fast startup.

To shorten the startup time, the output voltage is low, and when the ZVS pin voltage is below the ZVS Acceleration Threshold Voltage, the IC operates in critical mode rather than Discontinuous Current Mode to reduce the startup time.

When the ZVS pin voltage rises above the ZVS Acceleration Threshold Voltage, the mode changes to CC Mode.

<<CC Mode>>

CC Mode outputs a constant current. A detailed explanation of CC Mode can be found in 5-2 and 5-3.

<<CV Mode>>

CV Mode prevents the output voltage from exceeded the specified voltage. When the ZVS pin voltage rises higher than the ZVS CV Threshold Voltage, CV Mode turns off the power MOSFET and keeps the power MOSFET off until the ZVS pin voltage drops below the ZVS CV Threshold Voltage.

<< Over Voltage Protection >>

This mode prevents destruction of peripheral components when the output voltage goes into an over-voltage state. When the output voltage goes into an over-voltage state, the ZVS pin voltage rises, and when it exceeds the ZVS Over Voltage Threshold Voltage, this mode latches the power MOSFET in the off state. To release the latch state and return to normal operation, the V_{DD} pin voltage is lowered below the latch release voltage and then raised above the Startup Threshold Voltage.

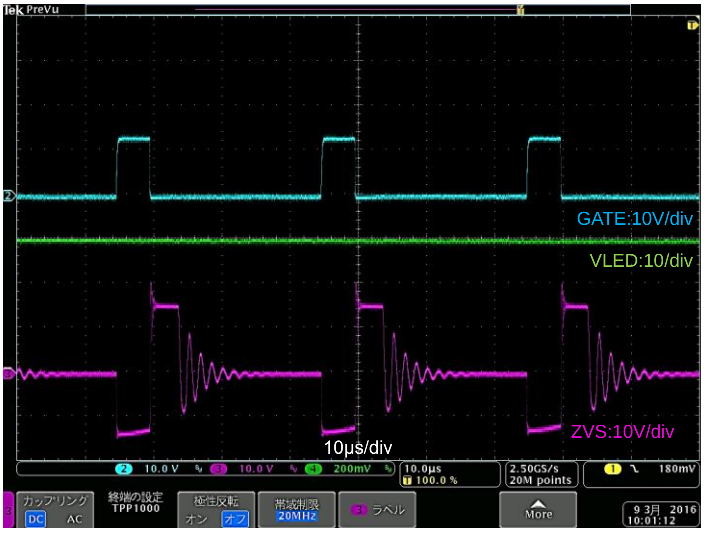


Fig. 4: Transformer auxiliary voltage and ZVS pin voltage

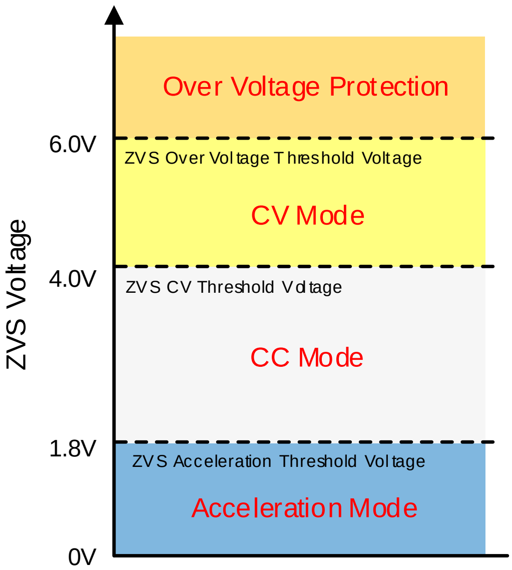
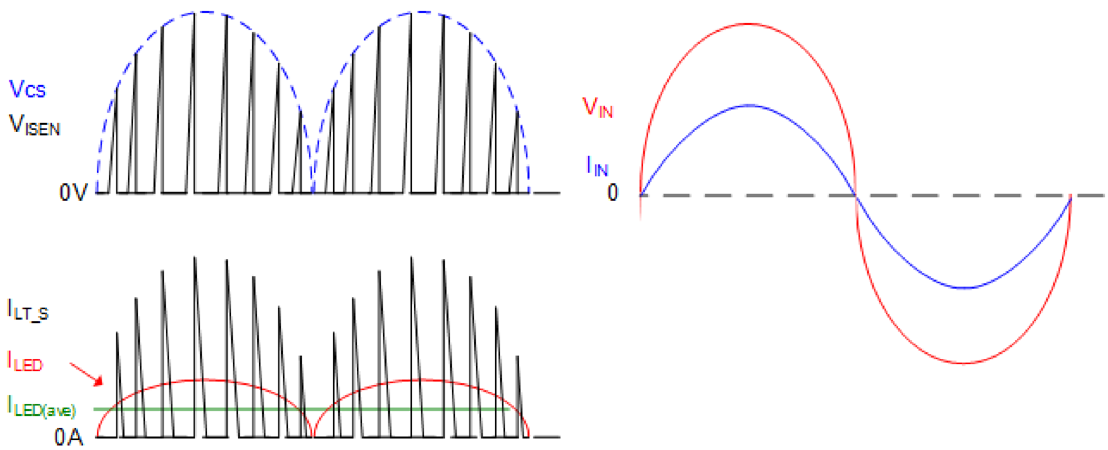


Fig. 5: ZVS pin voltages and corresponding operation modes

5-2.Overview of control methods

The XC9404 series controls the power MOSFET so that the I_{SEN} pin voltage and the IC internal voltage Vcs, which is the same phase as the input voltage (sine wave), are equalized. The input current, peak current of the primary coil, and peak current of the secondary coil of the transformer can be put in the same phase as the input voltage by means of this control, which makes it possible to achieve a high Power Factor and low THD.



(a) I_{SEN} pin voltage and transformer current waveform (b) Input current waveform

Fig. 6: Overview of operation waveforms

In addition, on-time and off-time are dynamically controlled based on the input voltage, LED voltage, and input voltage phase to keep the LED current constant regardless of the input voltage and LED voltage. By means of this control of on-time and off-time, stable LED current can be supplied regardless of the input voltage and LED voltage.

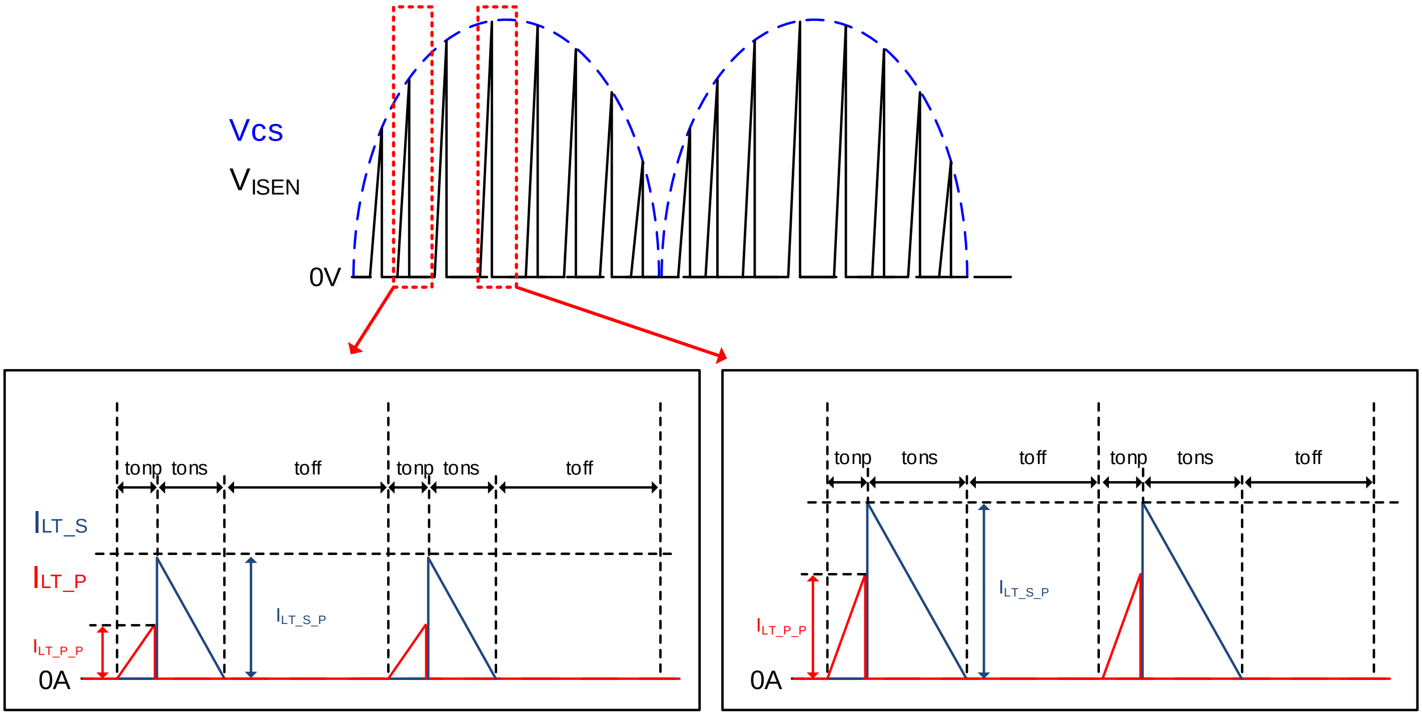


Fig. 7: Dynamic on-time and off-time control

5-3. Control method details and constant adjustment methods

5-3-1. Power Factor improvement function

To improve the Power Factor, the XC9404 series inputs input voltage phase information from the V_{SINE} pin and the average value of the input voltage from the V_{INS} pin. Using the V_{SINE} pin and V_{INS} pin, an IC internal voltage Vcs is created with the same phase as the input voltage. Vcs is given by Equation (1).

$$Vcs(t) = Kline \cdot sin\theta \quad (1)$$

$$Kline = \frac{V_{SINE\_peak}}{V_{INS}} = \frac{R6}{(R5 + R6)} \cdot \frac{\pi}{2} \quad (2)$$

Vcs	:	IC internal voltage
θ	:	Phase of input voltage
$Kline$	:	Duty adjustment variable (adjusted with R5,R6)
V_{SINE_peak}	:	Maximum V_{SINE} pin voltage
V_{INS}	:	V_{INS} pin voltage

The power MOSFET is controlled so that the I_{SEN} pin voltage, which is obtained by converting the transformer primary current into a voltage at each switching cycle, is equal to Vcs. This control can change the input current to the same phase as the input voltage to achieve a high Power Factor and low THD. (Refer to Fig. 6)

The transformer primary peak current and on-time tonp are given by Equations (3) and (4) using Vcs.

$$I_{LT\_P\_P}(t) = \frac{Vcs(t)}{Rs} = \frac{Kline}{Rs} \cdot sin\theta \quad (3)$$

$$tonp(t) = \frac{L_P}{\sqrt{2} \cdot Vrms \cdot sin\theta} \cdot I_{LT\_P\_P}(t) = \frac{L_P}{\sqrt{2} \cdot Vrms \cdot sin\theta} \cdot \frac{Vcs(t)}{Rs} \cdot tonp(\mathrm{t}) \quad (4)$$

$I_{LT\_P\_P}$	:	Transformer primary peak current
$tonp$	:	Transformer primary current conduction time (power MOSFET on-time)
$Vrms$	:	Input voltage root mean square
L_P	:	Transformer primary inductance value

5-3-2. Constant current control

To supply stable LED current regardless of the input voltage and LED voltage, the XC9404 series controls the on-time and off-time in each switching cycle. (Refer to Fig. 8)

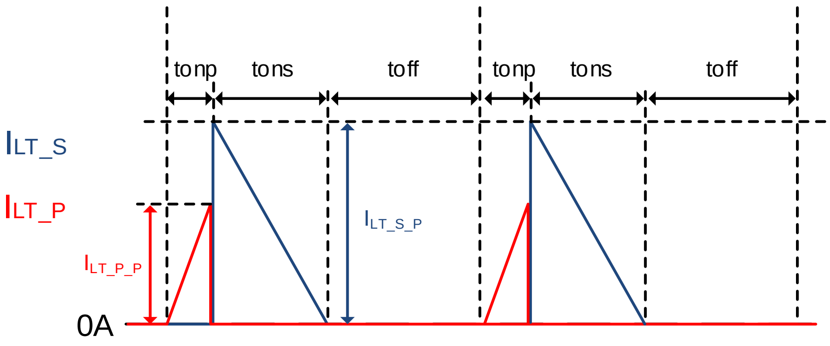


Fig. 8: Transformer current waveform

The LED current is the average value of the transformer secondary current, and is given in terms of the transformer secondary current and duty ratios D and D' by Equation (6).

$$ILED = \frac{1}{T} \cdot \int I_{LT\_S}(t)dt \approx \int \frac{1}{2} \cdot I_{LT\_S\_P}(t) \cdot D'(t)dt \quad (6)$$

$$D = \frac{tonp(t)}{(tonp(t) + tons(t) + toff(t))} \quad (7)$$

$$D' = \frac{tons(t)}{(tonp(t) + tons(t) + toff(t))} \quad (8)$$

$ILED$	:	LED current
T	:	Input voltage period
I_{LT_S}	:	Transformer secondary current
$I_{LT\_S\_P}$	:	Transformer secondary peak current
$tons$	:	Transformer secondary current conduction time
$toff$	:	Non-conduction time of transformer primary and secondary current

The transformer secondary peak current and transformer secondary current conduction time can be expressed by equations (9) and (10) using the transformer primary peak current and turn ratio, and the LED current is expressed by Equation (6').

$$I_{LT\_S\_P}(t) = N \cdot I_{LT\_P\_P}(t) = N \cdot \frac{Vcs(t)}{Rs} \tag{9}$$

$$tons(t) = I_{LT\_S\_P}(t) \cdot \frac{1}{(VLED + VF)} \cdot \frac{Lp}{N} = I_{LT\_P\_P}(t) \cdot \frac{Lp}{(VLED + VF)} \tag{10}$$

$$ILED \approx \frac{1}{2\pi} \cdot \frac{N \cdot Kline}{Rs} \int D' \cdot sin\theta dt = \frac{1}{2\pi} \cdot \frac{N \cdot Kline}{Rs} \int \left\{ \frac{tons(t)}{(tonp(t) + tons(t) + toff(t))} \cdot sin\theta \right\} dt \tag{6'}$$

N : Transformer turn ratio
VF : Forward voltage of rectifier diode D3

By controlling toff so that there is no dependence on the input voltage and LED voltage, stable LED current can be supplied over a wide range of input voltages and output voltages. In this case, toff and the LED current are given by Equations (11) and (6'').

$$toff(t) = \left(\frac{1}{Kline \cdot Kc \cdot sin\theta} - 1 \right) \cdot tons - tonp \tag{11}$$

$$ILED \approx \frac{N \cdot Kline^2 \cdot Kc}{4 \cdot Rcs} \tag{6''}$$

Kc : IC internal constant

5-3-3. Input current and THD

The input current is obtained using the average value of the transformer primary current, and is expressed by Equation (12). From Equation (12), the input current becomes a sine wave using this control method, and a higher Power Factor and lower THD can be obtained as compared to other control methods.

$$Iin(t) \approx \frac{1}{2} I_{LT\_P\_P}(t) \cdot D(t) = \frac{Kc \cdot Kline^2 \cdot N \cdot (VLED + VF)}{2\sqrt{2} \cdot Rs \cdot Vrms} \cdot sin\theta \tag{12}$$

Iin : Input current

In addition, operation is optimized for DCM in the XC9404 series. For this reason, peripheral components must be adjusted to operate in DCM.

To operate in DCM, Equation (13) must be satisfied, and Equation (14) follows from Equation (13). As such, Kline and the turn ratio must be adjusted to satisfy Equation (14).

With toff having been calculated, the switching frequency can be expressed by Equation (15).

$$toff(t) = \left(\frac{1}{Kline \cdot Kc \cdot sin\theta} - 1 \right) \cdot tons - tonp > 0 \tag{13}$$

$$N < \left(\frac{1}{Kline \cdot Kc} - 1 \right) \cdot \frac{\sqrt{2} \cdot Vrms\_min}{(VLED - VF)} \tag{14}$$

$$fosc(t) = \frac{1}{(tonp(t) + tons(t) + toff(t))} = \frac{Kc \cdot N \cdot (VLED + VF)}{Lp} \cdot Rcs \tag{15}$$

$Vrms\_min$: Lower limit of input voltage range
$fosc$: Switching frequency

5-3-4. Other operation

<<Minimum on-time>>

Immediately after the power MOSFET turns on, the charge stored in the Drain-Source capacitance of the power MOSFET flows to the sense resistance Rs and creates spike noise. To prevent malfunctioning of the internal circuitry due to this spike noise, the minimum on-time t_{ONMIN} is set to 750ns. The power MOSFET is forced off until the minimum on-time elapses to prevent malfunctioning of the IC. (Refer to Fig. 9)

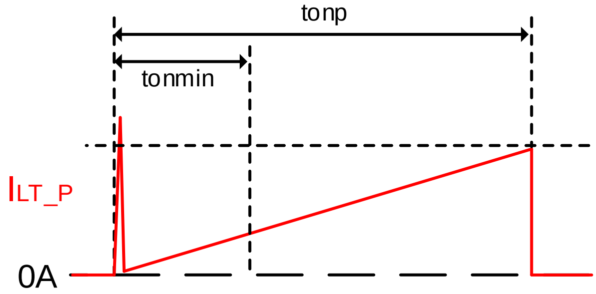


Fig. 9: Spike voltage and minimum on-time

<<Control in input voltage valleys>>

When the input voltage is low and the V_{SINE} pin voltage is low, normal control may not be possible during the toff time. For this reason, if the V_{SINE} pin voltage drops below a fixed voltage, the control method changes from DCM to critical current mode to prevent IC malfunctioning. (Refer to Fig. 10)

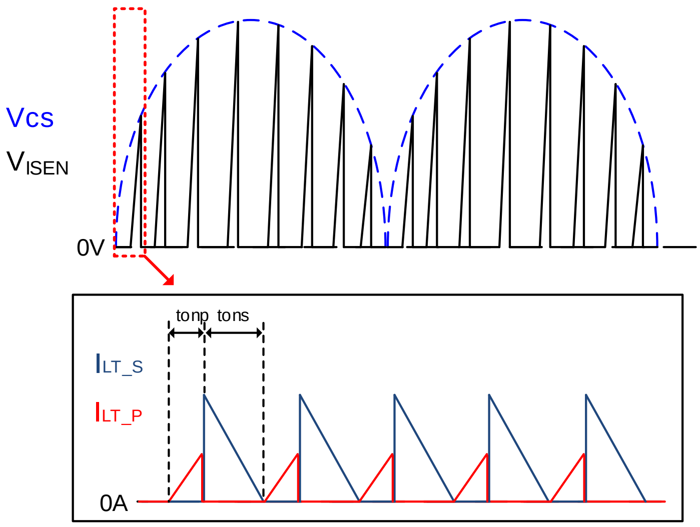


Fig. 10: Operation waveform in critical current mode in input voltage valleys

<<Effects of circuit delay and dissipation>>

The operation described in this section is ideal operation. Characteristics in the actual equipment may differ from ideal operation due to the switching time, circuit dissipation, IC internal circuitry delay, and other factors. These effects may cause the LED current to fluctuate when there are input voltage fluctuations or LED voltage fluctuations.

If LED current fluctuations are observed in the actual equipment, insert correction resistors R15 and R16 to correct the LED current.

5-4. Protective functions

<<Over Voltage Protection>>

This prevents destruction of peripheral components in the event that the output voltage goes into an over-voltage state. When the output voltage goes into an over-voltage state, the ZVS pin voltage rises, and when it exceeds the ZVS Over Voltage Threshold Voltage, the power MOSFET is latched in the off state. To release the latched state and return to normal operation, the V_{DD} pin voltage must be lowered below the 5.6V latch release voltage and then raised above the Start-up Threshold Voltage.

<<Short Circuit Protection Voltage>>

This prevents destruction of peripheral components in the event that over-current flows to the sense resistor Rs due to a short-circuit in the peripheral components or otherwise.

If over-current flows to the sense resistor Rs and the I_{SEN} pin voltage rises above the Short Circuit Protection Voltage, the power MOSFET is latched in the off state. This suppresses destruction of peripheral components due to over-current.

The latched state is released and normal operation resumes when the V_{DD} pin voltage is lowered below the latch release voltage at 5.6V and then raised above the Start-up Threshold Voltage.

<<UVLO>>

If the V_{DD} pin voltage drops below the UVLO detect voltage (V_{UVLO}), this function shuts off the power MOSFET to prevent malfunctioning of the IC. When the V_{DD} pin voltage rises above the Start-up Threshold Voltage, the UVLO state is released and normal operation starts.

<<V_{DD} Over Voltage Protection>>

This function prevents destruction of the IC due to V_{DD} pin over-voltage. When the V_{DD} pin voltage rises above V_{DD} Over Voltage Protection, the power MOSFET is turned off to suppress further increases of the V_{DD} pin voltage.

<Thermal shutdown>

To protect the IC from thermal destruction, the thermal shutdown function activates when the chip temperature reaches 170°C and forcibly puts the GATE pin voltage in the “L” state. When the chip temperature drops down to 145°C, normal operation resumes.

<<LED SHORT/OPEN Protection>>

<u>LED SHORT</u>

The operations that take place in the LED SHORT state are given in ① to ④ below.(Refer to Fig. 11) These operations do not involve the application of over-voltage or over-current to the IC and peripheral components, and thus there is no danger of smoke or fire.

① The V_{DD} pin voltage rises to the UVLO release voltage.
② When the UVLO release voltage is reached, the IC starts normal operation.
Power is not supplied from the auxiliary coil to the V_{DD} pin voltage because the LED is short-circuited, and the V_{DD} pin voltage falls.
③ When the V_{DD} pin voltage reaches the UVLO detect voltage, operation is stopped by the UVLO function.
④ Back to ①

<u>LED OPEN</u>

The operations that take place in the LED OPEN state are given in ① to ④ below.(Refer to Fig.12) These operations do not involve the application of over-voltage or over-current to the IC and peripheral components, and thus there is no danger of smoke or fire.

① The output voltage rises because the LED is in the open state. As the output voltage rises, the ZVS pin voltage rises.
② When the ZVS pin voltage rises above the ZVS CV Threshold Voltage, the power MOSFET is turned off.
③ The ZVS pin voltage falls, and when it drops below the ZVS CV Threshold Voltage, normal operation starts.
④ Back to ①

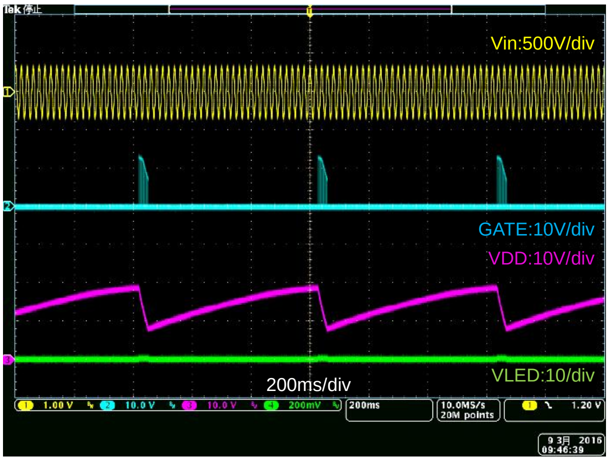


Fig. 11: LED SHORT waveform (Vin=230VAC)

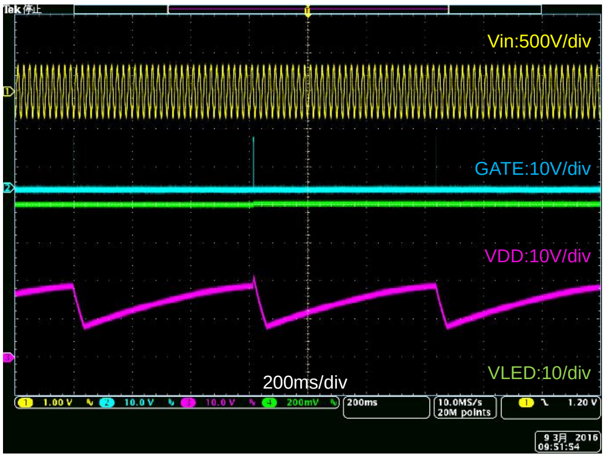


Fig. 12: LED OPEN waveform (Vin=230VAC)

6. Isolated flyback circuit: design example

This section gives an example of how to design an isolated flyback circuit using the XC9404 series. The LED lighting design specifications used for this design example are given in Table 1, and the circuit schematic is shown in Fig. 13.

The design constants below can be calculated using Design Sheet: ”XC9404 cal sheet”.

Table 1: Isolated flyback design specifications

	Min.	Typ.	Max.	Unit
Input Voltage	85	100/230	270	Vrms
Frequency	47	50/60	63	Hz
Power Factor	0.9	-	-	-
THD	-	-	15	%
Isolated/Non-Isolated	Isolated			-
Power		30		W
LED Voltage	27	30	33	V
LED Current		1000		mA
Start-up time	-	500	1000	ms

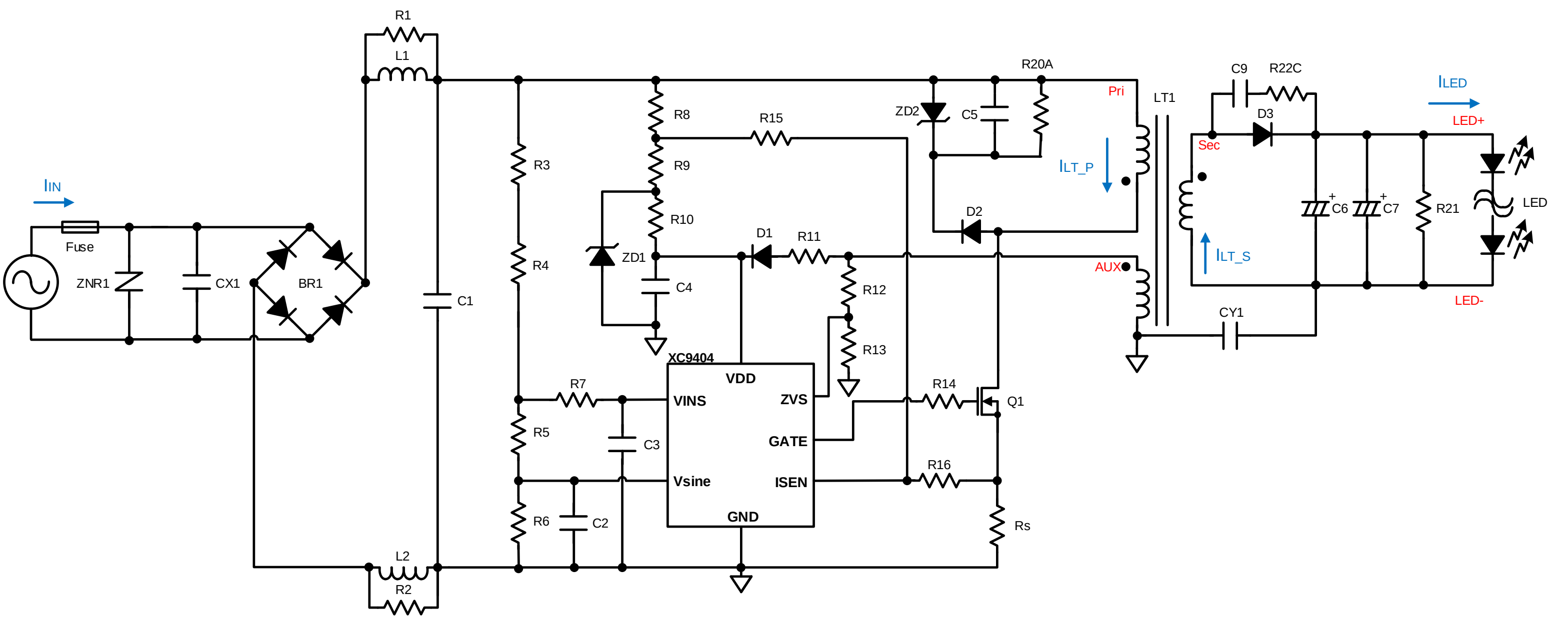


Fig. 13: Isolated flyback circuit example

6-1. Duty Adjustment

Here Kline is selected for duty adjustment.

The optimum value of Kline varies depending on the LED lighting specifications. Adjust so that operation is in DCM using the guidelines in Table 2. In addition, adjust the R3 to R6 resistances so that the maximum voltage of the V_{SINE} pin does not exceed 3V.

Table 2: Target values for isolated flyback Kline

Circuit type	Output power	Kline
Isolated flyback	Less than 20W	1.0
	20W or higher	1.0 to 1.1

In this design, the Kline target value is 1.0 and Kline = 1.02 with $\mathrm{R3} = 2000\mathrm{k\Omega}, \mathrm{R5} = 8.2\mathrm{k\Omega}, \mathrm{R6} = 15\mathrm{k\Omega}$.

6-2. Transformer &Sense Resistor

Select the transformer primary inductance value, turn ratio, and sense resistance.

The transformer turn ratio must satisfy

$$N < \left(\frac{1}{Kline \cdot Kc} - 1\right) \cdot \frac{\sqrt{2} \cdot Vrms\_min}{(VLED + VF)} = \left(\frac{1}{1.02 \cdot \frac{4}{9}} - 1\right) \cdot \frac{\sqrt{2} \cdot 85V}{(30V + 1V)} = 4.67$$

In this design, a turn ratio of 3.5 is used.

The turn ratio of the transformer auxiliary coil depends on the V_{DD} pin voltage and LED voltage. Using 16V for the V_{DD} pin voltage in this design, the turn ratio of the transformer auxiliary coil is

$$N_{AUX} = \frac{V_{DD\_SET}}{(VLED + VF)} = \frac{16V}{(30V + 1V)} = 0.516$$

N_{AUX} : Turn ratio of transformer auxiliary coil
V_{DD_SET} : Target value of V_{DD} pin voltage

In this design, a transformer auxiliary turn ratio of 0.524 is used.

Next, the sense resistance is adjusted. From Equation (6’’), the sense resistance Rs is

$$Rs \approx \frac{N \cdot Kline^2 \cdot Kc}{4 \cdot ILED} = \frac{3.5 \cdot 1.02^2 \cdot \frac{4}{9}}{4 \cdot 1A} = 0.405\Omega$$

In this design, 0.380Ω is used for Rs.

The LED current may not match the calculated value due to circuit dissipation, IC internal circuit delay, and other factors. Adjust the sense resistance in the actual equipment.

Next, the transformer primary inductance value is selected.

The transformer primary inductance value is determined by the lower limit of the switching frequency. In this design, 50kHz is used as a guideline for the lower limit of the switching frequency, and thus the transformer primary inductance Lp given by Equation (16) is

$$Lp = \frac{Kc \cdot N \cdot (VLED + VF)}{fosc} \cdot Rs = \frac{\frac{4}{9} \cdot 3.5 \cdot (30V + 1V)}{50kHz} \cdot 0.380\Omega = 400\mu H$$

In this design, 480μH is used for the transformer primary inductance value.

Verify that the circuit operates in DCM with the above designed constants.

If the circuit does not operate in DCM, repeat the steps of 6-1 and 6-2 and adjust so that operation is in DCM.

6-3. Other Parameters

<< Start-up Time >>

The start-up time is determined by the sum of the interval from power-on to IC start-up and the time needed for the output voltage to rise after IC start-up. However, most of the start-up time is the time required for the IC to start operation, and thus the startup time t_s can be roughly calculated as follows:

$$t_s \approx \frac{C4 \cdot (R8 + R9 + R10)}{\sqrt{2} \cdot Vrms} \cdot V_{ST}$$

t_s	:	Start-up time
V_{ST}	:	Start-up Threshold Voltage

In this design, $\mathrm{C4} = 4.7\mu\mathrm{F}, \mathrm{R8} + \mathrm{R9} + \mathrm{R10} = 1160\mathrm{k}\Omega$ is used to limit the start-up time to one second or less.

During start-up the output voltage is low, so power is not supplied to the V_{DD} pin from the auxiliary coil. If this causes the V_{DD} pin voltage to fall below the UVLO detect voltage during start-up, the IC will stop and the start-up time will lengthen.

This problem can be handled by increasing the C4 capacitance, or by decreasing the C6 and C7 output capacitances.

<<Line Regulation Correction>>

Circuit dissipation and deviations of the transformer primary peak current caused by the delay of the IC internal circuit may cause input voltage fluctuations that result in LED current fluctuations. To correct these LED current fluctuations, the input voltage fluctuations are corrected by correction resistances R15 and R16. The optimum values of the correction resistances vary depending on the LED lighting specifications and peripheral component constants. For the optimum values, refer to the resistance values on the calculation sheet, and test in the actual equipment to adjust.

<< CC/CV/OVP Voltage Adjustment >>

To adjust the CC/CV/OVP voltage, the resistances R12 and R13 that determine the ZVS pin voltage must be decided.

The ZVS pin voltage is determined from the LED voltage and the turn ratio of the transformer auxiliary coil, and thus the transformer auxiliary coil voltage is divided before input into the ZVS pin. To operate in CC Mode, the ZVS pin voltage must satisfy

$$V_{ZVSA} < V_{ZVS} < V_{ZVSN}$$

V_{ZVSA}	:	ZVS Acceleration Threshold Voltage
V_{ZVS}	:	ZVS pin Voltage
V_{ZVSN}	:	ZVS CV Threshold Voltage

In order to input a voltage for operation in CC Mode in the ZVS pin, the voltage division resistances R12 and R13 of the transformer auxiliary coil must satisfy

$$V_{ZVSA} < V_{ZVS} = (VLED + VF) \cdot N_{AUX} \cdot \left(\frac{R12}{R12 + R13}\right) < V_{ZVSN}$$

In this design, the target is $V_{ZVS} = 3.3V$, and $\mathrm{R12} = 47\mathrm{k}\Omega, \mathrm{R13} = 12\mathrm{k}\Omega$.

<<Smoothing Filter>>

This is an RC filter for input of the average value of the input voltage in the V_{INS} pin. In order to sufficiently smooth the frequency of the input voltage,

$$R7 \cdot C3 \gg T = \frac{1}{50Hz}$$

must be satisfied. In this design, $\mathrm{R7} = 330\mathrm{k}\Omega, \mathrm{C3} = 330\mathrm{nF}$.

<<Transformer auxiliary coil- V_{DD} pin (R11/D1) >>

Here D1 and R11, which connect the V_{DD} pin from the transformer auxiliary coil, are selected.

The operation waveform of the transformer auxiliary coil voltage is shown in Fig. 14. As such, the voltage V_{Dvdd} applied to D1 is

$$V_{Dvdd} = V_{DD} + \sqrt{2} \cdot Vrms\_max \cdot N_{AUX} + V_{spike}$$

$Vrms\_max$: Lower limit of input voltage range

V_{spike} : Spike voltage (~50V) accompanying switching

In this design, a rated voltage of 200V and a small signal type diode are used.

If the R11 resistance is too small in an isolated flyback circuit, the effects of switching noise will cause the V_{DD} pin voltage to rise above the design value. A resistance of several tens of ohms must be used for R11 to keep the V_{DD} pin voltage from rising. In this design, R11=47Ω is used.

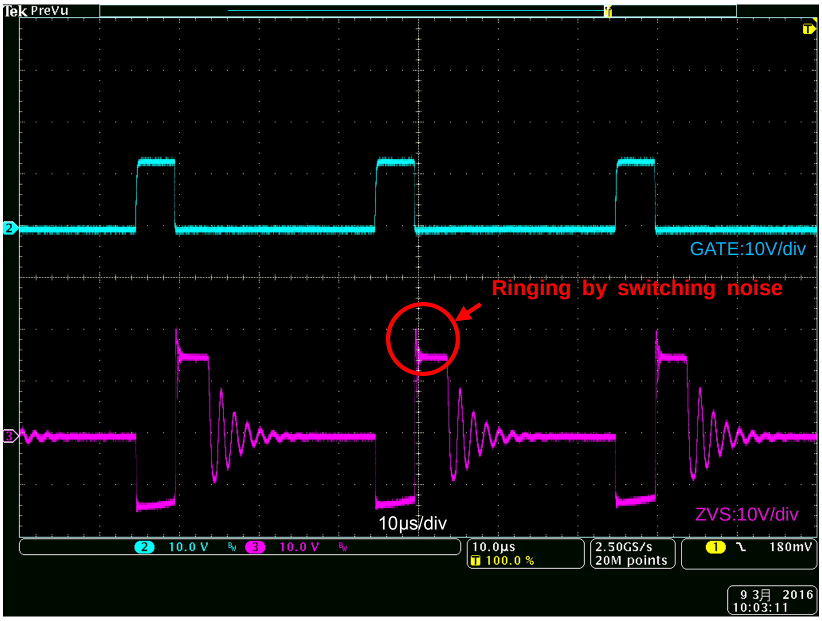


Fig 14: Voltage waveform of transformer auxiliary coil

6-4. Output capacitor

This output capacitor suppresses ripple current in the LED current.

The transformer secondary peak current is in the same phase as the input voltage, and flickering will occur if the output capacitance value is too small. An output capacitor with a large capacitance must be connected in parallel with the LED to suppress flicker and reduce ripple current.

The capacitance of the output capacitor can be roughly calculated from the ripple current rate of the target LED current and the I-V characteristics of the LED. In this design, the output capacitance value is calculated for a ripple current rate of 0.8 and a LED with the characteristics shown in Fig. 16.

First we determine the amplitude of the LED current. When the LED current is 1A and the ripple current rate is 0.8, the target value for the LED current amplitude is

$$ILED_{\_amp} = \frac{I_{ripple}}{2} \cdot ILED = \frac{I_{ripple}}{2} \cdot 1A = 0.4A$$

$ILED_{\_amp}$: Target value for LED current amplitude

(Refer to Fig. 15)

Here we calculate the difference in the VF voltage when the LED current changes $ILED_{\_amp}$ from 1A, using the I-V characteristics of the LED. On this LED, this is 0.4V.

The output capacitance can be roughly calculated from the LED voltage amplitude, LED current, and number of LEDs in series. The output capacitance must satisfy

$$C7 > \frac{T}{4} \cdot \frac{ILED_{\_amp}}{n_{LED} \cdot \Delta VF} = \frac{1}{4 \cdot 50Hz} \cdot \frac{0.4A}{10 \cdot 0.4V} = 500\mu F$$

n_{LED} : Number of LEDs in series (here $n_{LED} = 10, VF = 3V@1A$)

ΔVF : VF voltage difference at $ILED_{\_amp}$ change

In this design, a value of 940μF is used.

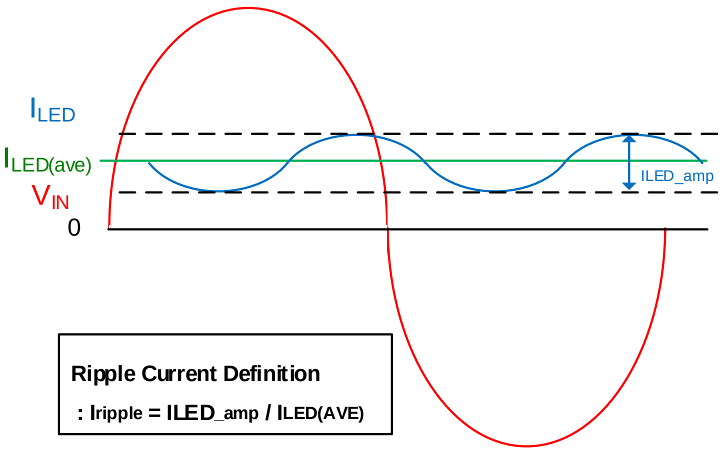


Fig.15: LED current and ripple current rate

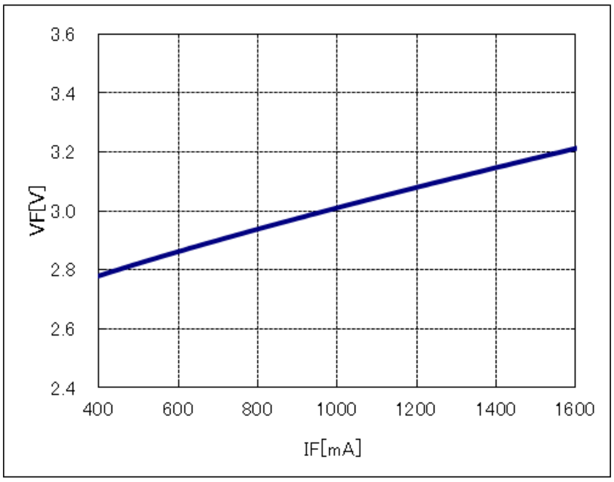


Fig.16: LED I-V characteristics

6-5. Snubber circuit

When the power MOSFET turns off, the snubber circuit prevents destruction of the power MOSFET due to the energy stored in the leakage inductance of the transformer. This design uses the snubber circuit shown in Fig. 17, and the operation waveform is shown in Fig. 18.

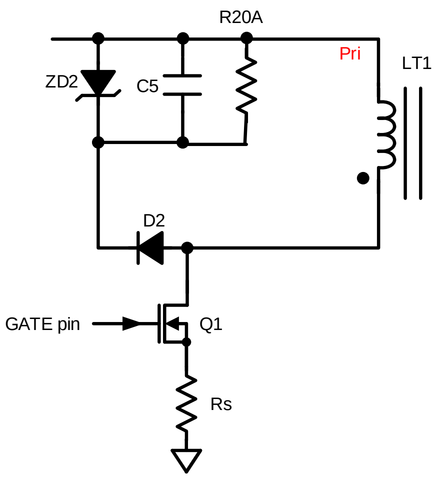


Fig. 17: Snubber circuit

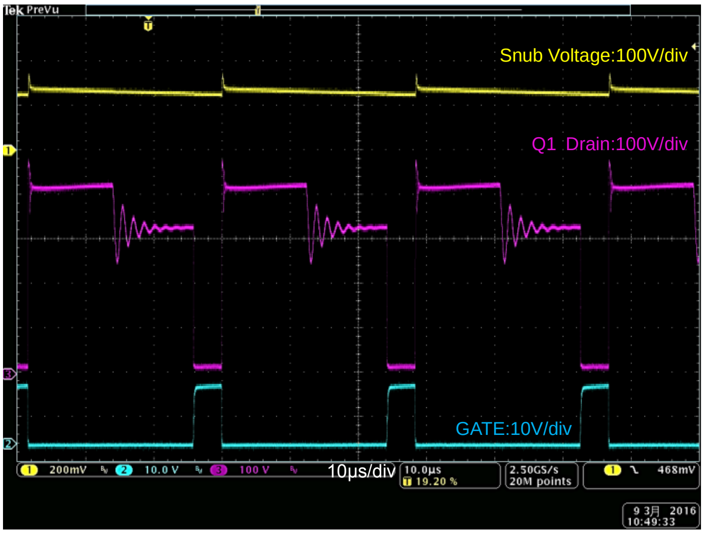


Fig.18: Operation waveform of snubber circuit

When this snubber circuit is used, the snubber voltage is determined by the ZD2 Zener voltage, and thus

$$V_{snub} \approx V_{ZD2}$$

V_{snub} : Snubber voltage
V_{ZD2} : ZD2 Zener voltage

For the ZD2 Zener voltage, a voltage that satisfies the relation

$$V_{ZD2} > N \cdot (VLED + VF) + V_{spike}$$

V_{spike} : Spike voltage that accompanies switching(~50V)

must be selected.

However, if the Zener voltage is set too high, the snubber voltage will increase. This means that a power MOSFET with a higher rated voltage must be used, and this may increase cost. In this design, a ZD2 Zener voltage of 160V is used.

In addition, ringing will occur in the drain voltage of the power MOSFET during switching, which may cause radiation noise. For this reason, C5 and R20 are connected as an EMI countermeasure to suppress ringing during switching. In this design, C5= 2.2nF and R20=150kΩ are used.

6-6. Switching elements

<<Power MOSFET >>

In an isolated flyback circuit, the flyback voltage (which occurs when the power MOSFET is off) and snubber voltage are applied to the power MOSFET in addition to the input voltage.

The maximum voltage applied to the power MOSFET is

$$V_{Q1} = \sqrt{2} \cdot Vrms\_max + N \cdot (VLED + VF) + V_{spike}$$

V_{q1} : Maximum voltage applied to power MOSFET Q1

V_{spike} : Spike voltage accompanying switching(100V or more)

The rated voltage of the power MOSFET must be higher than this. In this design, a power MOSFET with a rated voltage of 800V is used.

<<Rectifier diode>>

The rectifier diode causes the energy stored in the transformer to flow to the LED when power MOSFET Q1 is off. The maximum voltage applied to rectifier diode D3 in an isolated flyback circuit is

$$V_{D3} = VLED + \frac{\sqrt{2} \cdot Vrms\_max}{N} + V_{spike}$$

V_{D3} : Maximum voltage applied to rectifier diode D3

V_{spike} : Spike voltage accompanying switching(~50V)

The rated voltage of rectifier diode D3 must be higher than this. In this design, rectifier diode D3 has a rated voltage of 200V.

In addition, select a fast recovery diode with a short reverse recovery time. Note that a diode with a long reverse recovery time will cause poorer efficiency.

Fig. 19: Operation waveform of switching element area

7. Non-isolated buck-boost: design example

This section explains how to design a non-isolated buck-boost circuit using the XC9404 series. The transformer turn ratio, switching elements, and snubber circuit in a non-isolated buck-boost circuit are different from an isolated flyback circuit. In all other respects, the design of a non-isolated buck-boost circuit is virtually the same as an isolated flyback circuit.

In this example, the LED lighting specified in Table 3 is designed, and the circuit schematic is shown in Fig. 20.

The design constants below can be calculated using Design Sheet: ”XC9404 cal sheet”.

Table 3: Non-isolated buck-boost design specifications

	Min.	Typ.	Max.	Unit
Input Voltage	85	100/230	270	Vrms
Frequency	47	50/60	63	Hz
Power Factor	0.9	-	-	-
THD	-	-	15	%
Isolated/Non-Isolated		Non-Isolated		-
Power		30		W
LED Voltage	90	100	110	V
LED Current		300		mA
Start-up time	-	500	1000	ms

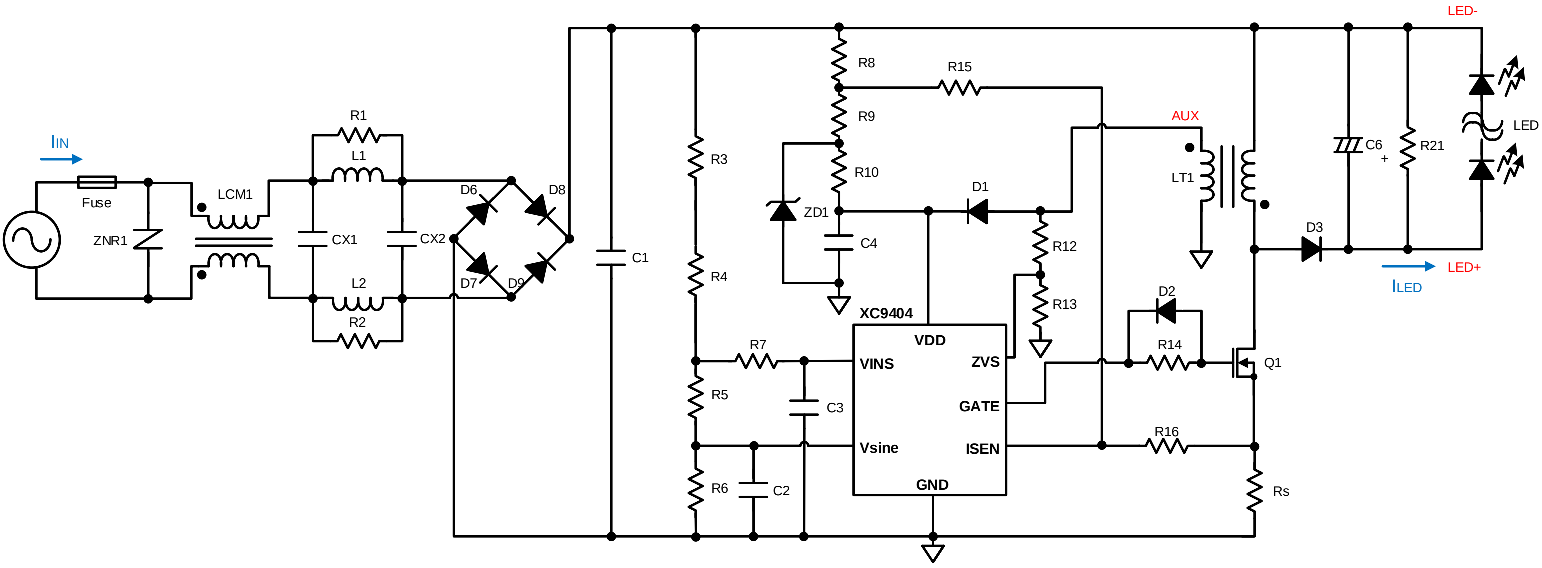


Fig. 20: Non-isolated buck-boost example

7-1. Duty Adjustment

Here Kline is selected for duty adjustment.

The optimum value of Kline varies depending on the LED lighting specifications. Adjust so that operation is in DCM using the guidelines in Table 4. In addition, adjust the R3 to R6 resistances so that the maximum voltage of the V_{SINE} pin does not exceed 3V.

Table 4: Target values for non-isolated buck-boost Kline

Circuit type	Output power	Kline
Non-isolated buck-boost	Less than 20W	1.0 to 1.1
	20W or higher	1.0 to 1.2

In this design, the Kline target value is 1.2 and Kline = 1.18 with R3=1360kΩ,R5=3.6kΩ,R6=11kΩ.

7-2. Transformer &Sense Resistor

Here we specify the inductance of the transformer and the sense resistance.

The turn ratio of the transformer auxiliary coil is determined by the V_{DD} pin voltage and the LED voltage. In this design, a V_{DD} pin voltage of 16V is used, and the turn ratio of the transformer auxiliary coil is

$$N_{AUX} = \frac{V_{DD\_SET}}{(VLED + VF)} = \frac{16V}{(100V + 1V)} = 0.158$$

N_{AUX} : Turn ratio of transformer auxiliary coil
V_{DD_SET} : V_{DD} pin voltage target value

In this design, a transformer auxiliary turn ratio of 0.165 is used.
However, the LED current may not match the calculated value due to factors such as circuit dissipation and delay in the IC internal circuit. Adjust the sense resistance using the actual equipment.

Next, the sense resistance is adjusted. From Equation (6''), the sense resistance Rs is

$$Rs \approx \frac{N \cdot Kline^2 \cdot Kc}{4 \cdot ILED} = \frac{1 \cdot 1.18^2 \cdot \frac{4}{9}}{4 \cdot 300mA} = 0.52\Omega$$

In this design, 0.53Ω is used for Rs.

Next, the transformer primary inductance value is selected.

The transformer primary inductance value is determined by the lower limit of the switching frequency. In this design, 50kHz is used as a guideline for the lower limit of the switching frequency, and thus the transformer primary inductance Lp given by Equation (16) is

$$Lp = \frac{Kc \cdot N \cdot (VLED + VF)}{fosc} \cdot Rcs = \frac{\frac{4}{9} \cdot 1 \cdot (100V + 1V)}{50kHz} \cdot 0.53\Omega = 475\mu H$$

In this design, 400μH is used for the transformer primary inductance value.

Verify that the circuit operates in DCM with the above designed constants.
If the circuit does not operate in DCM, repeat the steps of 7-1 and 7-2 and adjust so that operation is in DCM.

7-3. Other Parameter

<< Start-up time >>

The start-up time is determined by the sum of the interval from power-on to IC start-up and the time needed for the output voltage to rise after IC start-up. However, most of the start-up time is the time required for the IC to start operation, and thus the startup time t_s can be roughly calculated as follows:

$$t_s \approx \frac{C4 \cdot (R8 + R9 + R10)}{\sqrt{2} \cdot Vrms} \cdot V_{ST}$$

t_s	:	Start-up time
V_{ST}	:	Start-up Threshold Voltage

In this design, $\mathrm{C4} = 2.2\mu\mathrm{F}, \mathrm{R8} + \mathrm{R9} + \mathrm{R10} = 1000\mathrm{k}\Omega$ is used to limit the start-up time to one second or less.

During start-up the output voltage is low, so power is not supplied to the V_{DD} pin from the auxiliary coil. If this causes the V_{DD} pin voltage to fall below the UVLO detect voltage during start-up, the IC will stop and the start-up time will lengthen.

This problem can be handled by increasing the C4 capacitance, or by decreasing the C6 and C7 output capacitances.

<<Line Regulation Correction>>

Circuit dissipation and deviations of the transformer primary peak current caused by the delay of the IC internal circuit may cause input voltage fluctuations that result in LED current fluctuations. To correct these LED current fluctuations, the input voltage fluctuations are corrected by correction resistances R15 and R16. The optimum values of the correction resistances vary depending on the LED lighting specifications and peripheral component constants. For the optimum values, refer to the resistance values on the calculation sheet, and test in the actual equipment to adjust.

<< CC/CV/OVP Voltage Adjustment >>

To adjust the CC/CV/OVP voltage, the resistances R12 and R13 that determine the ZVS pin voltage must be decided.

The ZVS pin voltage is determined from the LED voltage and the turn ratio of the transformer auxiliary coil, and thus the transformer auxiliary coil voltage is divided before input into the ZVS pin. To operate in CC Mode, the ZVS pin voltage must satisfy

$$V_{ZVSA} < V_{ZVS} < V_{ZVSN}$$

V_{ZVSA}	:	ZVS Acceleration Threshold Voltage
V_{ZVS}	:	ZVS pin Voltage
V_{ZVSN}	:	ZVS CV Threshold Voltage

In order to input a voltage for operation in CC Mode in the ZVS pin, the voltage division resistances R12 and R13 of the transformer auxiliary coil must satisfy

$$V_{ZVSA} < V_{ZVS} = (VLED + VF) \cdot N_{AUX} \cdot \left(\frac{R12}{R12 + R13}\right) < V_{ZVSN}$$

In this design, the target is $V_{ZVS} = 3.5V$, and $\mathrm{R12} = 47\mathrm{k}\Omega, \mathrm{R13} = 13\mathrm{k}\Omega$.

<< Smoothing Filter >>

This is an RC filter for input of the average value of the input voltage in the V_{INS} pin. In order to sufficiently smooth the frequency of the input voltage,

$$R7 \cdot C3 \gg T = \frac{1}{50Hz}$$

must be satisfied. In this design, $\mathrm{R7} = 330\mathrm{k}\Omega, \mathrm{C3} = 330\mathrm{nF}$.

<<Transformer auxiliary coil- V_{DD} pin (R11/D1) >>

Here D1 and R11, which connect the V_{DD} pin from the transformer auxiliary coil, are selected.

The operation waveform of the transformer auxiliary coil voltage is similar to that shown in Fig. 21. As such, the voltage V_{Dvdd} applied to D1 is

$$V_{Dvdd} = V_{DD} + \sqrt{2} \cdot Vrms\_max \cdot N_{AUX} + V_{spike}$$

$Vrms\_max$: Lower limit of input voltage range

V_{spike} : Spike voltage (~50V) accompanying switching

In this design, a rated voltage of 200V and a small signal type diode are used.

There is no need to insert the R11 resistance because switching noise is not significant in a non-isolated buck-boost circuit. If the V_{DD} pin voltage increases, insert a resistance of several tens of ohms for R11 to suppress the V_{DD} pin voltage increase.

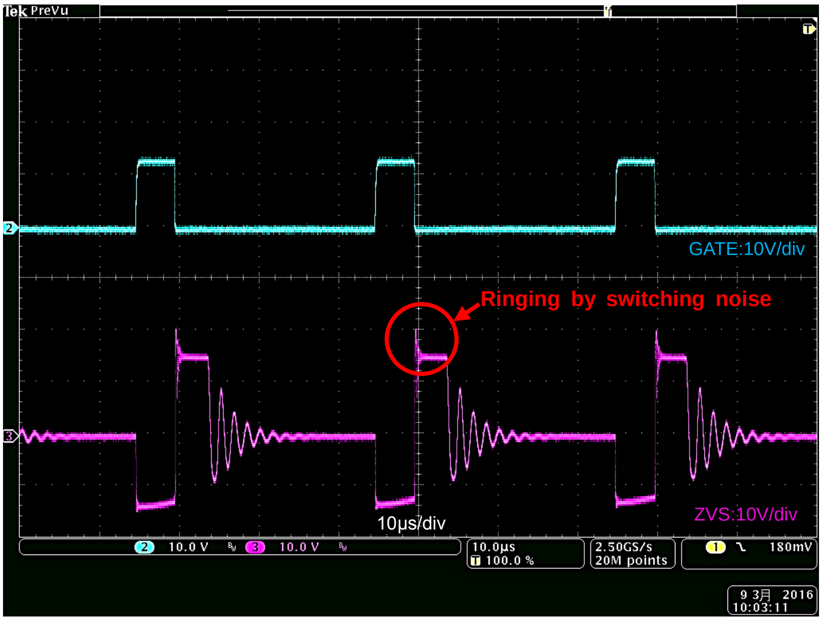


Fig 21: Voltage waveform of transformer auxiliary coil

7-4. Output capacitor

This output capacitor suppresses ripple current in the LED current.

The transformer secondary peak current is in the same phase as the input voltage, and flickering will occur if the output capacitance value is too small. An output capacitor with a large capacitance must be connected in parallel with the LED to suppress flicker and reduce ripple current.

The capacitance of the output capacitor can be roughly calculated from the ripple current rate of the target LED current and the I-V characteristics of the LED. In this design, the output capacitance value is calculated for a ripple current rate of 0.8 and a LED with the characteristics shown in Fig. 23.

First we determine the amplitude of the LED current. When the LED current is 0.3A and the ripple current rate is 0.8, the target value for the LED current amplitude is

$$ILED\_{amp} = \frac{I_{ripple}}{2} \cdot ILED = \frac{I_{ripple}}{2} \cdot 0.3A = 0.12A$$

$ILED\_{amp}$: Target value for LED current amplitude

(Refer to Fig. 22)

Here we calculate the difference in the VF voltage when the LED current changes $ILED\_{amp}$ from 0.3A, using the I-V characteristics of the LED. On this LED, this is 0.4V.

The output capacitance can be roughly calculated from the LED voltage amplitude, LED current, and number of LEDs in series. The output capacitance must satisfy

$$C7 > \frac{T}{4} \cdot \frac{ILED\_{amp}}{n_{LED} \cdot \Delta VF} = \frac{1}{4 \cdot 50Hz} \cdot \frac{0.12A}{33 \cdot 0.4V} = 45\mu F$$

n_{LED} : Number of LEDs in series (here $n_{LED} = 33, VF = 3V@0.3A$)

ΔVF : VF voltage difference at $ILED\_{amp}$ change

In this design, a value of 940μF is used.

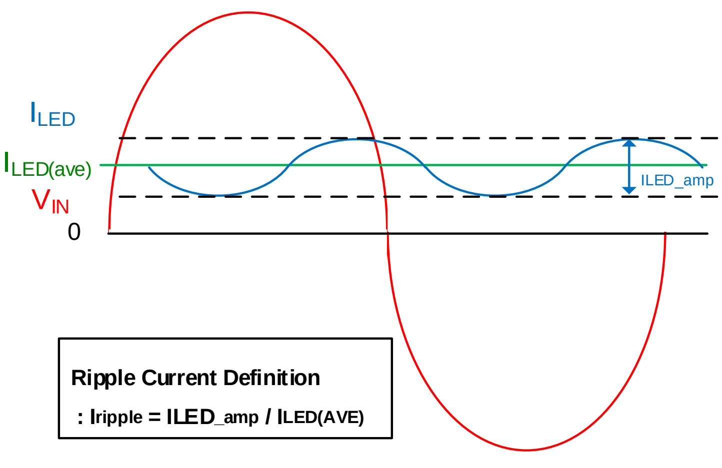


Fig.22: LED current and ripple current rate

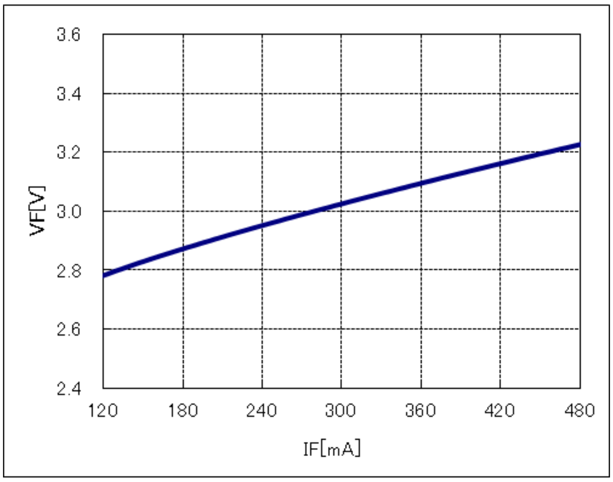


Fig.23: LED I-V characteristics

7-5. Switching elements

<<Power MOSFET >>

In a non-isolated buck-boost circuit, the LED voltage is applied to the power MOSFET in addition to the input voltage. The maximum voltage applied to the power MOSFET is

$$V_{Q1} = \sqrt{2} \cdot Vrms\_max + VLED + V_{spike}$$

V_{q1} : Maximum voltage applied to power MOSFET Q1

V_{spike} : Spike voltage accompanying switching(100V or more)

A power MOSFET with a rated voltage higher than this is required. In this design a power MOSFET with a rated voltage of 650V is used.

<<Rectifier diode>>

The rectifier diode causes the energy stored in the transformer to flow to the LED when power MOSFET Q1 is off. The maximum voltage applied to rectifier diode D3 in a non-isolated buck-boost circuit is

$$V_{D3} = \sqrt{2} \cdot Vrms\_max + VLED + V_{spike}$$

V_{D3} : Maximum voltage applied to rectifier diode D3

V_{spike} : Spike voltage accompanying switching(~50V)

The rated voltage of rectifier diode D3 must be higher than this. In this design, rectifier diode D3 has a rated voltage of 600V.

In addition, select a fast recovery diode with a short reverse recovery time. Note that a diode with a long reverse recovery time will cause poorer efficiency.

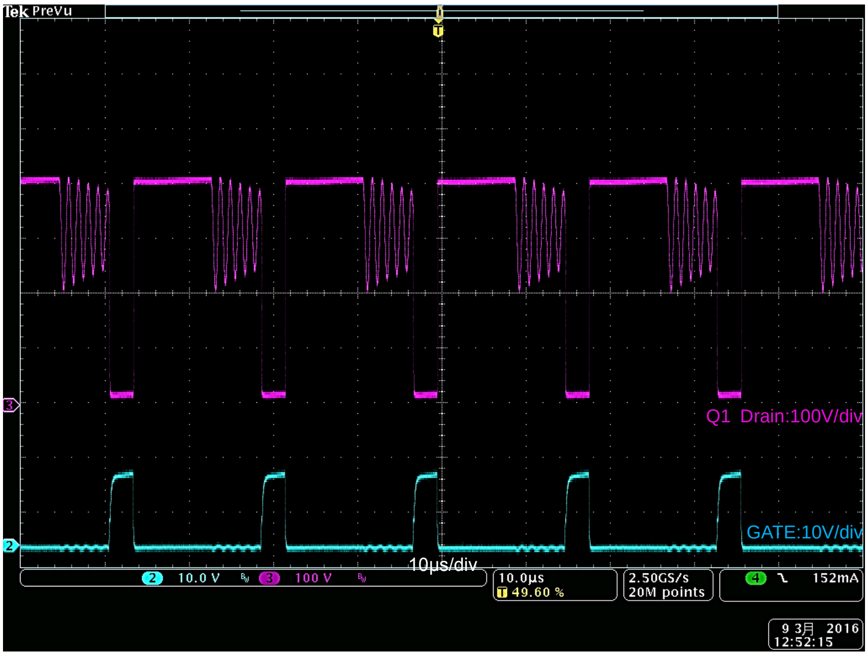


Fig. 24: Operation waveform of switching element area

8. Examples of solutions and characteristics

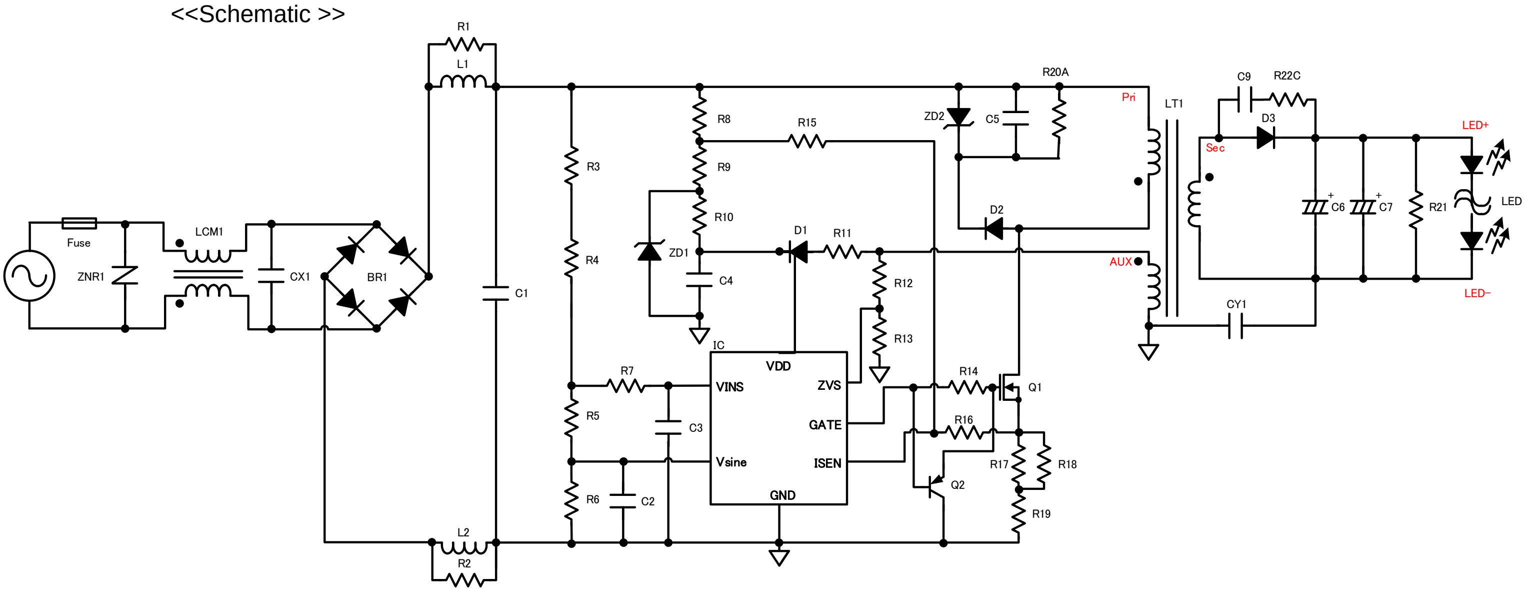
8-1. Isolated 30W LED Lighting Solution

(Vin=85~270VAC ->Isolated, VLED/ILED=30V/1A)

<< Spec >>

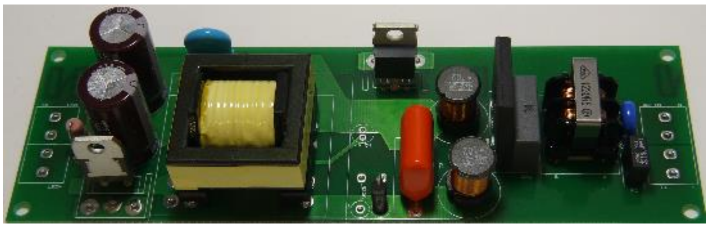
	Min.	Typ.	Max.	Unit
Input Voltage	85	100/230	270	Vrms
Frequency	47	50/60	63	Hz
Power Factor	0.9	-	-	-
THD	-	-	15	%
Isolated/Non-Isolated		Isolated		-
Power		30		W
LED Voltage	27	30	33	V
LED Current		1000		mA
Start-up time	-	500	1000	ms

<<Schematic >>

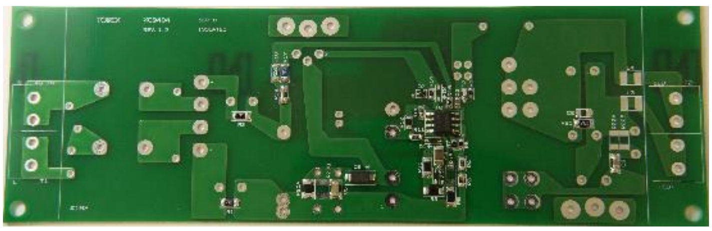


<< Test board Photo of exterior >>

Top View



Bottom View

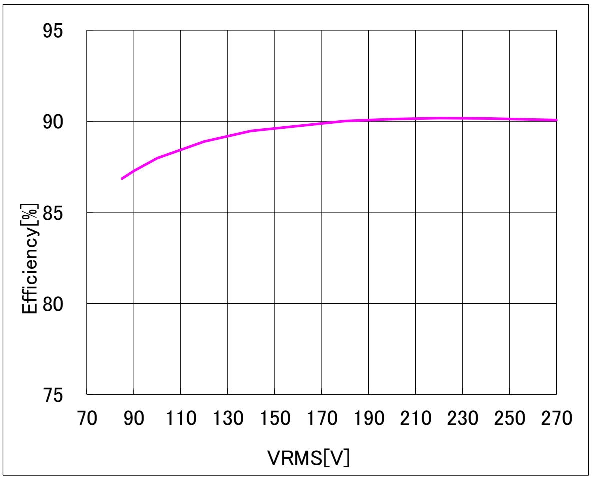


48mm

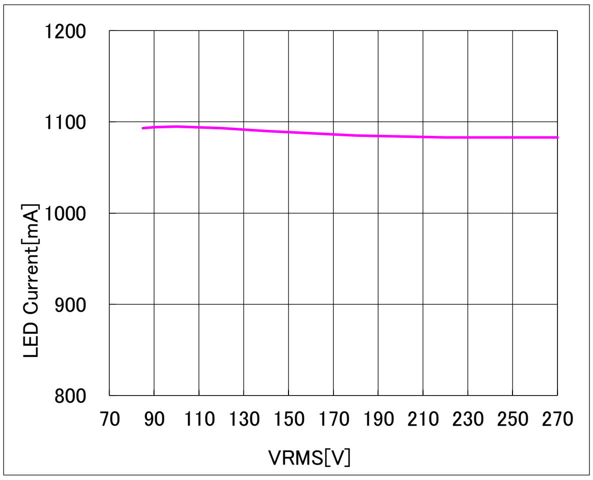
160mm

<< Test board Photo of exterior >>

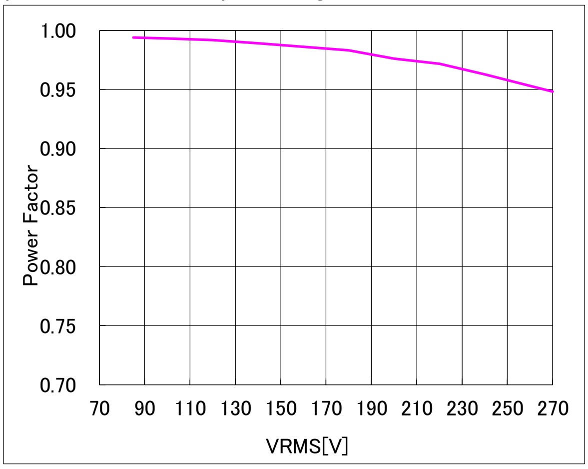
(1) Efficiency vs Input Voltage



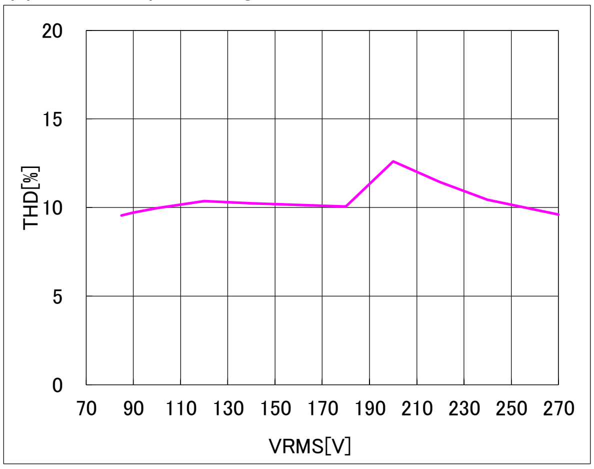
(2) LED Current vs Input Voltage



(3) Power Factor vs Input Voltage

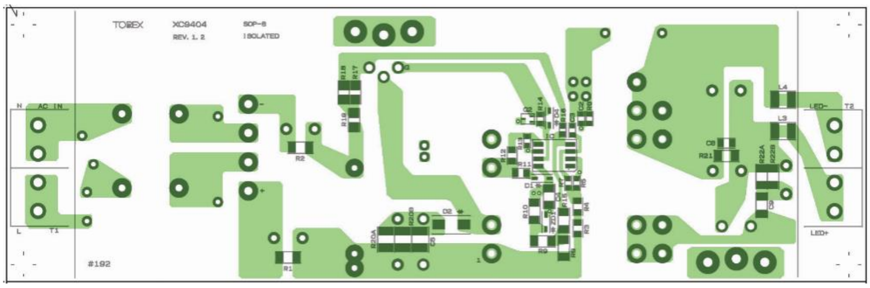


(4) THD vs Input Voltage

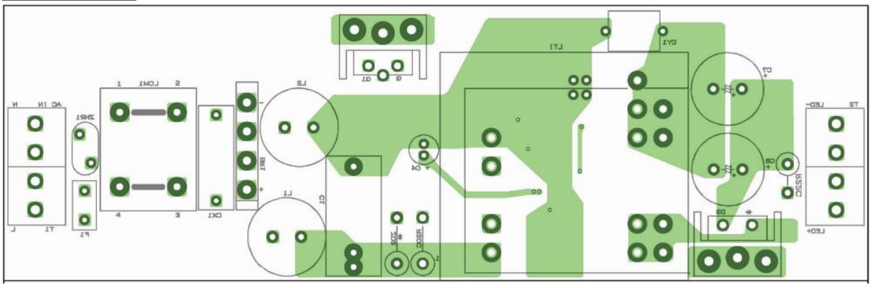


<<PCB Layout>>

Top View



Bottom View



<< BOM LIST >>

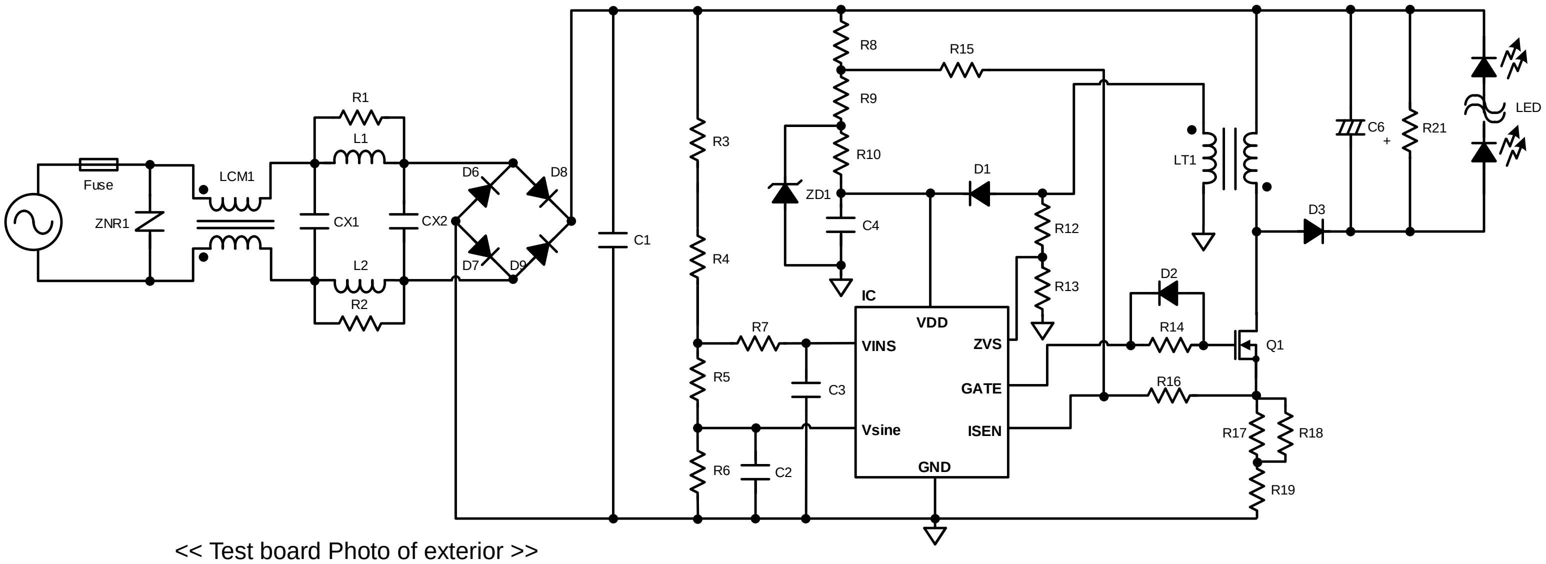
Item	Q'ty	Value	Description	Size / PKG	Part Number	Manufacturer
IC	1	-	Offline controller IC for LED lighting	SOP-8D	XC9404AL03SR-G	TOREX
C1	1	330nF	Capacitor, Polypropylene,400V,±5%	18.5×9.0	MPE *0400J33400000000	NISSEI
C2	1	100pF	Capacitor, Ceramic,50V,CH,±5%	1608	GRM1882C1H101JA01D	Murata
C3	1	330nF	Capacitor, Ceramic,16V,X7R,±10%	1608	GRM188R71C334KA01D	Murata
C4	1	4.7μF	Capacitor, Ceramic,50V,X7R,±10%	3216	GRM31CR71H475KA88L	Murata
C5	1	2.2nF	Capacitor, Ceramic,1kV,X7R,±10%	3216	GRM31BR73A222KW01L	Murata
C6,7	1	680μF	Capacitor,Electrolysis,50V,±20%	φ12.5×25.0	EKZN500ELL681MK25S	Nippon Chemi-con
C9	1	1nF	Capacitor, Ceramic,250V,X7R,±10%	2012	GRM21AR72E102KW01D	Murata
CY1	1	4.7nF	Safety Capacitor Y1,300VAC,E	10mm pitch	DE1E3KX472MA4BP01F	Murata
CX1	1	150nF	Safety Capacitor X2,275VAC	6.0×18.0	R46KI322000M2K	Kemet
L1,2	1	1mH	Inductor, 0.8A(Isat), 1.15Ω	φ10.5×14.5	7447480102	WürthElektronik
LCM1	1	12mH	Common mode choke	18.0×16.0	PLA10AS1230R6R2	Murata
LT1	1	480μH	transformer	ER28/17	750841247 Rev.03	WürthElektronik
D1	1	-	Diode, Fast Rec., 0.2A, 200V	SOD-323	BAS20HT1G	On semiconductor
D2	1	-	Diode, Fast Rec., 1.0A, 1000V	SMA	STTH110A	STMicroelectronics
D3	1	-	Diode, Fast Rec., 8.0A, 200V	TO-220AC	STTH802D	STMicroelectronics
ZD1	1	-	Zener Diode, 27V	SOD-323	PDZ27B	ON semiconductor
ZD2	1	-	TVS, 160V	DO-15	P6KE160A	Fairchild
R1,2	1	4.7kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-074K7L	Yageo
R3,4	1	1MΩ	Resistor, Chip, 0.125W, 400V	2012	RVC20K105F	Kamaya
R5	1	8.2kΩ	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD8201F	KOA
R6	1	15kΩ	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD1502F	KOA
R7	1	330kΩ	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD3303F	KOA
R8,9	1	470kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-07470KL	Yageo
R10	1	220kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-07220KL	Yageo
R11	1	33Ω	Resistor, Chip, 0.125W, 50V	2012	RK73H2ATTD33R0F	KOA
R12	1	47kΩ	Resistor, Chip, 0.125W, 150V	2012	RK73H2ATTD4702F	KOA
R13	1	11kΩ	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD1102F	KOA
R14	1	20Ω	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD20R0F	KOA
R16	-	Jumper	-	-	-	-
R17	1	0.56Ω	Resistor, Chip, 0.5W	3216	RLC32-R560F	Kamaya
R18	1	1.2Ω	Resistor, Chip, 0.5W	3216	RLC32K1R20F	Kamaya
R19	-	Jumper	-	-	-	-
R20A	1	150kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-07150KL	Yageo
R21	1	240kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-07240KL	Yageo
R22C	1	100Ω	Resistor, Axial, 2W, 500V	φ3.9×9.0	FMP200JR-52-100K	Yageo
Q1	1	-	MOSFET, Nch, 650V, 7A, 0.54Ω	TO-220	AOT7S65L	ALPHA&OMEGA
Q2	1	-	PNP transistor, 50V, 100mA	SC-73	2SA1774G	On semiconductor
BR1	1	-	Bridge Rectifier, 4.0A, 800V	GBU	GBU4K	Micro Commercial Co
Fuse	1	-	Fuse, Time-lag, 2A, 277VAC	4.0×8.4	RST2	bel
ZNR1	1	-	Varistor, 275VAC	5mm pitch	S07K275	EPCOS

8-2. Non-isolated 30W LED Lighting Solution
(Vin=85~270VAC -> Non-Isolated, VLED/ILED=100V/300mA)

<< Spec >>

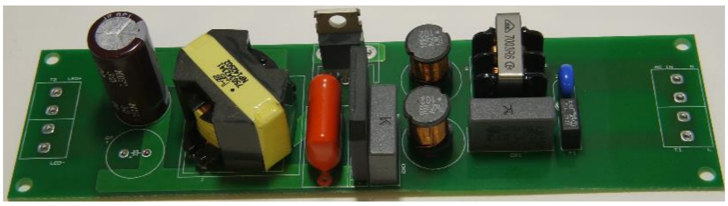
	Min.	Typ.	Max.	Unit
Input Voltage	85	100/230	270	Vrms
Frequency	47	50/60	63	Hz
Power Factor	0.9	-	-	-
THD	-	-	10	%
Isolated/Non-Isolated	Non-Isolated			-
Power		30		W
LED Voltage	90	100	110	V
LED Current		300		mA
Start-up time	-	500	1000	ms

<<Schematic >>

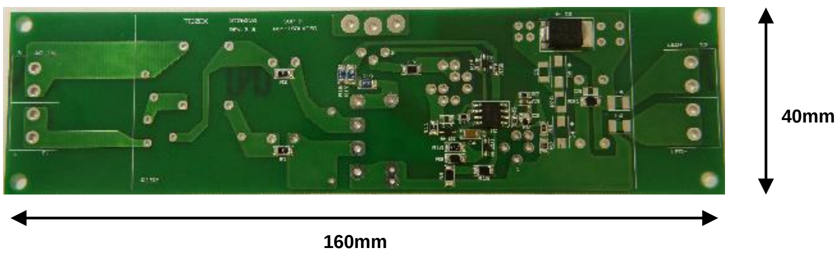


<< Test board Photo of exterior >>

Top View

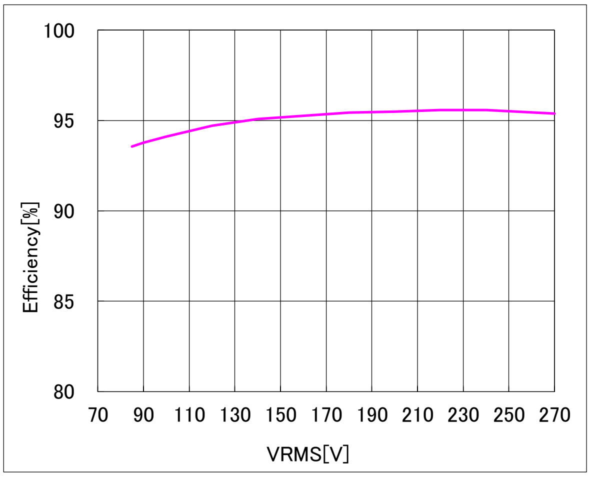


Bottom View

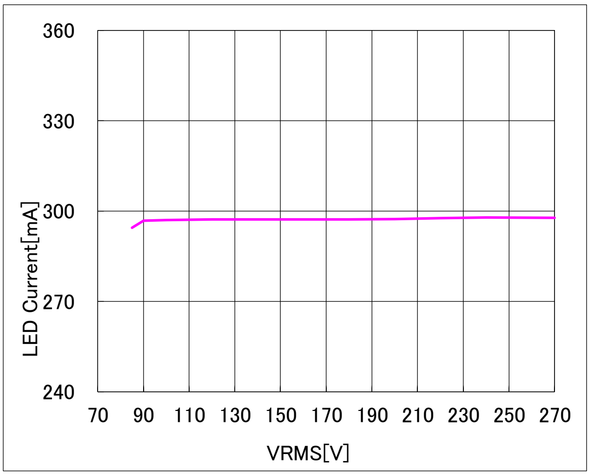


<< Test board Photo of exterior >>

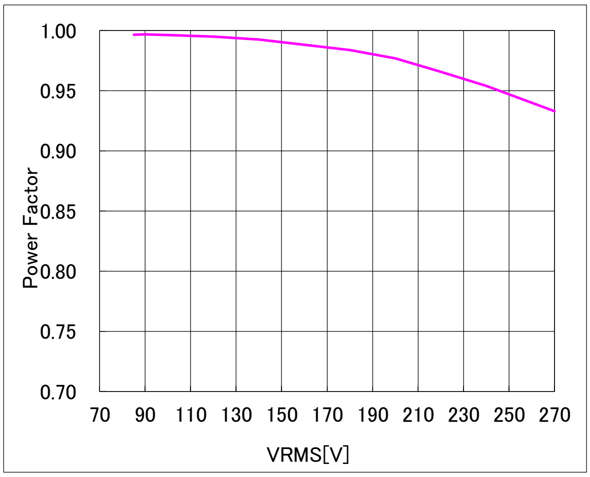
(1) Efficiency vs Input Voltage



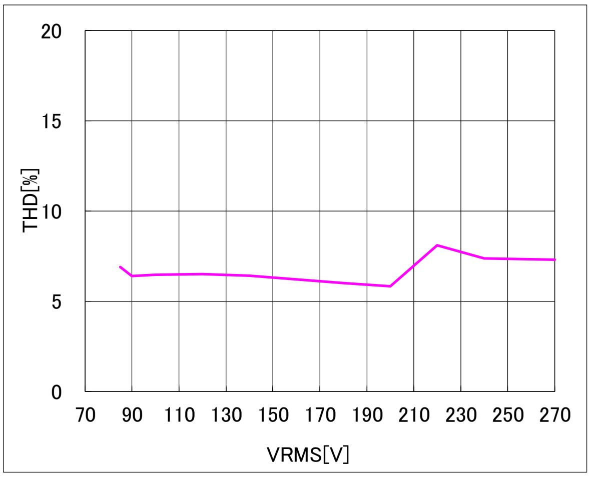
(2) LED Current vs Input Voltage



(3) Power Factor vs Input Voltage

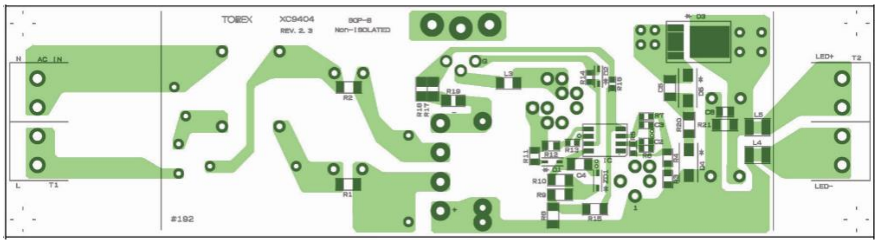


(4) THD vs Input Voltage

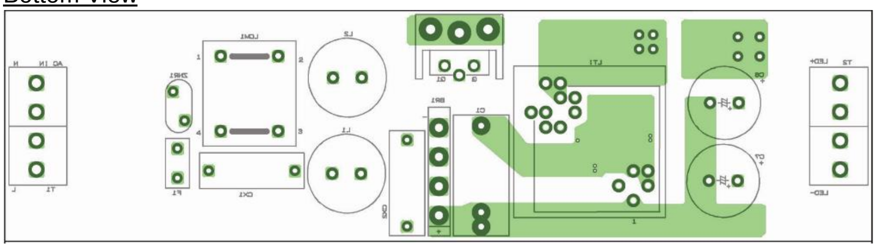


<< PCB Layout >>

Top View



Bottom View



<< BOM LIST >>

Item	Q'ty	Value	Description	Size / PKG	Part Number	Manufacturer
IC	1	-	Offline controller IC for LED lighting	SOP-8D	XC9404AL03SR-G	TOREX
C1	1	330nF	Capacitor, Polypropylene,400V,±5%	18.5×9.0	MPE *0400J33400000000	NISSEI
C2	1	100pF	Capacitor, Ceramic,50V,CH,±5%	1608	GRM1882C1H101JA01D	Murata
C3	1	330nF	Capacitor, Ceramic,16V,X7R,±10%	1608	GRM188R71C334KA01D	Murata
C4	1	2.2μF	Capacitor, Ceramic,50V,X7R,±10%	3216	GRM31CR71H225KA88L	Murata
C6	1	150μF	Capacitor,Electrolysis,160V,±20%	φ12.5×20.0	EKZN101ELL151MJ20S	Nippon Chemi-con
CX1	1	100nF	Safety Capacitor X2,275VAC	5.0×18.0	R46KI3100JBM1K	Kemet
CX2	1	100nF	Safety Capacitor X2,275VAC	5.0×18.0	R46KI3100JBM1K	Kemet
L1,2	1	1mH	Inductor, 0.8A(Isat), 1.15Ω	φ10.5×14.5	7447480102	WürthElektronik
LCM1	1	70μH	Common mode choke	16.0×18.0	PLH10AS7003R6P2	Murata
LT1	1	400μH	transformer	RM10	750342341 Rev.02	WürthElektronik
D1	1	-	Diode, Fast Rec., 0.2A, 200V	SOD-323	BAS20HT1G	On semiconductor
D2	1	-	Diode, Fast Rec., 0.15A, 75V	SOD-323	1N4148WS	Fairchild
D3	1	-	Diode, Fast Rec., 3.0A, 600V	SMC	ES3J	Fairchild
ZD1	1	-	Zener Diode, 27V	SOD-323	PDZ27B	ON semiconductor
R1,2	1	4.7kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-074K7L	Yageo
R3,4	1	680kΩ	Resistor, Chip, 0.125W, 400V	2012	RVC20K684F	Kamaya
R5	1	3.6kΩ	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD3602F	KOA
R6	1	11kΩ	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD1102F	KOA
R7	1	330kΩ	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD3303F	KOA
R8,9	1	470kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-07470KL	Yageo
R10	1	47kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-0747KL	Yageo
R12	1	47kΩ	Resistor, Chip, 0.125W, 150V	2012	RK73H2ATTD4702F	KOA
R13	1	13kΩ	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD1302F	KOA
R14	1	100Ω	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD1000F	KOA
R15	1	4.7MΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-074M7L	Yageo
R16	1	2kΩ	Resistor, Chip, 0.1W, 50V	1608	RK73H1JTTD2001F	KOA
R17	1	0.91Ω	Resistor, Chip, 0.5W	3216	RLC32KR910F	Kamaya
R18	1	0.91Ω	Resistor, Chip, 0.5W	3216	RLC32KR910F	Kamaya
R19	1	0.08Ω	Resistor, Chip, 0.5W	3216	RLC32KR080F	Kamaya
R21	1	1MΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-071ML	Yageo
Q1	1	-	MOSFET, Nch, 650V, 7A, 0.54Ω	TO-220	AOT7S65L	ALPHA&OMEGA
BR1	1	-	Bridge Rectifier, 4.0A, 800V	GBU	GBU4K	Micro Commercial Co
Fuse	1	-	Fuse, Time-lag, 2A, 277VAC	4.0×8.4	RST2	bel
ZNR1	1	-	Varistor, 275VAC	5mm pitch	S07K275	EPCOS

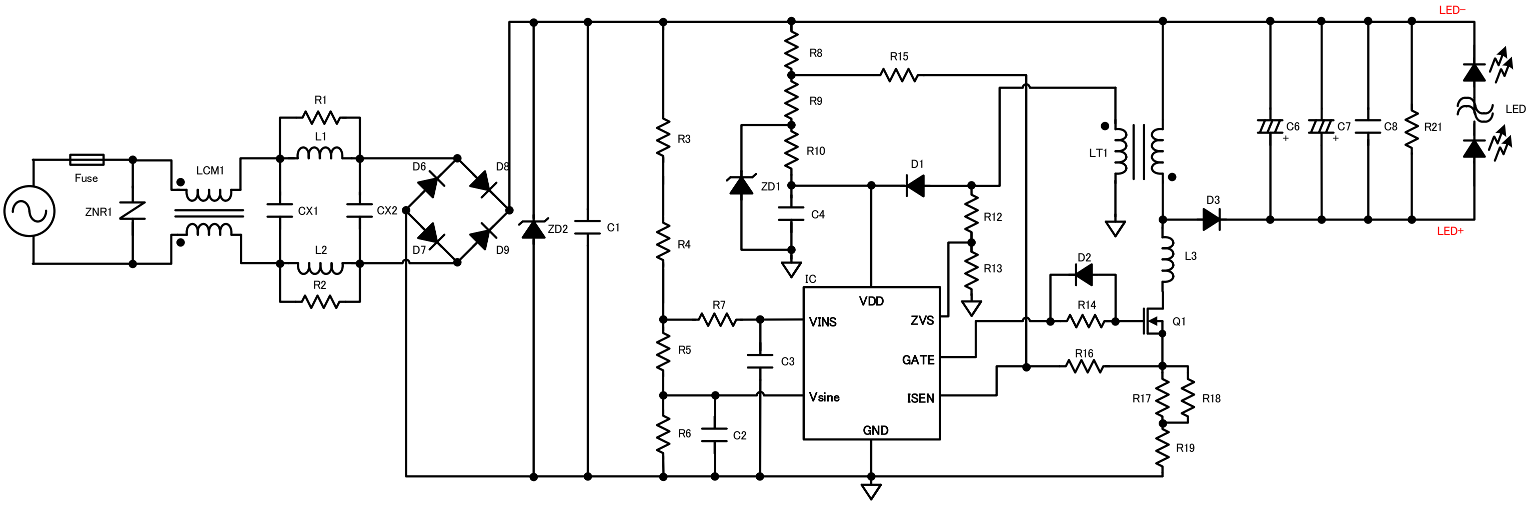
8-3. 15W LED Lighting Solution for LED-Tube(T8)

(Vin=85~270VAC -> Non-Isolated, VLED/ILED=100V/150mA)

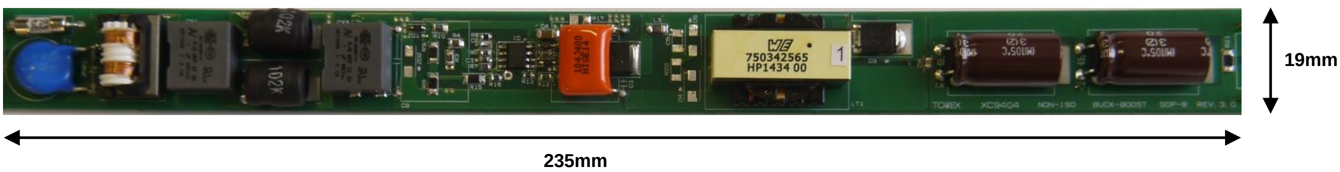
<< Spec >>

	Min.	Typ.	Max.	Unit
Input Voltage	85	100/230	270	Vrms
Frequency	47	50/60	63	Hz
Power Factor	0.9	-	-	-
THD	-	-	10	%
Isolated/Non-Isolated		Non-Isolated		-
Power		15		W
LED Voltage	90	100	110	V
LED Current		150		mA
Start-up time	-	500	1000	ms

<<Schematic>>

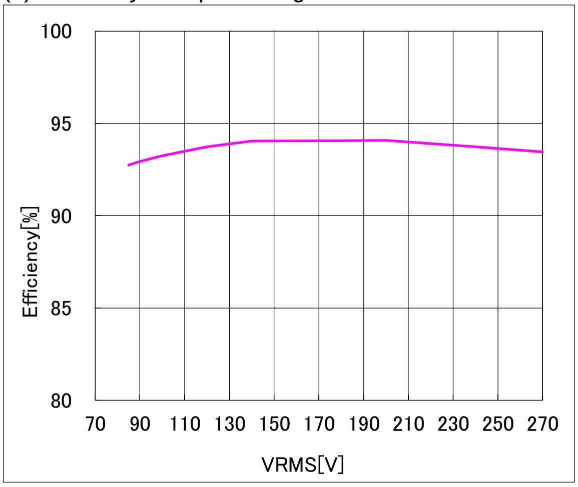


<<Test board Photo of exterior>>

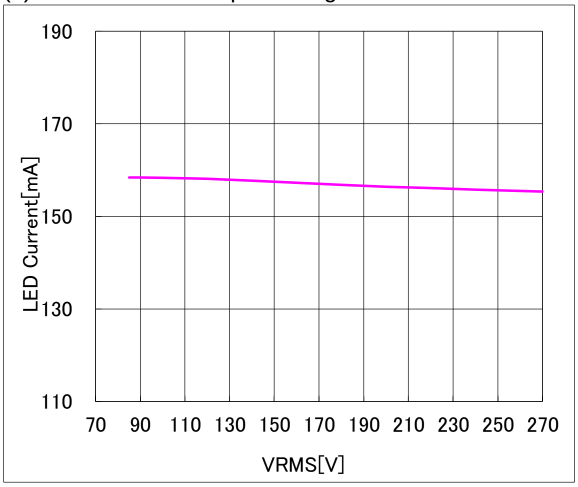


<< Test board Photo of exterior >>

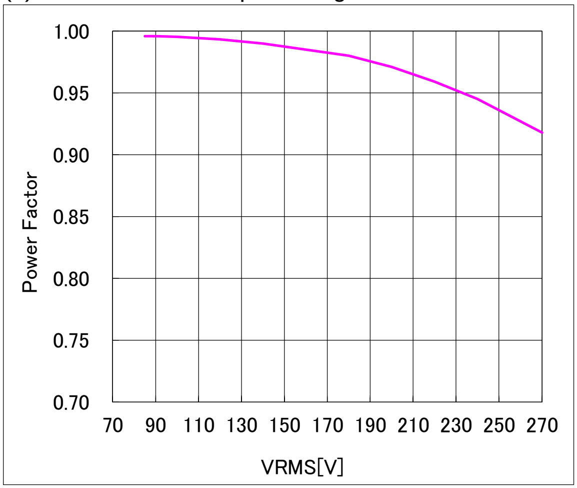
(1) Efficiency vs Input Voltage



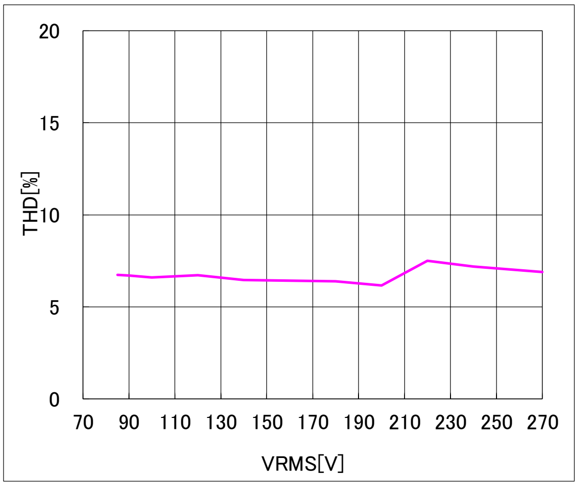
(2) LED Current vs Input Voltage



(3) Power Factor vs Input Voltage

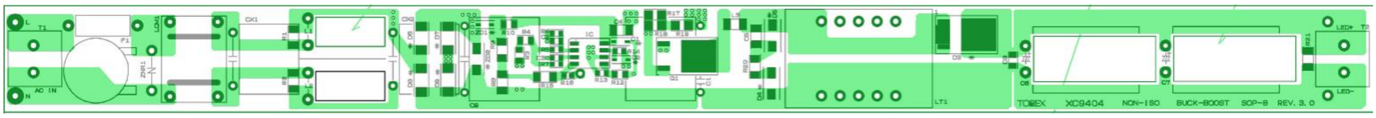


(4) THD vs Input Voltage

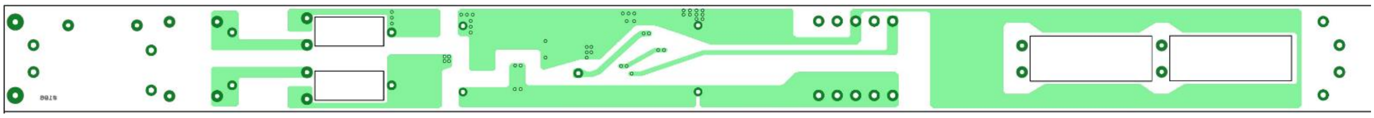


<< PCB Layout >>

Top View



Bottom View



<< BOM LIST >>

Item	Q'ty	Value	Description	Size / PKG	Part Number	Manufacturer
IC	1	-	Offline controller IC for LED lighting	SOP-8D	XC9404AL03SR-G	TOREX
C1	1	100nF	Capacitor, Polypropylene,400V,±5%	15.5×6.5	MPE *0400J10400000000	NISSEI
C2	1	100pF	Capacitor, Ceramic,50V,CH,±5%	1608	GRM1882C1H101JA01D	Murata
C3	1	330nF	Capacitor, Ceramic,16V,X7R,±10%	1608	GRM188R71C334KA01D	Murata
C4	1	2.2μF	Capacitor, Ceramic,50V,X7R,±10%	3216	GRM31CR71H225KA88L	Murata
C6,7	1	56μF	Capacitor,Electrolysis,160V,±20%	φ10.0×20.0	EKXJ161ELL560MJ20S	Nippon Chemi-con
C8	1	10nF	Capacitor, Ceramic,250V,X7R,±10%	2012	GRM21BR72E103KW03L	Murata
CX1	1	100nF	Safety Capacitor X2,275VAC	6.0×13.0	R46KF310000M1K	Kemet
CX2	1	100nF	Safety Capacitor X2,275VAC	6.0×13.0	R46KF310000M1K	Kemet
L1,2	1	1mH	Inductor, 0.51A(Isat), 1.18Ω	φ8.5×12.5	AIUR-02H-102	ABRACON
L3	1	-	Ferrite Bead, 390Ω@100MHz	3216	BLM31PG391SN1B	Murata
LCM1	1	470μH	Common mode choke	13.0×17.0	LF1290NP-471	Sumida
LT1	1	700μH	transformer	ER25/20	750342565 Rev.00	WürthElektronik
D1	1	-	Diode, Fast Rec., 0.2A, 200V	SOD-323	BAS20HT1G	On semiconductor
D2	1	-	Diode, Fast Rec., 0.15A, 75V	SOD-323	1N4148WS	Fairchild
D3	1	-	Diode, Fast Rec., 3.0A, 600V	SMC	ES3J	Fairchild
D6-9	1	-	Diode, 1.0A, 1000V	SMAF	GS1MF	PANJIT
ZD1	1	-	Zener Diode, 27V	SOD-323	PDZ27B	ON semiconductor
ZD2	-	OPEN	-	-	-	-
R1,2	1	4.7kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-074K7L	Yageo
R3,4	1	680kΩ	Resistor, Chip, 0.125W, 400V	2012	RVC20K684F	Kamaya
R5	1	3.6kΩ	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K362F	Kamaya
R6	1	11kΩ	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K113F	Kamaya
R7	1	330kΩ	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K334F	Kamaya
R8,9	1	470kΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-07470KL	Yageo
R10	1	47kΩ	Resistor, Chip, 0.125W, 200V	2012	RC0805FR-0747KL	Yageo
R12	1	47kΩ	Resistor, Chip, 0.125W, 150V	2012	RC0805FR-0747KL	Yageo
R13	1	13kΩ	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K133F	Kamaya
R14	1	100Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K101F	Kamaya
R15	1	4.7MΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-074M7L	Yageo
R16	1	3.9kΩ	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K392F	Kamaya
R17	-	OPEN	-	-	-	-
R18	-	Jumper	-	-	-	-
R19	1	1.0Ω	Resistor, Chip, 0.5W	3216	RLC32K1R00F	Kamaya
R21	1	1MΩ	Resistor, Chip, 0.25W, 200V	3216	RC1206FR-071ML	Yageo
Q1	1	-	MOSFET, Nch, 650V, 7A, 0.54Ω	D-PAK	AOD7S65	ALPHA&OMEGA
Fuse	1	-	Fuse, Fast-Acting, 2A, 250VAC	φ3.6×10.0	0874002.MXEP	Littlefuse
ZNR1	1	-	Varistor, 275VAC	5mm pitch	S10K275	EPCOS

9. Usage Cautions

1) For the phenomenon of temporal and transitional voltage decrease or voltage increase, the IC may be damaged or deteriorated if IC is used beyond the absolute MAX. specifications.

2) Make sure to use this IC within specified electric characteristics.

3) Take care not to exceed the absolute maximum ratings of the peripheral components and this IC.

4) The characteristics of a circuit that uses this product will vary depending on the peripheral components and board layout. In particular, efficiency and EMI are affected by the transformer, power MOSFET, diodes, and board layout. Test sufficiently using the actual equipment.

5) Because a circuit using this product performs high-current and high-voltage switching using components such as a transformer, power MOSFET, and diodes, switching-caused noise occurs. The effects of this switching noise may cause the IC to malfunction. Select a board layout and components that minimize the susceptibility of the IC to the effects of noise, and test sufficiently using the actual equipment.

6) Give consideration to derating when selecting external components.
In particular, external components may become hot due to heat generated by LEDs and other components.
Select components and design for heat radiation.

7) Select external components and design the test circuit board so as to satisfy applicable regulations and standards.

8) TOREX places an importance on improving our products and their reliability.
We request that users incorporate fail-safe designs and post-aging protection treatment when using TOREX products in their systems.