XC9401

Application Notes

1. General Description

The XC9401 series are offline controller ICs for LED lighting. By optimizing external components, operation from 85VAC to 270VAC is possible, as well as operation by DC input, and a wide variety of specifications can be realized by selecting components appropriate for the circuit configuration. These application notes describe the operation of both non-isolated and isolated LED lighting, and how to select components.

2. Product Features

This series provides simple operation that is suitable for a variety of solution circuits, from non-isolated circuits that use a coil to isolated circuits that use a transformer. The SOT-26 package enables reduction of the board mounting area and easier mounting on the light bulb.

Unlike an isolated type, a non-isolated circuit configuration does not require external components such as a photo-coupler or snubber circuit, making it possible to reduce the number of components, the mounting area, and total cost.

<< Control Method >>

Fixed off time is used for the basic control method, and the LED current is monitored by detecting the current in the external power MOSFET to provide a stable power supply for LED lighting. The product series is available in two functional types, the XC9401A type and the XC9401B type, and either can be selected as appropriate for the required characteristics.

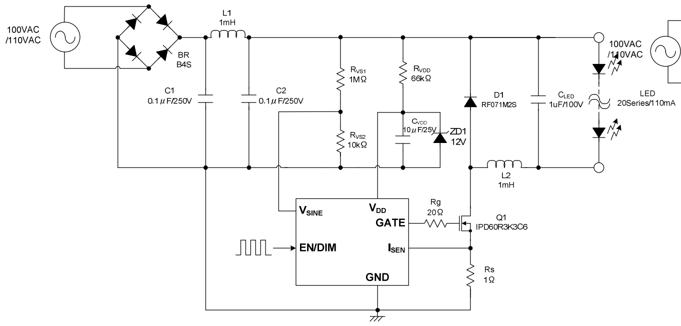


Fig.1 XC9401 A type (Non-isolated Circuits Examples)

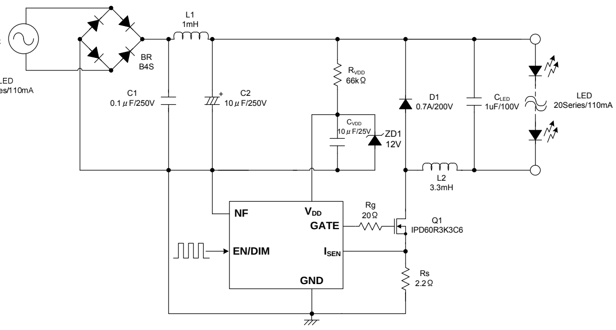


Fig.2 XC9401 B type (Non-isolated Circuits Examples)

The circuit configuration of the A type is designed to achieve a high power factor by synchronizing the LED current with the input voltage (sine wave).

This circuit configuration makes it unnecessary to add a high-capacitance, high-voltage electrolytic capacitor after the bridge rectifier circuit from the AC input. The input filter removes high-frequency switching noise from the AC line, and thus a low-capacitance ceramic capacitor can be used.

The peak current that flows through the external power MOSFET due to switching constant is made constant in the B type, allowing the LED current to be kept constant. By keeping the LED current constant, this circuit configuration makes it possible to achieve a stable light source with high efficiency.

<< Oscillation Frequency >>

A control method with a fixed off time is used, and thus the switching frequency is determined by the voltage of the connected LED and the input voltage. For details, refer to section 5-1-2.

<< PWM Dimming >>

PWM dimming is possible by inputting the PWM signal into the EN/DIM pin.

For details, refer to section 5-4.

<< Protection Functions >>

Over-current protection, thermal shutdown, UVLO, and VDD over-voltage protective circuits are incorporated to protect the IC. For details, refer to section 5-5.

<< Consideration for harmonic wave regulations >>

With A type and B type of the XC9401 series, each of which has different functions, it is possible to meet harmonic wave regulations. The input current in each type is described below.

In the A type, because the LED current is synchronized with the input voltage (sine wave), the input current waveform is in phase with the input voltage (sine wave) (Fig. 3). For this reason, the input current contains almost no high-order harmonic wave current components and easily satisfies IEC61000-3-2.

In the B type, a high-capacitance input capacitor C2 is connected to smooth the voltage after full wave rectification. The voltage Vrec that has been smoothed after full wave rectification and the input current are shown in Fig. 4. The waveform of the input current varies depending on the capacitance of the input capacitor, and thus input filter can be adjusted to satisfy IEC61000-3-2 Class D (devices with an effective input power of 25 W or less).

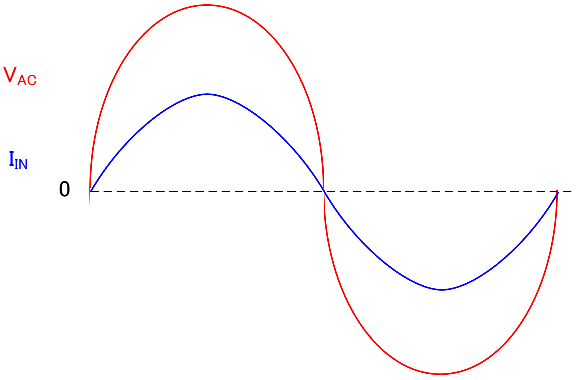


Fig.3 XC9401 A type input voltage and input current

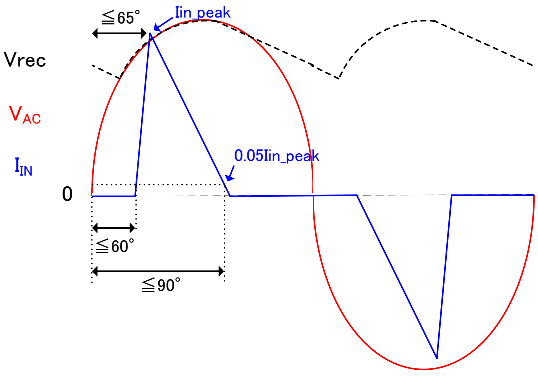


Fig.4 XC9401 B type input voltage and input current

3. Block Diagram and Pin Functions

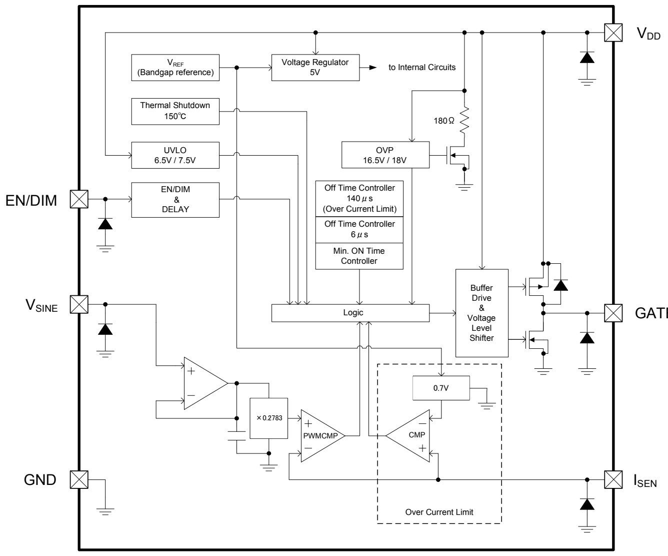


Fig.5 XC9401 A type block diagram

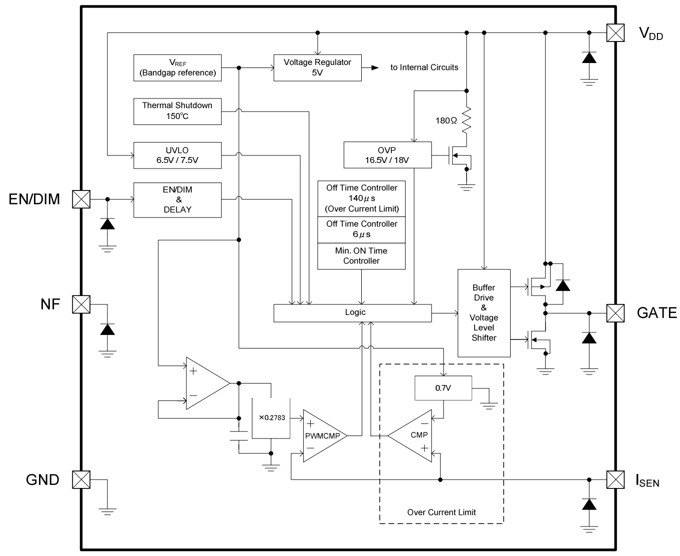


Fig.6 XC9401 B type block diagram

Diodes inside the circuit are an ESD protection diode and a parasitic diode.

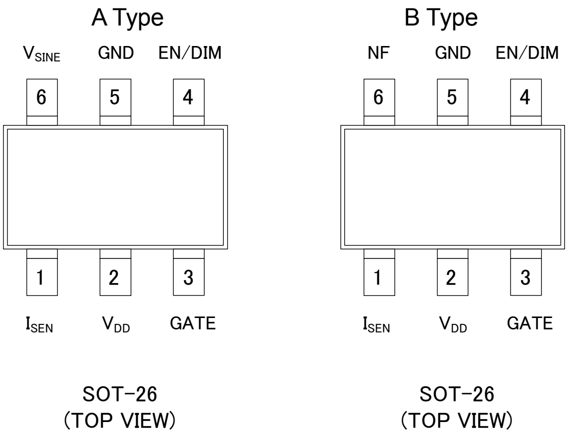


Fig.7 Pin configuration

PIN NUMBER	PIN NAME	FUNCTION
1	I_{SEN}	Current sensing pin. Connect between the external power MOSFET source and the sensing resistance. Senses by converting the current in the external power MOSFET (coil current) to a voltage.
2	V_{DD}	Power supply pin. Supplies power to the IC. Note the input operation range.
3	GATE	Output pin for drive of external power MOSFET. Connect with a resistor inserted between this pin and the gate pin of the external power MOSFET
4	EN/DIM	Enable pin / PWM dimming pin. Controls GATE output on/off.
5	GND	Ground pin.
6	A type: V_{SINE} B type: NF	A type: Reference voltage input pin for current sensing. Divide the voltage after full wave rectification with external resistors and input the result. B type: Connect to ground. (Refer to Fig. 6)

4. Typical circuit schematic and reference component table

<< 100VAC/110VAC Non-isolated Buck, B type >>

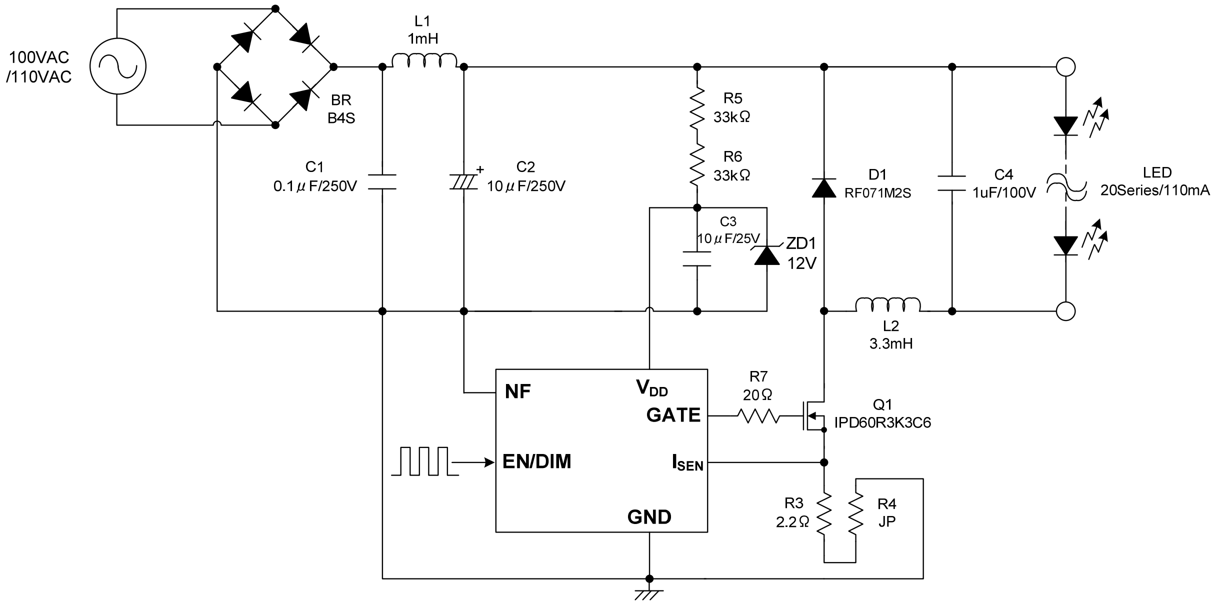


Fig.8 100VAC/110VAC Non-isolated Buck, B type Typical Application Circuit

Item	Q'ty	Value	Description	Size/PKG	Part Number	Manufacture
IC	1	-	LED Driver IC	SOT-26	XC9401B605MR-G	TOREX
C1	1	0.1µF	Capacitor, Ceramic,250V,JB,±10%	3216	QMK316BJ104KL-T	Taiyo Yuden
C2	1	10µF	Capacitor, Alminium,250V,±20%	ϕ10.0x20.0	UCS2E100MPD	Nichicon
C3	1	10µF	Capacitor, Ceramic,25V,X5R,±10%	3216	TMK316BJ106KL-T	Taiyo Yuden
C4	1	1µF	Capacitor, Ceramic,100V,X7R,±10%	3216	GRM31CR72A105A01L	Murata
L1	1	1mH	Inductor, 0.50A(Isat), 1.84Ω	ϕ7.4x9.8	744772102	Würth Elektronik
L2	1	3.3mH	Inductor, SMD, 0.35A, 6.4Ω	12.7x12.7	SRR1208-332KL	BOURNS
D1	1	-	Diode, Fast Rec., 0.7A, 200V	SOD-123	RF071M2S	Rohm
ZD1	1	-	Zener Diode, 12V	Smin2-F5-B	DZ2J120M0L	Panasonic
R3	1	2.2Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16-2R2F	Kamaya
R4	-	Jumper	-	-	-	-
R5	1	33kΩ	Resistor, Chip, 0.33W, 200V	3225	RK73B2ETTD333J	KOA
R6	1	33kΩ	Resistor, Chip, 0.33W, 200V	3225	RK73B2ETTD333J	KOA
R7	1	20Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K200F	Kamaya
Q1	1	-	MOSFET, Nch, 600V, 1.7A, 2.97Ω	TO-252	IPD60R3K3C6	Infineon
BR1	1	-	Bridge Rectifier, 0.8A, 400V	MDI	B4S	PANJIT

*LED: VLED=3.0V x 20, ILED Target = 110mA (Both average value)

<< 220VAC/240VAC Isolated Flyback, A type >>

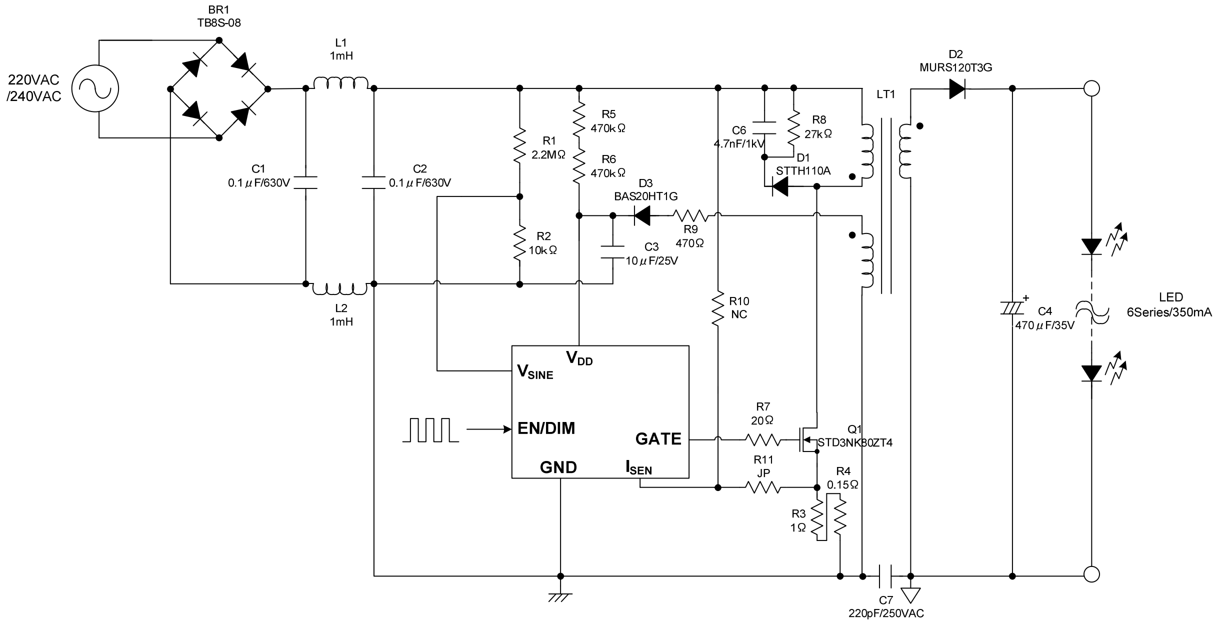


Fig.9 220VAC/240VAC Isolated Flyback, A type Typical Application Circuit

Item	Q'ty	Value	Description	Size/PKG	Part Number	Manufacture
IC	1	-	LED Driver IC	SOT-26	XC9401A605MR-G	TOREX
C1	1	0.1μF	Capacitor, Ceramic,630V,JB,±10%	4532	C4532JB2J104K	TDK-EPC
C2	1	0.1μF	Capacitor, Ceramic,630V,JB,±10%	4532	C4532JB2J104K	TDK-EPC
C3	1	10μF	Capacitor, Ceramic,25V,X5R,±10%	3216	TMK316BJ106KL-T	Taiyo Yuden
C4	1	470μF	Capacitor, Alminium,50V,±20%	φ12.5x20.0	50PX470M	Rubycon
C6	1	4.7nF	Capacitor,Ceramic,1kV,X7R	3216	GRM31BR73A472KW01L	Murata
C7	1	220pF	Safety Capacitor Y1,250VAC,B	-	DE1B3KX221KN5AL01	Murata
L1,2	1	1mH	Inductor, 0.40A(Isat), 2.2Ω	-	5800-102-RC	BOURNS
LT1	1	-	transformer	-	750813551	Würth Elektronik
D1	1	-	Diode, Fast Rec., 1.0A, 1000V	SMA	STTH110A	STMicroelectronics
D2	1	-	Diode, Fast Rec., 1.0A, 200V	SMB	MURS120T3G	On semiconductor
D3	1	-	Diode, Fast Rec., 0.2A, 200V	SOD-323	BAS20HT1G	On semiconductor
R1	1	2.2MΩ	Resistor, Chip, 0.25W, 400V	2012	RVC1/10K225FTP	Kamaya
R2	1	10kΩ	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K104FTP	Kamaya
R3	1	1.0Ω	Resistor, Chip, 0.5W	3216	RLC32-1R00F	Kamaya
R4	1	0.15Ω	Resistor, Chip, 0.5W	3216	RLC32-R470F	Kamaya
R5	1	470kΩ	Resistor, Chip, 0.25W, 500V	3216	HV732BTBK474J	KOA
R6	1	470kΩ	Resistor, Chip, 0.25W, 500V	3216	HV732BTBK474J	KOA
R7	1	20Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K200F	Kamaya
R8	1	27kΩ	Resistor, Chip, 0.5W, 200V	3225	ERJT14J273U	Panasonic
R9	1	470Ω	Resistor, Chip, 0.25W, 150V	2012	ERJT06J471V	Panasonic
R10	-	-	-	-	-	-
R11	-	Jumper	-	-	-	-
Q1	1	-	MOSFET, Nch, 800V, 2.5A, 3.8Ω	D-PAK	STD3NK80ZT4	STMicroelectronics
BR1	1	-	Bridge Rectifier, 0.8A, 800V	MICRO DIP	TB8S-08	PANJIT

*LED: VLED=3.2V x 6, ILED Target = 350mA (Both average value)

5. Operational explanation

This section explains the control method and operation states of the XC9401 series.

To select external components, refer to section 6 for non-isolated circuits, or section 7 for isolated circuits.

5-1. Normal operation

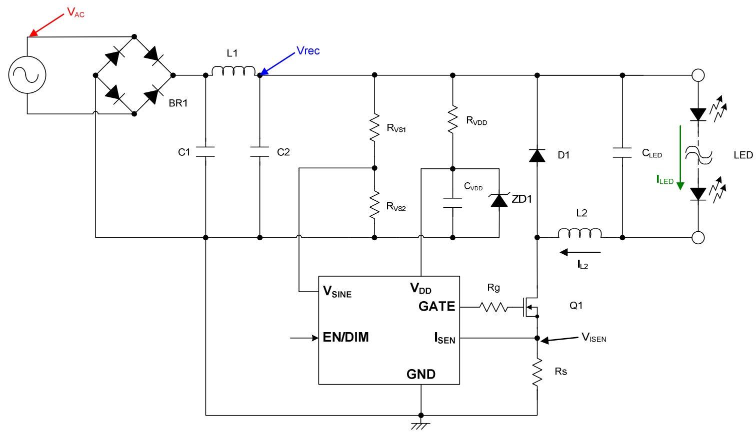
5-1-1. Current control method and input voltage / input current

The XC9401 series adjusts the LED current by comparing the V_{SINE} pin voltage or IC internal reference voltage to the I_{SEN} pin voltage, which results from conversion of the coil current or transformer primary coil current to a voltage. The operation of the coil current and LED current in each type using a non-isolated circuit is described below.

<< A type: Supports a high power factor >>

The A type compares the V_{SINE} pin voltage to the I_{SEN} pin voltage to control the peak current of the coil so that it follows the V_{SINE} pin voltage.

The voltage after full wave rectification is resistance-divided and a voltage in phase with the input voltage (sine wave) is input into the V_{SINE} pin. The voltage input from the V_{SINE} pin is multiplied by 0.2783 inside the IC and compared in the comparator (PWMCMP) to the I_{SEN} pin voltage, which monitors the peak current of the coil due to switching. When the I_{SEN} pin voltage is higher than the comparison voltage, switching is stopped and the peak current of the coil becomes in phase with the V_{SINE} pin voltage, so that the input voltage and input current are in phase and a high power factor can be achieved.



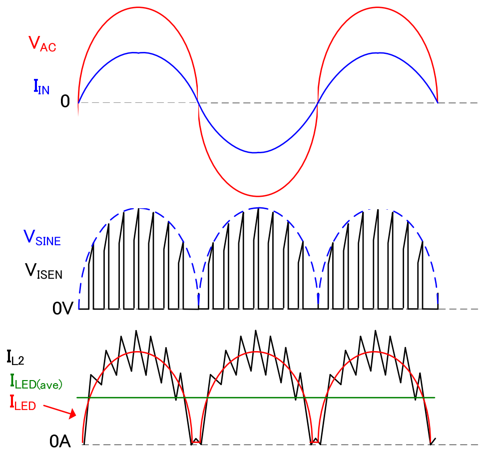


Fig.10 XC9401 A type Non-isolated circuit and operation waveforms

<< B type: Constant current control >>

The B type controls the peak current of the coil by comparing the I_{SEN} pin voltage to a voltage of 0.343V (typ.) obtained by multiplying the reference voltage in the IC by 0.2783. This makes the peak current of the coil constant regardless of the input voltage, enabling good line regulation characteristics as a LED current to be obtained.

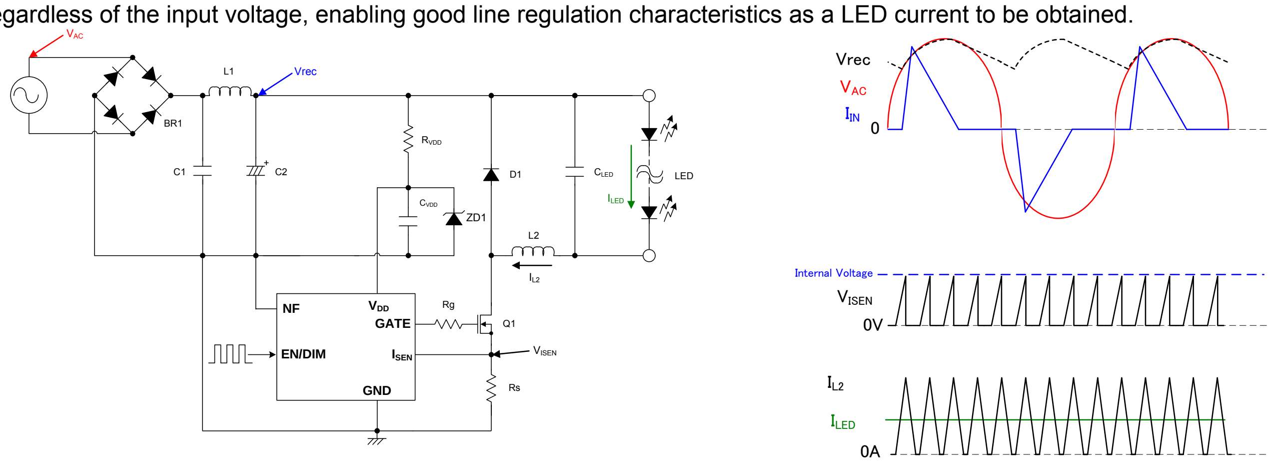


Fig.11 XC9401 B type Non-isolated circuit and operation waveforms

5-1-2. Off-time fixed control and calculation of on time/off time

The XC9401 series fixes the off time of the external power MOSFET to 6.0μs (typ.) and controls the current that flows to the power MOSFET. During switching on operation, off occurs when the peak current of the coil or transformer primary coil is detected, and the next on operation starts after the fixed off time elapses. This sequence is repeated continuously.

Because the peak current of the coil is monitored by means of the I_{SEN} pin voltage, the on time depends on the slope of the coil current or transformer primary coil current (which depends on the inductance value and voltage Vrec after full wave rectification during switching) and the comparator (PWMCMP) comparison voltage. Particularly in the B type, which is the source of the comparison voltage, changes continuously, and the on time changes accordingly. As a result, the switching frequency is dispersed rather than becoming a specific frequency, which makes it possible to reduce the EMI level.

The method of calculating on time / off time and the current waveform during operation are different in a non-isolated circuit and an isolated circuit, as explained the next section.

<< Non-isolated Circuit >>

During operation in discontinuous mode in a non-isolated circuit, the fixed off time is maintained until the next on even if the coil current becomes 0A (Fig. 12). In continuous mode, on occurs after the fixed off time when the coil current is 0A or higher (Fig. 12).

The on time t_{ON} and off time t_{OFF}' of discontinuous mode are given by Equations (1) and (2).

To stabilize IC operation, the minimum on time is set internally to 0.2μs.

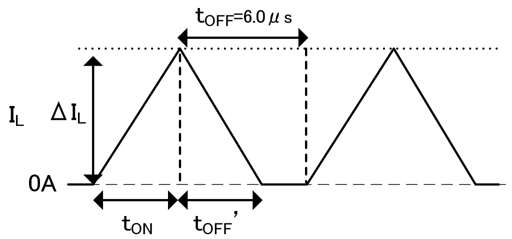


Fig.12 Coil Current in discontinuous mode

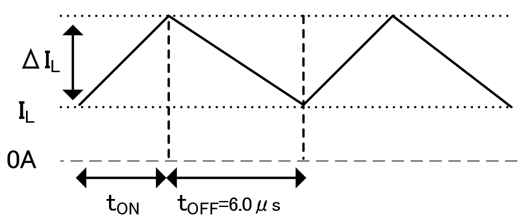


Fig.13 Coil Current in continuous mode

$$t_{ON} = \Delta I_L \cdot \frac{L}{V_{rec}(t) - V_{LED}} \qquad (1)$$

$$t_{OFF}' = \Delta I_L \cdot \frac{L}{V_{LED} + VF} \qquad (2)$$

V_{LED}	: LED voltage
Vrec(t)	: Voltage after full wave rectification at time t
ΔI_L	: Coil current amplitude
VF	: Forward voltage of flywheel diode
L	: Coil inductance value

Reference calculation results can be calculated in the separate calculation file.

<< Isolated Circuit >>

In an isolated circuit, current flows to the transformer primary coil while the external power MOSFET is on, and current flows in the secondary coil while the MOSFET is off. (Fig. 14, Fig. 15)

In discontinuous mode, the fixed off time is maintained until the next on even if the transformer secondary coil circuit becomes 0A. In continuous mode, on occurs when the transformer secondary coil current is 0A or higher after the fixed off time.

The on time t_{ON} and off time t_{OFF}' of discontinuous mode are given by Equations (3) and (4).

To stabilize IC operation, the minimum on time is set internally to 0.2μs.

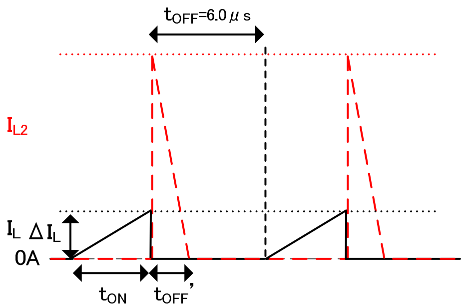


Fig.14 transformer Current in discontinuous mode

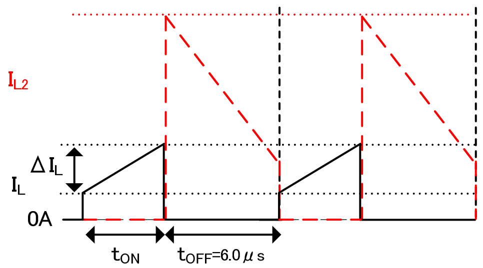


Fig.15 transformer Current in continuous mode

$$t_{ON} = \Delta I_L \cdot \frac{L}{V_{rec}(t)} \tag{3}$$

$$t_{OFF}' = \Delta I_L \cdot \frac{L}{V_{LED} + VF} \cdot \left(\frac{N2}{N1}\right) \tag{4}$$

V_{LED} : LED voltage
Vrec(t) : Voltage after full wave rectification at time t
ΔI_L : Transformer primary current amplitude
VF : Forward voltage of rectification diode
L : Inductance value of transformer
N1 : Number of windings of transformer primary coil
N2 : Number of windings of transformer secondary coil

Reference calculation results can be calculated in the separate calculation file.

5-2. Startup

To allow PWM dimming to be performed from the EN/DIM pin, the XC9401 does not have a soft start function.

When the IC starts, the I_{SEN} pin voltage is monitored by means of the external RSEN resistance and the peak current in the coil or transformer primary coil is controlled, so a rush current higher than the set current never flows.

<< EN Startup >>

When a voltage higher than the UVLO release voltage is applied to the V_{DD} pin, the IC can be started by inputting a signal higher than the H level voltage into the EN/DIM pin. Normal operation starts following a delay of 140 μs (typ.) after the EN/DIM pin reaches the H level voltage. (Fig. 16)

<< AC Startup >> (V_{DD}=EN)

Following AC power supply input, C_{VDD} is charged through R_{VDD} from the voltage Vrec that has been smoothed after full wave rectification, and this raises the voltage of the V_{DD} pin. When the UVLO release voltage 7.5V (typ.) is reached, UVLO is released and normal operation resumes. (Fig. 17)

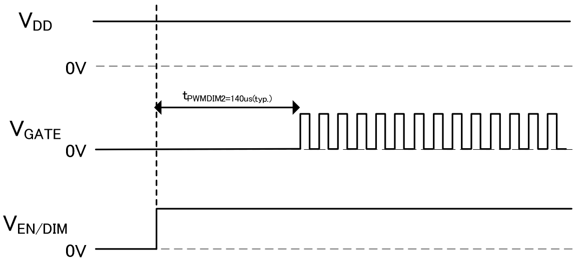


Fig.16 EN Startup

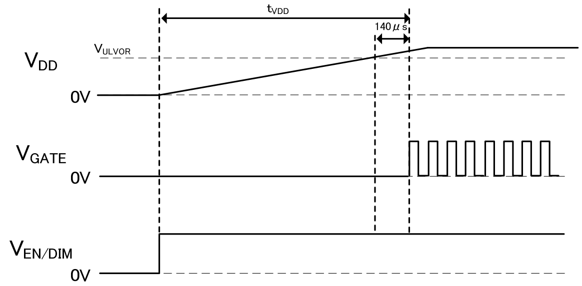


Fig.17 AC Startup

An approximate value for the time from AC power supply input until normal operation can be calculated using Equation (5).

$$t_{VDD} = (C_{VDD} \cdot V_{UVLOR}) \Big/ \left(\frac{\sqrt{2} \cdot V_{rms}}{R_{VDD}} - I_{STB}\right) + 140\mu s \qquad (5)$$

R_{VDD} : Refer to fig.18.
C_{VDD} : Refer to fig.18.
V_{UVLOR} : UVLO release voltage 7.5V (typ.)
I_{STB} : Stand-by Current 225μA (typ.)
Vrms : Input RMS Voltage (ex.220V)

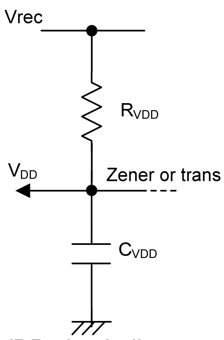


Fig.18 VDD circuit diagram

5-3. Standby state

The internal circuitry of the IC is put in the standby state by inputting a voltage lower than the L level voltage into the EN/DIM pin. In the standby state, switching stops but the internal circuitry of the IC continues to operate. This turns off the LED and reduces power consumption.

5-4. Dimming

By inputting the PWM signal into the EN/DIM pin, on/off of the GATE output is controlled in synchronization with the PWM signal to perform PWM dimming. As a guideline, the frequency used for PWM dimming should be about 500Hz to 1kHz. The GATE output that drives the external power MOSFET outputs a signal 140μs after the EN/DIM pin voltage reaches the H level voltage, and thus a minimum on duty of 140μs or longer is required, and the maximum on duty less than 100% duty is one cycle minus 140μs.

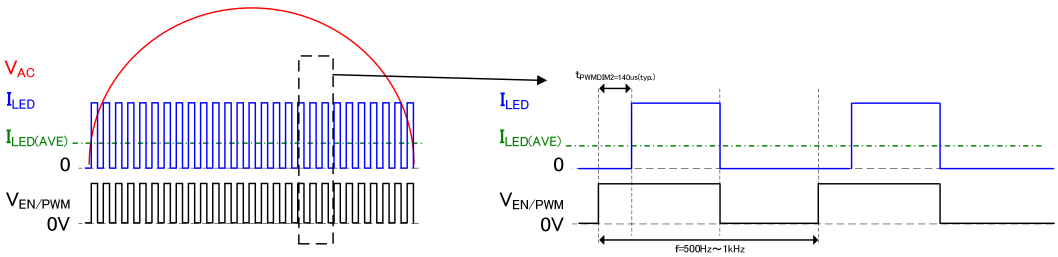


Fig.19 Timing of PWM Dimming (XC9401 B type)

5-5. Protective Functions

The XC9401 series has four protective functions: over-current protection, thermal shutdown, UVLO, and VDD over-voltage protection.

5-5-1. Over Current Limit

When the switching current of the external power MOSFET is in the over-current state and the I_{SEN} pin voltage reaches 0.7V (typ.), L level voltage is output to the GATE pin and the external power MOSFET is turned off. In addition, the off time is extended from the normal 6.0μs to 140μs. When the I_{SEN} pin voltage falls below 0.7V (typ.) after the extended off time, normal operation resumes.

When a short circuit occurs between LEDs in a non-isolated circuit, the current slope of the coil (L2) during the off time becomes smaller than the slope during normal switching, and in an off time of 6.0μs, sufficient discharge cannot take place. The external power MOSFET Q1 always turns on during the minimum on time, so the coil current gradually increases. The I_{SEN} pin voltage becomes higher in synchronization with the increase of coil current, and when the I_{SEN} pin voltage reaches 0.7V, the off time is extended to about 140μs. (Fig. 20)

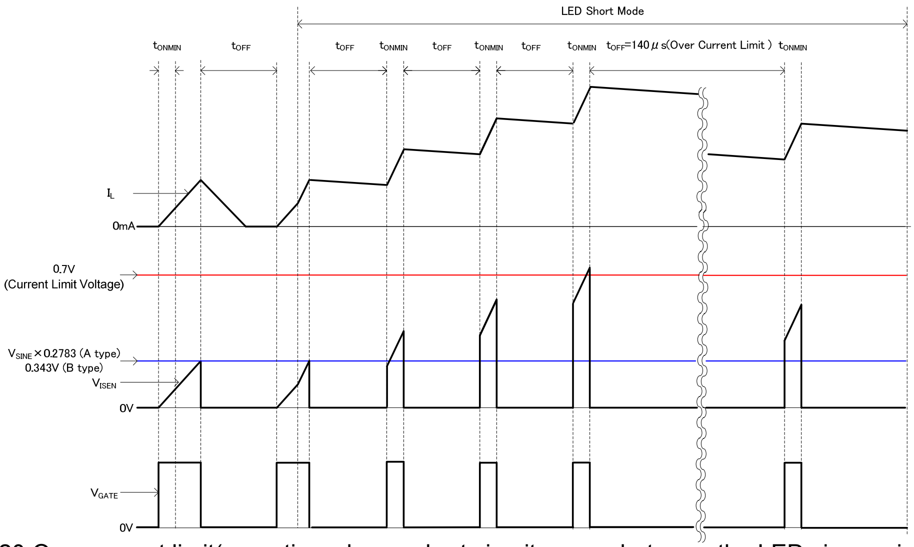


Fig.20 Over current limit(operation when a short circuit occurs between the LEDs in non-isolated circuit)

5-5-2. Thermal Shutdown

To protect the IC from thermal destruction, thermal shutdown activates when the chip temperature reaches 150°C(typ.), and the GATE pin voltage is forcibly put in the “L” state to reduce the power supplied to the LED. When the chip temperature drops to 130°C(typ.), normal operation automatically resumes.

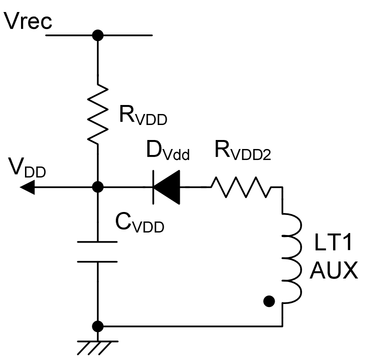
5-5-3. UVLO

When the V_{DD} pin voltage falls below the UVLO detection voltage (V_{UVLO}), the GATE pin voltage is forcibly put in the “L” state to prevent the output of false pulses. When the V_{DD} pin voltage rises above the UVLO release voltage (V_{UVLOR}), normal operation resumes.
When UVLO is detected, switching is stopped but the internal circuitry of the IC continues to operate.

5-5-4. VDD Over-voltage Protection

This function prevents IC destruction when over-voltage is input into the V_{DD} pin in the standby state and other states. When the V_{DD} pin voltage exceeds the VDD over-voltage detection voltage (V_{OVP}), the capacitor C_{VDD} between the V_{DD} pin and GND pin is discharged through the internal IC resistance between the V_{DD} pin and GND pin (Fig. 21). At this time, the GATE pin voltage is forcibly put in the “L” state. When the V_{DD} pin voltage drops below the VDD over-voltage release voltage (V_{OVPR}), normal operation resumes. (Fig. 22)

In a configuration where a transformer is used in the power supply to the IC (Fig. 21), the above operation (Fig. 22) actually takes place when the IC goes into the standby state.



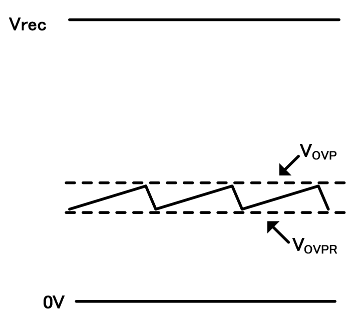


Fig.21 VDD power supply circuit using a transformer

Fig.22 VDD Over-voltage protection operation

6. Selection of the external components of a non-isolated circuit

Selection of the external components of a non-isolated circuit is explained below using the non-isolated circuit shown in Fig. 23 as an example. This circuit uses the XC9401 series B type at 100VAC.

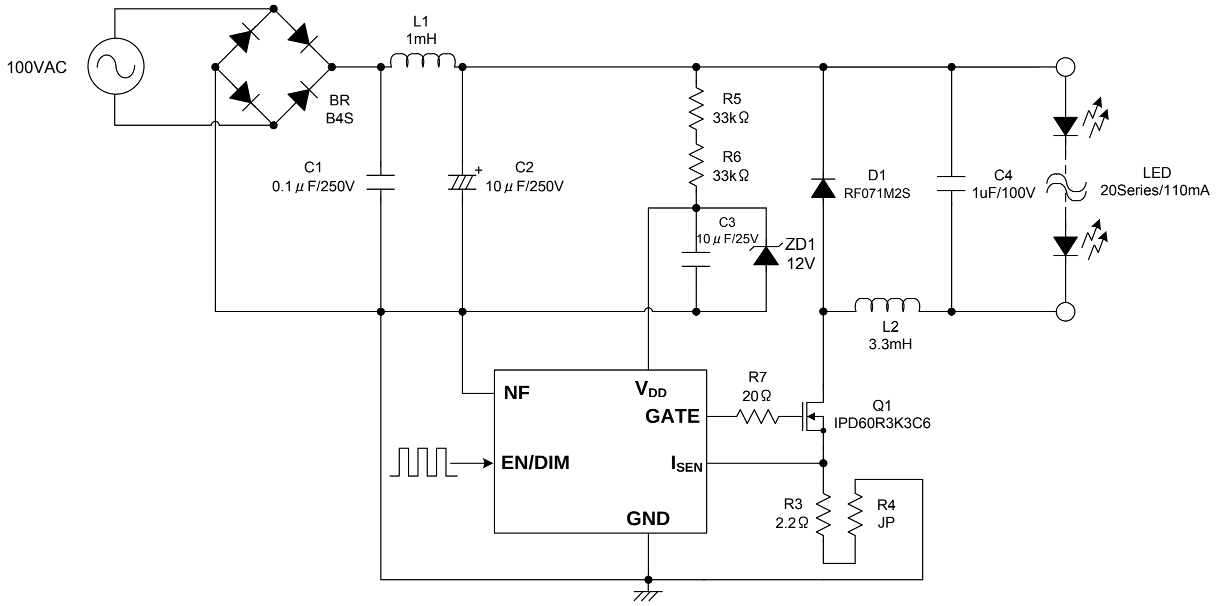


Fig.23 100VAC Non-isolated Buck, B type Typical Application Circuit

6-1. Number of LED Series

First, the criteria for selecting the number of LED series in this application is described.

The LED connection method, number of LED series, and LED current play an important role in efficient LED illumination. The general relation between the number of LED series and the LED current at a fixed LED output power is shown in Fig. 24.

It can be seen that increasing the number of LED series reduces LED current. When LED current decreases in a non-isolated circuit, loss in peripheral components of the power circuit decreases, efficiency improves, and smaller components can be used. This makes it possible to reduce mounting area and cost. It is actually possible to hold down the total cost of LEDs and peripheral components by selecting an optimum value for the number of LED series.

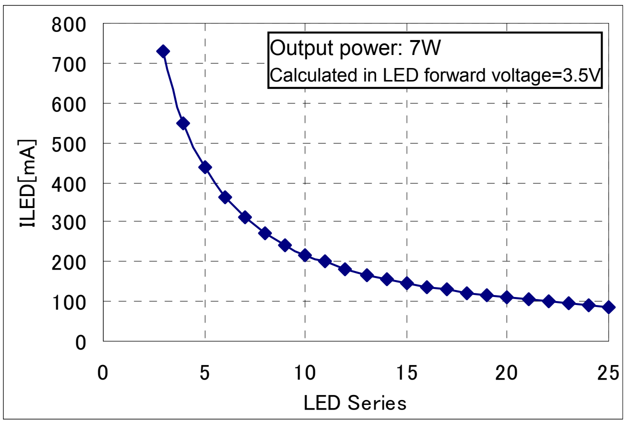


Fig.24 The general relation between the number of LED series and the LED current at a fixed LED output power

When the input voltage is large and the LED voltage is small in a non-isolated circuit, the on time may in some cases become shorter than the minimum on time t_{ONMIN}. When the on time is shorter than the minimum on time, control of the LED current is not possible and the LED current becomes higher than the set value.
For this reason, select a LED voltage that satisfies equation (6) to keep the on time from becoming shorter than the minimum on time.

$$t_{ONMIN} > \frac{(V_{LED} + VF)}{(\sqrt{2}V_{rms\_max} - V_{LED})} \cdot t_{OFF} \qquad (6)$$

t_{ONMIN} : Minimum on time
V_{LED} : LED voltage
VF : Forward voltage of rectification diode
V_{rms_max} : Maximum input RMS voltage
t_{OFF} : Off time 6.0μs(typ.)

In this example, external components will be selected based on 20 LED series and a LED current of 110mA.

6-2. Bridge Diode (BR)

This is a bridge diode for full wave rectification of the AC input. Select a bridge diode with a peak inverse voltage and average rectification current that are more than sufficient for the input voltage and current.

In this example, the peak value of the input current is about 500mA and the maximum voltage applied to the bridge diode is about 282V, and thus a product with a rated current of 0.8A and a rated voltage of 400V is selected.

6-3. Input Filter (L1,C1,C2)

C1 and L1 form a filter circuit that reduces noise from the AC input and noise that returns to the AC input. In the typical circuit example (Fig. 23), a filter is formed that attenuates 20kHz and higher noise to remove switching frequency (50kHz to 150kHz) and higher noise. The capacitance value of C1 must be kept small to limit rush current from the AC input, so select a capacitor that is about 0.1μF.

It will be necessary to adjust the input filter constants and filter circuit to meet the regulations and standards that will actually apply.

The voltage after full wave rectification is smoothed by C2. LED flickering is reduced by using a higher capacitance for C2. When the smoothed voltage Vrec after full wave rectification drops lower than the LED voltage, switching stops and the LED current falls (Fig. 25). The longer switching stops, the more the LED current falls, and when it falls below 5% of its peak value, flickering occurs. (The PSE definition is used for the definition of flickering.)

To prevent flickering, the LED voltage and C2 capacitance value must be selected to satisfy Equation (7). Note, however, that the power factor decreases as the capacitance value is increased.

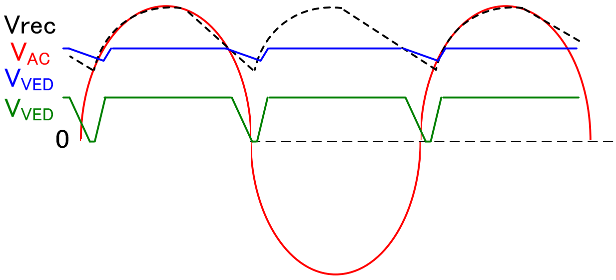


Fig.25 Various waveforms in flickering

$$C2 > \frac{P_{IN}}{V_{rms\_min}(\sqrt{2}V_{rms\_min} - V_{LED})}\left\{\frac{1}{4f} + \frac{1}{2\pi f}\sin^{-1}\left(\frac{V_{LED}}{\sqrt{2}V_{rms\_min}}\right)\right\} \tag{7}$$

P_{IN} : Input Power
f : Utility frequency 50Hz / 60Hz
V_{rms_min} : Minimum input RMS voltage

An example calculation is given below.
When V_{LED} = 60V, I_{LED} = 0.11A, f = 50Hz, and V_{rms_min} = 90V, the minimum value of the C2 capacitance is

$$C2 >= \frac{60V \cdot 0.11A}{90V(\sqrt{2} \cdot 90V - 60V)}\left\{\frac{1}{4 \cdot 50Hz} + \frac{1}{2\pi \cdot 50Hz}\sin^{-1}\left(\frac{60V}{\sqrt{2} \cdot 90V}\right)\right\} = 7.15\mu F$$

and flickering can be prevented by using a capacitance of 7.15μF or higher.

The result of the above calculation is an ideal value.
The actual capacitance value to be used can be calculated from the separate calculation file.

6-4. NF Pin

The B type used in this example compares the I_{SEN} voltage to the internal reference voltage. Connect the NF pin voltage to the GND pin. With the A type, it is necessary to resistance divide the full wave rectified voltage and apply the resulting voltage to the V_{SINE} pin. Refer to section 7-4, which explains how to select components for the A type.

6-5. Power Supply to VDD pin (R5,R6,C3,ZD1)

This circuit supplies power to the power pin (V_{DD} pin) of the IC. There are two power supply methods: a method that uses a Zener diode and a method that uses a transformer auxiliary coil. The method that uses a transformer supplies power to the V_{DD} pin through an auxiliary coil. This reduces loss in R_{VDD} and enables a higher efficiency than the Zener diode method to be obtained.

This example uses the Zener diode method, but the transformer auxiliary coil method is also explained. Selection of components for each method is described below.

<< Method using a Zener diode >>

A VDD power supply circuit using a Zener diode is shown in Fig. 26.

・ZD1

This is a Zener diode that determines the voltage applied to the V_{DD} pin.

Use a Zener diode that satisfies

V_{DD} minimum voltage (9V) < Zener voltage < V_{DD} maximum voltage (15V)

In this example, a product with a Zener voltage of 12V has been selected.

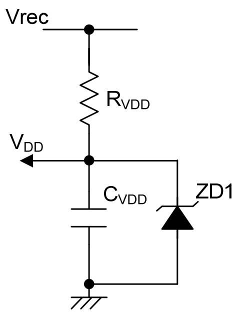


Fig.26 VDD power supply circuit using a Zener diode

・C_{VDD}

This capacitor stabilizes the V_{DD} pin voltage. Use a capacitor with a capacitance of 10μF or higher.

If a ceramic capacitor will be used, select a product in which the electrostatic capacitance falls minimally when a B type (JIS Standards) or X7R/X5R (EIA Standards) DC bias is applied.

・R_{VDD}

This resistance determines the current to the V_{DD} pin and ZD1 from the smoothed voltage after full wave rectification. The current that flows through R_{VDD} is the steady IC supply current plus the current for charging the external power MOSFET gate for switching. Setting too high a value for this resistance lowers the V_{DD} pin voltage and may cause unstable operation. Setting too low a value increases the loss in R_{VDD} and reduces efficiency. Therefore, it is important to set an appropriate value.

In this example, the total value of the IC supply current and the current for charging the external power MOSFET gate is assumed to be 1 mA, and 66kΩ is selected for R_{VDD} (the total value of R5 and R6 in Fig. 23).

The optimum resistance value depends on the input voltage, gate capacitance of the external power MOSFET, coil inductance value, and other parameters. To calculate the actual resistance value to be used, refer to the separate calculation file.

<< Method using a transformer >>

A VDD power supply circuit using a transformer is shown in Fig. 27.

・LT1

Current is supplied to the VDD pin using the LT1 auxiliary coil.

For selection of the transformer, refer to section 6-6.

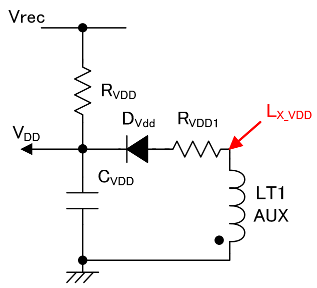


Fig.27 VDD power supply circuit using a transformer

・D_{VDD}

This is a rectifying diode that supplies power voltage from LT1. A reverse bias voltage V_{Dvdd} that depends on the LED voltage and transformer turn ratio as shown in Equation (8) is applied to D_{VDD}. Select a diode with a rated voltage appropriate for this reverse bias voltage.

$$V_{Dvdd} = V_{DD} + \sqrt{2} \cdot V_{rms\_max} \cdot \frac{N_{AUX}}{N1} + V_{spike} \qquad (8)$$

N1	: Number of windings of transformer primary coil
N_{AUX}	: Number of windings of transformer auxiliary coil
V_{DD}	: VDD pin voltage
V_{rms_max}	: Maximum input RMS voltage
V_{spike}	: Spike voltage that accompanies switching (to 50 V)

A calculation example is shown below.
When N1 = 150, N_{AUX} = 30, V_{DD} = 12V, V_{rms_max} = 110V, and V_{spike} = 50V, the reverse bias voltage V_{Dvdd} is

$$V_{Dvdd} = 12V + \sqrt{2} \cdot 110V \cdot \frac{30}{150} + 50V = 93V$$

The same calculation is made in the separate calculation file. Please make use of this file.

・C_{VDD}

This capacitor stabilizes the V_{DD} pin voltage. Use a capacitor with a capacitance of 10μF or higher.

If a ceramic capacitor will be used, select a product in which the electrostatic capacitance falls minimally when a B type (JIS Standards) or X7R/X5R (EIA Standards) DC bias is applied.

・R_{VDD}

This resistance is used to supply current to the V_{DD} pin at startup. When the input voltage is applied and the V_{DD} pin voltage rises above the UVLO release voltage, GATE output starts and normal operation takes place. After startup, power is mainly supplied to the V_{DD} pin through the auxiliary coil of the transformer.

When R_{VDD} is large and the current through R_{VDD} is smaller than the current consumed in the IC, the V_{DD} pin voltage does not rise higher than the UVLO release voltage and startup is not possible. For this reason, select a resistance value for R_{VDD} that satisfies Equation (9). (Fig. 27)

$$R_{VDD} < \frac{(\sqrt{2}V_{rms\_min} - V_{UVLOR})}{I_{STB}} \qquad (9)$$

I_{STB}	: Stand-by Current 225μA (typ.)
V_{UVLOR}	: UVLO Release Voltage 7.5V (typ.)
V_{rms_min}	: Minimum input RMS voltage

A calculation example is shown below.
When I_{STB} = 225μA, V_{UVLOR} = 7.5V, and V_{rms_min} = 90V, R_{VDD} is

$$R_{VDD} < \frac{(\sqrt{2} \cdot 90V - 7.5V)}{225\mu A} = 532k\Omega$$

and the IC can be started normally by using a resistance lower than 532kΩ.

The same calculation is made in the separate calculation file. Please make use of this.

・R_{VDD1}

To supply current to the V_{DD} pin, L_{X_VDD} is made to oscillate and supply voltage to the V_{DD} pin (refer to Fig. 28). However, in actuality a spike voltage sometimes occurs in L_{X_VDD} and causes the V_{DD} pin voltage to rise higher than the V_{DD} target voltage (= V_{LED} × N3/N2). A countermeasure for this V_{DD} pin voltage rise is to insert a resistance in R_{VDD1} to reduce the current supplied to the V_{DD} pin.

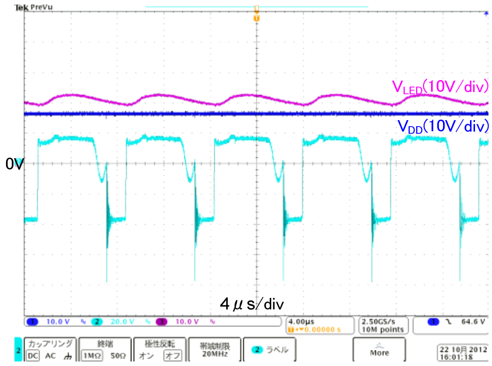


Fig.28 Operation waveforms (VDD power supply circuit using a transformer)

6-6. Coil (L2)

In the XC9401 series, the external power MOSFET off time is fixed at 6.0μs (typ.) and the peak current of the coil is controlled. For this reason, the operation mode, continuous mode or discontinuous mode, is determined by the smoothed voltage after full wave rectification and the inductance value of the coil

In control continuous mode, which has a fixed off time, the LED current ideally does not fluctuate due to fluctuations in the input voltage. However, in discontinuous mode, the LED current fluctuates with fluctuations in the input voltage. For this reason, select a coil with an inductance value suitable for operation in continuous mode. The detailed method is described below.

First, calculate from Equation (10) the minimum inductance value required to enter continuous mode. In continuous mode, deviations in the LED current due to deviations in the inductance are smaller when the inductance value is larger, so choose an inductance value that is as large as possible. Using a product with good inductance accuracy can also reduce LED current fluctuation.

If the inductance value is too large, the switching frequency may enter the audible range (20 to 20kHz), so make sure the inductance satisfies the equations below to prevent entry into the audible range.

Once you have selected an inductance value, select a coil taking peak coil current and heat generation into consideration.

$$L_{\min} = \frac{1}{2} \cdot \frac{(V_{LED} + VF)}{I_{LED}} \cdot t_{OFF} \tag{10}$$

$$\frac{L}{(V_{\text{rec\_min\_ave}} - V_{LED})} \cdot \Delta I_{\text{L}} + t_{OFF} < \frac{1}{20kHz} \tag{11}$$

V_{LED} : LED voltage
VF : Forward voltage of rectification diode
I_{LED} : LED current
t_{OFF} : Off time 6.0μs(typ.)
L : Coil inductance value
ΔI_L : Coil current amplitude
$V_{rec\_min\_ave}$: Average value of voltage smoothed after full wave rectification at minimum input voltage (The calculation is complex, so please check the calculation file.)

A calculation example is shown below.

When V_{LED} = 60V, VF = 1.0V, I_{LED} = 0.11A, and t_{OFF} = 6.0μs, the minimum value of the inductance is

$$L_{\min} = \frac{1}{2} \cdot \frac{(60V + 1.0V)}{0.11A} \cdot 6.0\mu s = 1.66mH$$

and an indactance of 1.66 mH or higher should be selected. Because it is desired to minimize deviations in the LED current, a 3.3 mH coil is selected here.

Next, we check if the switching frequency is within the audible range when the selected inductance is used.

When L = 3.3mH, $V_{rec\_min\_ave}$ = 120V and ΔI_L = 0.11A, therefore equation (11) is

$$\frac{3.3mH}{(120V - 60V)} \cdot 0.11A + 6.0\mu s = 12.05\mu s < \frac{1}{20kHz} = 50\mu s$$

and it can be seen that the switching frequency is not within the audible range.

To select the coil that will actually be mounted, refer to the separate calculation file.

6-7. Flywheel Diode (D1)

Flywheel diode for discharge of the energy that is stored in the inductance when MOSFET Q1 is in the off state. Use a flywheel diode with a short reverse recovery time. A diode with a long reverse recovery time will adversely affect efficiency.

Because the peak current reaches 180mA, a product with a rated current of 0.7A is selected in this example.

6-8. MOSFET, Gate Resistor (R7)

Power MOSFET for switching and gate resistor for switching time adjustment.
Inserting a gate resistance makes it possible to slow the MOSFET switching time and reduce the high-frequency EMI level. However, a larger gate resistance and a slower switching speed increases MOSFET switching loss, resulting in lower efficiency. The optimum value depends on the MOSFET that is used, but in general a gate resistance of about 5 to 50Ω should be selected.

The MOSFET selection method varies depending on the VDD power supply method. The selection methods are explained below.

Power Supply to VDD pin：Method using a Zener diode

When a MOSFET with a large gate capacitance is selected, the current for gate charging supplied to the VDD pin is larger, resulting in increased loss in R5 and R6 and decreased efficiency. A larger loss in R5 and R6 means that resistors with a larger allowable loss must be selected, which increases the mounting area and results in higher cost.
For this reason, it is important to select a MOSFET with a small gate capacitance and increase the efficiency of the overall circuit. In this example, the IPD60R3K3C6 (Gate charge total: 4.6nC @10V) is selected as a MOSFET with a small gate capacitance.

Power Supply to VDD pin：Method using a transformer

Unlike the Zener diode method, power is supplied with high efficiency through the transformer to the V_{DD} pin when the transformer method is used, and thus using a MOSFET with a small on-resistance to reduce MOSFET loss even when the gate capacitance is large results in high efficiency.

For this reason, select a MOSFET with a small on-resistance.

6-9. LED current adjustment (R3,R4)

Sensing resistor that adjusts the external power MOSFET current in order to adjust the LED current. The LED current is set by adjusting the sensing resistance.

In the B type used in this example, the I_{SEN} voltage is compared to the internal reference voltage, and the peak value of the MOSFET current is determined by the sensing resistances R3 and R4 as given in Equation (12). (Refer to Fig. 29.)

$$Ip = \frac{V_{ISEN}}{(R3 + R4)} \qquad (12)$$

Ip : Peak value of MOSFET current (same as peak value of coil current described above)
V_{ISEN} : I_{SEN} Voltage 0.343V (typ.)

The MOSFET current, coil current, and LED current in continuous mode in a non-isolated circuit are shown in Fig. 30. The LED current is the average value of the coil current, and thus by using the resistance values calculated in Equation (13) for the sensing resistors R3 and R4, the LED current can be adjusted to the target value.

$$R3 + R4 = V_{ISEN} \Big/ \left\{ I_{LED} + \frac{(V_{LED} + VF)}{2L} \cdot t_{OFF} \right\} \qquad (13)$$

V_{ISEN} : I_{SEN} Voltage 0.343V (typ.)
I_{LED} : Target value of LED current
V_{LED} : LED voltage
VF : Forward voltage of flywheel diode
L : Coil inductance value
t_{OFF} : Off time 6.0μs(typ.)

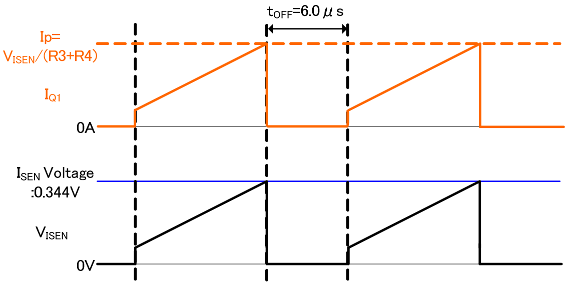


Fig.29 MOSFET Current and I_{SEN} Voltage

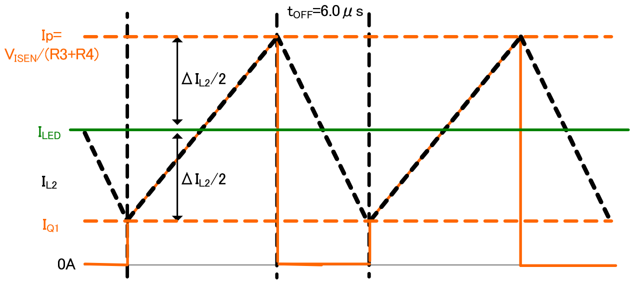


Fig.30 MOSFET Current, Coil , LED Current

A calculation example is shown below.

When V_{ISEN} = 0.343V, I_{LED} = 0.11A, V_{LED} = 60V, VF = 1.0V, L = 3.3mH, and t_{OFF} = 6.0μs, the LED current can be set to 0.11A by using resistance values for sensing resistors R3 and R4 that satisfy.

$$R3 + R4 = 0.343V \Big/ \left\{ 0.11A + \frac{(60V + 1.0V)}{2 \cdot 3.3mH} \cdot 6.0\mu s \right\} = 1.98\Omega$$

The actual resistance values that are used must be calculated by a formula that includes parameters such as the circuit delay, so calculate these using the separate calculation file.

6-10. Output Capacitor (C4)

Capacitor that limits LED ripple current and ripple voltage.

As in this example, if the smoothed voltage after full wave rectification Vrec never falls below the LED voltage, flickering does not occur and a smaller capacitance value can be used for the output capacitance C4. For this reason, a ceramic capacitor can be used for the output capacitance instead of an electrolytic capacitor, and this enables improvement of the reliability of the LED lighting.

The capacitance value of the output capacitance is determined by the ripple current ratio of the LED current.

If the ripple current ratio is to be kept under 0.8 (ripple current: 110mA ×0.8 = 88mA) for ILED = 110mA, first calculate the allowed Vripple from the LED IV characteristic that is used. Here this is 0.35V×20=7.0V from Fig. 31.

If a ceramic capacitor is used, select a capacitor for the output capacitance with a larger capacitance value than that given in Equation (14) to attain Vripple = 7.0V. A DC bias, temperature changes, and other conditions will cause the capacitance of a ceramic capacitor to drop lower than the nominal value, so select a product whose effective capacitance satisfies Equation (14), taking into consideration conditions such as the DC bias and temperature changes.

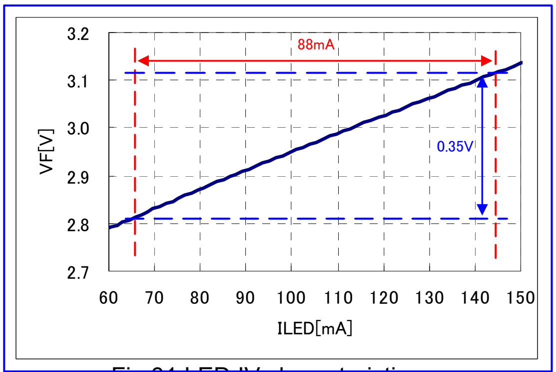


Fig.31 LED IV characteristic

$$C > \frac{1}{8} \cdot \frac{(t_{ON} + t_{OFF}) \cdot \Delta I_L}{V_{ripple}} \qquad (14)$$

C	: Minimum effective capacitance value of output capacitance C4
Vripple	: Ripple voltage allowed in LED voltage
t_{ON}	: On time
t_{OFF}	: Off time 6.0μs(typ.)
ΔI_L	: Coil current amplitude

A calculation example is shown below.

When Vripple = 7.0V, t_{ON} = 6.05μs, t_{OFF} = 6.0μs, and ΔIL = 0.11A, the minimum effective capacitance value of the output capacitor C4 is

$$C > \frac{1}{8} \cdot \frac{(6.05\mu s + 6.0\mu s) \cdot 0.11A}{7.0V} = 0.024\mu F$$

By selecting a capacitance of 0.024μF or higher for the effective capacitance during operation, the ripple current ratio can be held to 0.8 or less.

The same calculation is made in the separate calculation file. Please make use of this.

The actual capacitor ESR effects and LED IV characteristics are non-linear, and thus the value may vary in the actual equipment. Test in the actual equipment before selecting the capacitance value.

6-11. Line regulation improvement circuit

In the XC9401 series, the LED current may sometimes fluctuate due to input voltage fluctuations caused by delay times inside the circuit and other factors. If input voltage fluctuations of the LED current are observed, line regulation can be improved using the circuit shown in Fig. 32.

For the resistors, select resistance values such that the voltage applied to both ends of R_{L2} is 0.1V or less. Using this circuit as a countermeasure causes a lower LED current than normal. For this reason, lower resistance values must be used for the sensing resistances than those calculated in Equation (13).

The effectiveness of the improvement varies depending on the input voltage, coil inductance value, and sensing resistance value, so check using the calculation sheet and in the actual equipment.

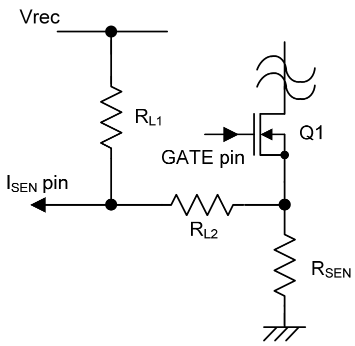


Fig.32 Line regulation improvement circuit

7. Selection of the external components of an isolated circuit

This section explains how to select external components for an isolated circuit. An isolated circuit using the XC9401 A type at 220VAC as shown in Fig. 33 is used as an example.

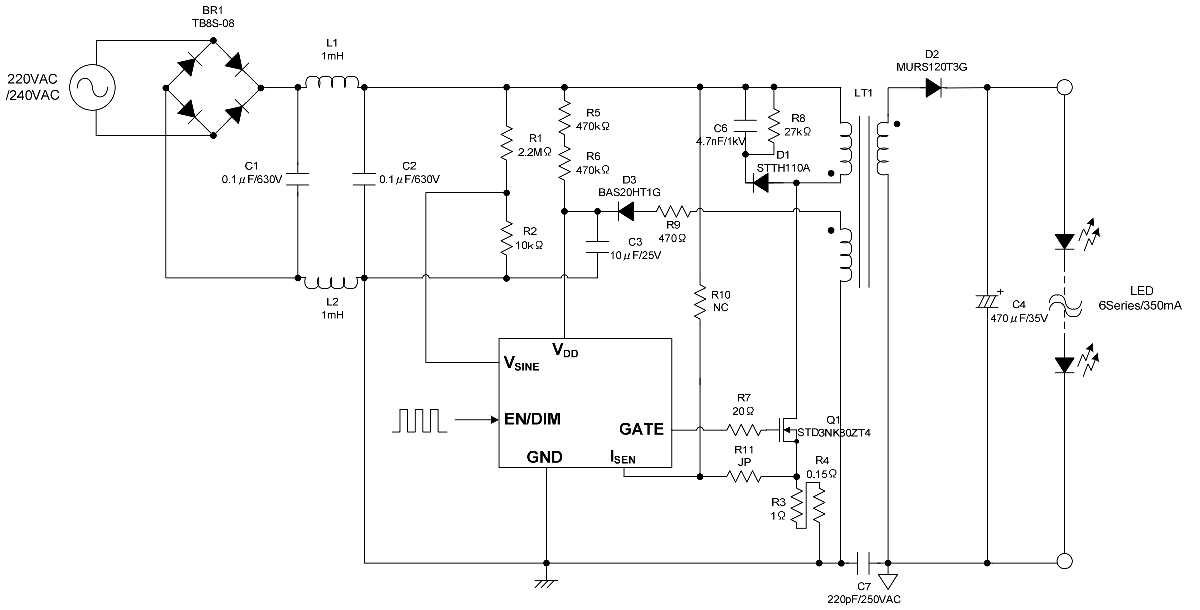


Fig.33 220VAC/240VAC Isolated flyback, A type Typical Application Circuit

7-1. Number of LED Series

The criteria for selecting the number of LED series in this application is as follows.
In an isolated flyback circuit, a flyback voltage proportional to the LED voltage is applied to the external power MOSFET in addition to the AC input (refer to section 7-9). For this reason, if the number of LED series is large, the voltage applied to the external power MOSFET increases, a larger rated voltage must be used, and cost increases or efficiency decreases due to larger on-resistance.

For this reason, in an isolated flyback circuit, it is important to set a small number of LED series and reduce overall cost, including peripheral components.

7-2. Bridge Diode (BR1)

This is a bridge diode for full wave rectification of the AC input. Select a bridge diode with a peak inverse voltage and average rectification current that are more than sufficient for the input voltage and current.

In this example, the peak value of the input current is about 70mA and the maximum voltage applied to the bridge diode is about 620V, and thus a product with a rated current of 0.8 A and a rated voltage of 800V is selected.

7-3. Input Filter (L1,L2,C1,C2,C7)

C1 and L1 form a filter circuit that reduces noise from the AC input and noise that returns to the AC input. In the typical circuit shown in Fig. 33, a filter is formed that attenuates 20kHz and higher noise to remove switching frequency (50kHz to 150kHz) and higher noise. It will be necessary to adjust the input filter constants and filter circuit to meet the regulations and standards that will actually apply. The capacitance value of C1 must be kept small to limit rush current from the AC input, so select a capacitor that is about 0.1μF.

To improve the power factor in this circuit (Fig. 33), a signal in phase with the AC input is input into the V_{SINE} pin. For this reason, if the C2 capacitance value is large, the signal input into the V_{SINE} pin falls out of phase with the AC input and the power factor decreases. Select a capacitance value of about 0.1μF.

C7 is a capacitor that is connected between the primary side and secondary side to reduce the EMI level. Because the primary side and secondary side are isolated from each other, a normal capacitor cannot be inserted. Instead, select a certified capacitor that meets the applicable regulations and safety standards.

7-4. V_{SINE} Pin (R1,R2)

In the A type used in this example, the voltage after full wave rectification is divided by R1 and R2 and applied to the V_{SINE} pin. By comparing the V_{SINE} pin voltage to the I_{SEN} pin voltage that results from converting the current that flows to the external power MOSFET to a voltage with R3 and R4, the current that flows to the external power MOSFET is controlled. (Fig. 34)

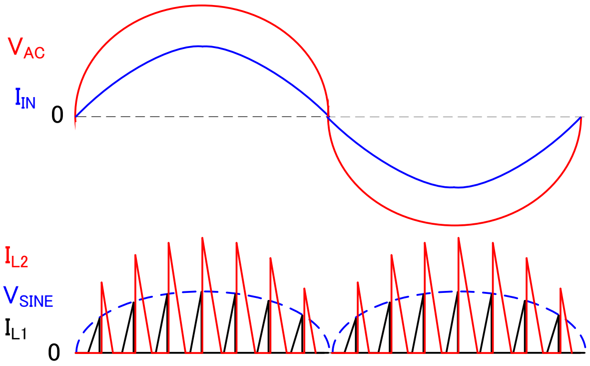


Fig. 34 Current to the external power MOSFET and transformer

For the R1 and R2 resistance values, select values that satisfy Equation (15) with the R2 value no more than 10kΩ.

$$R2 \cdot \left(\frac{\sqrt{2}V_{rms\_max}}{1.6V} - 1\right) < R1 < R2 \cdot \left(\frac{\sqrt{2}V_{rms\_max}}{1.2V} - 1\right) \quad (15)$$

R1,R2 : Refer to fig.33.
V_{rms_max} : Maximum input RMS voltage

A calculation example is shown below.
When R2 = 10kΩ with V_{rms_max} = 240V, the resistance value of R1 is

$$10k\Omega \cdot \left(\frac{\sqrt{2} \cdot 240V}{1.6V} - 1\right) = 2.11M\Omega < R1 < 10k\Omega \cdot \left(\frac{\sqrt{2} \cdot 240V}{1.2V} - 1\right) = 2.81M\Omega$$

Select a resistance value within this range.

The same calculation is made in the separate calculation file. Please make use of this.

7-5. Power Supply to VDD pin (R5,R6,R9,C3,D3,LT1)

This supplies power to the power pin (V_{DD} pin) of the IC using the auxiliary coil of the transformer.

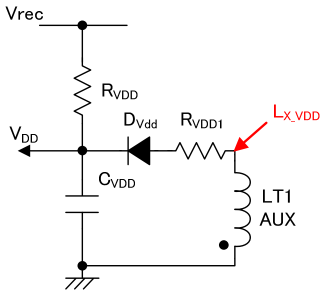


Fig.35 VDD power supply circuit using a transformer

・LT1

Current is supplied to the VDD pin using the LT1 auxiliary coil.
For selection of the transformer, refer to section 7-6.

・D_{VDD}

This is a rectifying diode that supplies power voltage from LT1. A reverse bias voltage V_{Dvdd} that depends on the LED voltage and transformer turn ratio as shown in Equation (16) is applied to D_{VDD}. Select a diode with a rated voltage appropriate for this reverse bias voltage.

$$V_{Dvdd} = V_{DD} + \sqrt{2} \cdot V_{rms\_max} \cdot \frac{N_{AUX}}{N1} + V_{spike} \quad (16)$$

N1	: Number of windings of transformer primary coil
N_{AUX}	: Number of windings of transformer auxiliary coil
V_{DD}	: VDD pin voltage
V_{rms_max}	: Maximum input RMS voltage
V_{spike}	: Spike voltage that accompanies switching (to 50 V)

A calculation example is shown below.
When $N_{AUX}/N1$ = 1/6.74, V_{DD} = 12V, V_{rms_max} = 240V, and V_{spike} = 50V, the reverse bias voltage V_{Dvdd} is

$$V_{Dvdd} = 12V + \sqrt{2} \cdot 240V \cdot \frac{1}{6.74} + 50V = 112V$$

The same calculation is made in the separate calculation file. Please make use of this file.

・C_{VDD}

This capacitor stabilizes the V_{DD} pin voltage. Use a capacitor with a capacitance of 10μF or higher.

If a ceramic capacitor will be used, select a product in which the electrostatic capacitance falls minimally when a B type (JIS Standards) or X7R/X5R (EIA Standards) DC bias is applied.

・R_{VDD}

This resistance is used to supply power to the V_{DD} pin at startup. When the input voltage is applied and the V_{DD} pin voltage rises above the UVLO release voltage, GATE output starts and normal operation takes place. After startup, power is mainly supplied to the V_{DD} pin through the auxiliary coil of the transformer.

When R_{VDD} is large and the current through R_{VDD} is smaller than the current consumed in the IC, the V_{DD} pin voltage does not rise higher than the UVLO release voltage and startup is not possible. For this reason, select a resistance value for R_{VDD} that satisfies Equation (17). (Fig. 35)

$$R_{VDD} < \frac{(\sqrt{2}V_{rms\_min} - V_{UVLOR})}{I_{STB}} \tag{17}$$

I_{STB} : Stand-by Current 225μA (typ.)
V_{UVLOR} : UVLO Release Voltage 7.5V (typ.)
V_{rms_min} : Minimum input RMS voltage

A calculation example is shown below.
When I_{STB} = 225μA, V_{UVLOR} = 7.5V, and V_{rms_min} = 200V, R_{VDD} is

$$R_{VDD} < \frac{(\sqrt{2}\cdot 200V - 7.5V)}{225\mu A} = 1.22M\Omega$$

and the IC can be started normally by using a resistance value lower than 1.22 MΩ.

The same calculation is made in the separate calculation file. Please make use of this.

・R_{VDD1}

To supply current to the V_{DD} pin, $Lx_{\_VDD}$ is made to oscillate and supply voltage to the V_{DD} pin (refer to Fig. 36). However, in actuality a spike voltage sometimes occurs in $Lx_{\_VDD}$ and causes the V_{DD} pin voltage to rise higher than the V_{DD} target voltage (= V_{LED} × N3/N2). A countermeasure for this V_{DD} pin voltage rise is to insert a resistance in R_{VDD1} to reduce the current supplied to the V_{DD} pin.

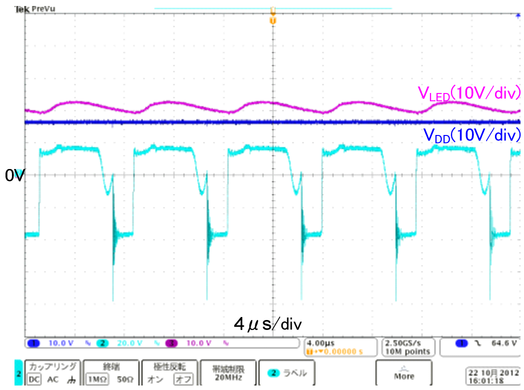


Fig.36 Operation waveforms (VDD power supply circuit using a transformer)

7-6. Transformer (LT1)

This is a transformer in the isolated flyback circuit that transfers electrical energy from the primary side to the secondary side by magnetic coupling. The peripheral transformer circuit is shown in Fig. 37.
For the transformer, either a general purpose transformer or a transformer with custom specifications can be used. Component selection is explained below for each case.

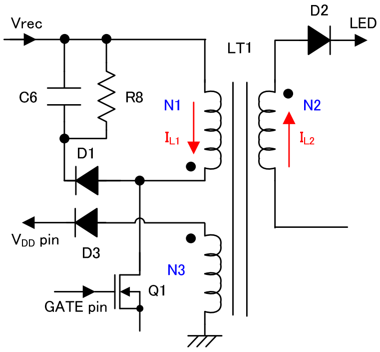


Fig.37 Peripheral circuit of transformer

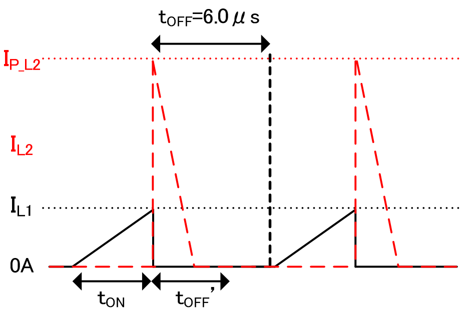


Fig.38 Transformer current and on time/off time

Selection method for general purpose transformer

Selection of a general purpose transformer is based on whether the output power, turn ratio, and inductance value satisfy the applicable regulations and standards. The method of selecting each parameter is explained below.

<< Output power >>

Select a transformer with an output power that has sufficient allowance for the output power of the LED. The amount of loss will vary depending on the operation frequency and other factors, so determine usability by checking the transformer temperature in the actual equipment.
In this example, a transformer with an output power of 12 W is selected for a LED output power of 7W.

<< Turn ratio >>

Select a turn ratio for the primary and secondary windings of the transformer (= N1/N2) of about 5 to 10. In general, a larger turn ratio causes a larger leakage inductance, which decreases efficiency and increases the allowable loss of resistor R8 in the snubber circuit. This results in increased cost.

By setting the number of turns of the auxiliary coil that supplies power to the V_{DD} pin to the value calculated from Equation (22), the V_{DD} pin voltage can be set to the target value. Note, however, that if the number of LED series changes, the V_{DD} pin voltage will also change.
In actuality, pike voltages may occur and cause the V_{DD} pin voltage to occasionally rise higher than the V_{DD} voltage target value. Refer to section 7-5 for the countermeasure for this.

<< Inductance value >>

This application is controlled to operate normally in discontinuous mode. In continuous mode, operation may become unstable. For this reason, select an inductance value for the transformer primary coil that keeps operation in discontinuous mode.
First, calculate the maximum inductance required to enter discontinuous mode from Equation (18). Select an inductance value for the primary coil that is smaller than the maximum inductance value. As a general guideline, select an inductance value that gives a oscillation frequency of about 100 kHz.

The maximum voltage applied to the MOSFET, rectifying diode, snubber circuit, and other peripheral components depends on the turn ratio (N (= N1/N2) of the primary coil and secondary coil. For this reason, the optimum rated voltage of the peripheral components varies depending on the turn ratio. Select the turn ratio to optimize the overall cost, including peripheral components.

$$L_{1\_max} = \frac{N \cdot (V_{LED} + VF) \cdot t_{OFF}}{I_{L1\_max}} \qquad (18)$$

N	: Turn ratio of transformer primary coil and secondary coil (=N1/N2)
VF	: Forward voltage of rectifying diode
V_{LED}	: LED voltage
t_{OFF}	: Off time 6.0μs(typ.)
I_{L1_max}	: Maximum value of current in primary coil

<< Applicable regulations and safety standards >>

Conduct testing to verify whether the transformer selected above can meet the applicable regulations and standards.

Procedure for designing a custom transformer

A procedure for designing a transformer with custom specifications is given as an example below. In actual practice, consult with the transformer manufacturer prior to considering and developing transformer specifications.

The transformer characteristics may deviate from the design values due to leakage inductance, the coil winding method, and other factors. Test in the actual equipment before selecting the transformer.

<< Inductance value and turn ratio of primary and secondary coils>>

This application is controlled to operate normally in discontinuous mode. In continuous mode, operation may become unstable. For this reason, select an inductance value for the transformer primary coil that keeps operation in discontinuous mode.

First, calculate the maximum inductance required to enter discontinuous mode from Equation (18). Select an inductance value for the primary coil that is smaller than the maximum inductance value. As a general guideline, select an inductance value that gives a oscillation frequency of about 100 kHz.

The maximum voltage applied to the MOSFET, rectifying diode, snubber circuit, and other peripheral components depends on the turn ratio (N (= N1/N2) of the primary coil and secondary coil. For this reason, the optimum rated voltage of the peripheral components varies depending on the turn ratio. Select the turn ratio to optimize the overall cost, including peripheral components.

<< Core Size >>

Next, the core size is selected. Select a core size that satisfies Equation (19).

$$A_W \cdot A_E = \left(\frac{L_1 \cdot I_{L1\_max}}{B_{max}} \cdot \frac{I_{L1\_rms}}{K}\right)^{4/3} cm^4 \qquad (19)$$

A_E	: Effective core cross section area [cm^2]
A_W	: Core window area [cm^2]
L_1	: Inductance value of transformer primary
I_{L1_max}	: Maximum transformer primary current
I_{L1_rms}	: Transformer primary RMS current
B_{max}	: Maximum operating flux density
K	: $0.2J_{max} \times 10^{-4}$ (J_{max}: Max current density A/cm^2)

<< Number of turns of coil and wire diameter >>

Following the turn ratio and coil size of the transformer primary coil and secondary coil, the number of turns of the primary coil and secondary coil are selected. First, use Equation (20) to calculate the number of turns of the primary coil at which flux saturation will not occur in the selected core.

After calculating the number of turns of the primary coil, calculate the number of turns of the secondary coil from Equation (21).

By setting the number of turns of the auxiliary coil that supplies power to the V_{DD} pin to the value calculated from Equation (22), the V_{DD} pin voltage can be set to the target value. Note, however, that if the number of LED series changes, the V_{DD} pin voltage will also change.

In actuality, Spike voltages may occur and cause the V_{DD} pin voltage to occasionally rise higher than the V_{DD} voltage target value. Refer to section 7-5 for the countermeasure for this.

$$N1 = \frac{L_1 \cdot I_{L1\_max}}{B_{max} \cdot A_E} \quad (20)$$

$$N2 = \frac{N1}{N} \quad (21)$$

$$N3 = \frac{V_{DD}}{(V_{LED} + VF)} \cdot N2 \quad (22)$$

A_E : Effective core cross section area [cm^2]
I_{L1_max} : Maximum transformer primary current
L_1 : Inductance value of transformer primary
B_{max} : Maximum operating flux density
V_{DD} : Target value of V_{DD} pin voltage (11 to 13V)
V_{LED} : LED voltage
VF : Forward voltage of rectification diode
N : Turn ratio of transformer primary coil and secondary coil (=N1/N2)
N1 : Number of windings of transformer primary coil
N2 : Number of windings of transformer secondary coil
N3 : Number of windings of transformer auxiliary coil

Next, the selection method for the wire diameter is explained.

The wire diameter is selected based on whether the skin effect becomes apparent at the operation frequency and the current density of the maximum current that flows in the coil.

First, select the wire diameter of the primary coil and secondary coil so that the current density at the maximum current does not exceed 6A/mm^2. The current in the auxiliary coil is small, so this is not a concern.

Next, to verify that the skin effect does not occur, check if the wire diameter selected above satisfies Equation (23).

If the selected wire diameter does not satisfy Equation (23), consider connecting the coils in parallel. In this case, select a wire diameter and parallel number that satisfy Equation (23) without exceeding a current density of 6A/mm^2.

$$d > \frac{76}{\sqrt{f}} [mm] \quad (23)$$

<< Evaluate possibility of building transformer based on evaluation specifications >>

Evaluate whether a transformer can actually be built based on the core and coil specifications selected above. Calculate the ratio of the total cross sectional area of the copper wire of all coils to the window area. This varies by application, but it can be judged that the transformer can be built if this is less than 20% of the window area in an isolated flyback circuit.

If Equation (24) is not satisfied, reconsider the transformer specifications and increase the core size, decrease the number of windings, or decrease the wire diameter.

$$\frac{N1 \cdot S_1 \cdot p_1 + N2 \cdot S_2 \cdot p_2 + N3 \cdot S_3}{A_W} < 0.2 \tag{24}$$

A_W : Core window area [cm^2]
S_1 : Wire cross-sectional area of primary coil of transformer (=(πd_1^2)/2)
S_2 : Wire cross-sectional area of secondary coil of transformer (=(πd_1^2)/2)
S_3 : Wire cross-sectional area of auxiliary coil of transformer (=(πd_1^2)/2)
N1 : Number of windings of transformer primary coil
N2 : Number of windings of transformer secondary coil
N3 : Number of windings of transformer auxiliary coil
p_1 : Parallel number of transformer primary coil
p_2 : Parallel number of transformer secondary coil

<< Transformer structure>>

Strengthening the coupling between coils in the transformer structure is very important for lowering leakage inductance, improving efficiency, and reducing transformer heat generation. An example of a recommended transformer structure is shown in Fig. 39.

The transformer structure of Fig. 39 is designed using TEX or space tape to satisfy the creeping distance in 220VAC/240VAC systems. Design the actual transformer structure so that it can satisfy applicable regulations and standards.

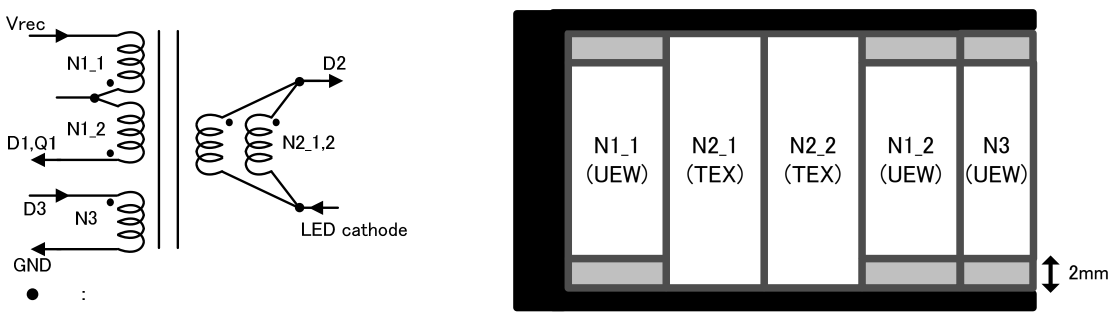


Fig. 39 Recommended schematic for transformer structure

<< Applicable regulations and safety standards >>

Verify the standards for the withstand voltage and other characteristics of the isolated transformer to be used in the isolated flyback circuit. Design the transformer that meets the applicable regulations and safety standards.

7-7. Snubber Circuit (C6,R8,D1)

The snubber circuit prevents the external power MOSFET from being destroyed by the energy stored in the transformer leakage inductance when the external power MOSFET is turned off. The snubber circuit used in this example is shown in Fig. 40, and the MOSFET drain voltage and the snubber circuit voltage when the MOSFET is off are shown in Fig. 41.

As shown in Fig. 41, the drain voltage rises steeply when the MOSFET is turned off, but the snubber circuit limits the drain voltage rise and prevents destruction of the MOSFET.

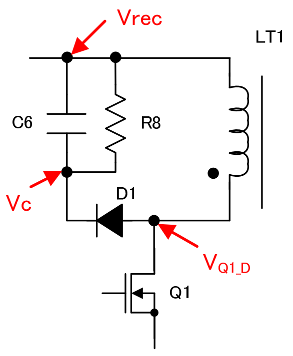


Fig.40 Snubber circuit

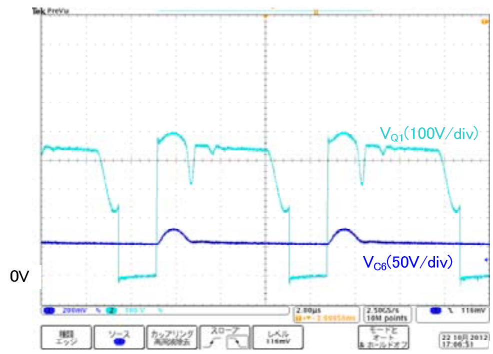


Fig.41 MOSFET drain voltage and snubber circuit voltage

Next, the methods for selecting the values of R8 and C6 and deciding the snubber voltage are explained.

Energy is generated by the transformer leakage inductance, and the energy is stored in the capacitor C6 when the MOSFET is turned off. The relation between the voltage applied to C6 and the leakage inductance at this time is shown in Equation (25).

$$\frac{1}{2}\cdot C6\cdot\left\{(V_{C6}+\Delta V_{C6})^2-V_{C6}{}^2\right\}=\frac{1}{2}\cdot L_{leak}\cdot I_{L1\_max}{}^2 \qquad (25)$$

ΔV_{C6} is the voltage drop due to discharge through R8, and when $V_{C6} >> \Delta V_{C6}$, ΔV_{C6} is given by Equation (26).

$$\Delta V_{C6}=\frac{V_{C6}}{C6\cdot R8}\cdot t_{OFF} \qquad (26)$$

As an approximation, it can be assumed that the snubber voltage Vsnub is equal to V_{C6}, so C6 and R8 can be determined from Equations (27) and (28) using Equations (25) and (26).

$$R8=(t_{OFF}\cdot V_{snub}{}^2)\Big/\left(\frac{L_{leak}\cdot I_{L1\_max}{}^2}{2}\right) \qquad (27)$$

$$C6=\frac{L_{leak}\cdot I_{L1\_max}{}^2}{2}\cdot\frac{1}{V_{C6}\cdot\Delta V_{C6}} \qquad (28)$$

C6	: Effective capacitance value of C6
V_{C6}	: Voltage applied to C6 immediately before MOSFET is turned off
ΔV_{C6}	: Difference in voltage applied to C6 immediately after MOSFET is turned off
Vsnub	: Snubber voltage (100V～150V)
L_{leak}	: Transformer leakage inductance
I_{L1_max}	: Maximum transformer primary current
t_{OFF}	: Off time 6.0μs(typ.)

By setting the snubber voltage Vsnub to a value from 100V to 150V and taking ΔV_{C6} = 5V, the resistance value for R8 and the capacitance value for C6 can be determined. If the snubber voltage Vsnub is too large, it will be necessary to increase the rated voltages of the external power MOSFET, C6, and D3, resulting in higher cost.

For the diode D3, use a fast recovery diode with a sufficiently high rated voltage and a short reverse recovery time. In actual use, parasitic inductance from the wiring and the effects of the transformer may cause deviation from the above result. For this reason, select components after verifying the snubber voltage and component heat generation in the actual equipment.

A calculation example is shown below.
When L_{leak} = 30μH, I_{L1_max} = 0.4A, and t_{OFF} = 6.0μs, and the set values are Vsnub = 100V and ΔV_{C6} = 5V, R8 and C6 are

$$R8 = 6.0\mu s \cdot (100V)^2 \Big/ \left\{ \frac{30\mu H \cdot (0.4A)^2}{2} \right\} = 25k\Omega$$

$$C6 = \frac{30\mu H \cdot (0.4A)^2}{2} \cdot \frac{1}{100V \cdot 5V} = 4.8nF$$

The same calculation is made in the separate calculation file. Please make use of this.

7-8. Rectifying Diode (D2)

This rectifying diode prevents reverse flow to the secondary coil of the transformer when MOSFET Q1 is in the off state and the energy stored in the transformer flows to the anode side of the LED. In an isolated flyback circuit, the maximum voltage applied to the rectifying diode D2 is given by Equation (29), and thus a product with a rated voltage higher than that must be selected.

Select a fast recovery diode or Schottky diode with a short reverse recovery time. A diode with a long reverse recovery time will adversely affect efficiency.

$$V_{D2} = V_{LED} + \frac{N2}{N1} \cdot \sqrt{2} \mathrm{V}_{\mathrm{rms\_max}} \tag{29}$$

V_{rms_max} : Maximum input RMS voltage
N1 : Number of windings of transformer primary coil
N2 : Number of windings of transformer secondary coil
V_{LED} : LED voltage

A calculation example is shown below.
When V_{rms_max} = 240V, N2/N1 = 1/4, V_{LED} = 19.2V, and VF = 1.0V, it can be seen that the maximum voltage applied to the rectifying diode is

$$V_{D2} = 19.2V + \frac{1}{4} \cdot \sqrt{2} \cdot 240V = 104V$$

In this example, a product with a rated voltage of 200 V is selected.

The same calculation is made in the separate calculation file. Please make use of this.

7-9. MOSFET,Gate Resister (Q1,R7)

Power MOSFET for switching and gate resistance for switching time adjustment.

By inserting a gate resistance, the MOSFET switching time can be slowed and the high-frequency EMI level reduced. However, a large gate resistance and a slower switching speed increases the switching loss of the MOSFET, decreasing efficiency. The optimum value varies depending on the MOSFET that is used, but in general a gate resistance from 5 to 50Ω should be selected.

In an isolated flyback circuit, the flyback voltage that occurs during MOSFET off time and the snubber voltage are applied to the MOSFET in addition to the AC input. (Refer to Fig. 41.) The maximum voltage V_{Q1} that is applied is given by Equation (30), and thus a product with a rated voltage higher than that must be selected. In addition, using a MOSFET with a small on-resistance can reduce MOSFET loss and improve efficiency.

In this example, a product with a rated voltage of 800V and a rated current of 2.5A is selected.

$$V_{\mathrm{Q1}} = \sqrt{2}\mathrm{V}_{\mathrm{rms\_max}} + \frac{N1}{N2} \cdot \left(V_{LED} + VF\right) + V_{snub} \quad (30)$$

V_{rms_max} : Maximum input RMS voltage
N1 : Number of windings of transformer primary coil
N2 : Number of windings of transformer secondary coil
V_{LED} : LED voltage
VF : Forward voltage of rectification diode (D2)
V_{snub} : Snubber voltage (=100V～150V)

A calculation example is shown below.

When V_{rms_max} = 240V, N1/N2 = 4, V_{LED} = 19.2V, VF = 1.0V, and V_{snub} = 150V, it can be seen that the maximum voltage applied to the MOSFET is

$$V_{\mathrm{Q1}} = \sqrt{2} \cdot 240\mathrm{V} + 4 \cdot \left(19.2V + 1.0V\right) + 150V = 570V$$

The same calculation is made in the separate calculation file. Please make use of this.

7-10. LED current adjustment (R3,R4)

Sensing resistance used to adjust the current that flows in the external power MOSFET in order to adjust the LED current. The LED current is set by adjusting the sensing resistance.

In the A type used in this example, the voltage after full wave rectification is divided by R1 and R2 and applied to the V_{SINE} pin. By comparing the V_{SINE} pin voltage to the I_{SEN} pin voltage obtained by converting the current in the external power MOSFET to a voltage using R3 and R4, the current in the external power MOSFET is controlled.

The peak value of the current in the MOSFET is determined by the sensing resistances R3 and R4 according to Equation (31). However, unlike the B type, the signal input into the V_{SINE} pin is in phase with the AC input, and thus the peak value of the current in the MOSFET changes continuously. (Refer to Fig. 34.)

$$Ip(t) = \frac{Vrec(t)}{(R3+R4)} \cdot \frac{R2}{(R1+R2)} \cdot \alpha \tag{31}$$

Ip(t)	: Peak value of current in MOSFET at time t
Vrec(t)	: Voltage after full wave rectification at time t
R1~R4	: Refer to fig.30.
α	: Internal constant 0.2783

In discontinuous mode in an isolated flyback circuit, the current in the MOSFET and the coil current are as shown in Fig. 35. The LED current is the average value of the current that flows in the transformer secondary coil I_{L2}, and thus in order to set the LED current to the target value, the sensing resistance must be adjusted to satisfy Equation (32).

The value in the actual equipment may differ from the value of Equation (32), so calculate this using the separate calculation file, taking the IC internal delay and other factors into consideration.

$$I_{LED} = \int_0^{1/(2f)} I_{L2}(t)dt \Big/ (2f) \tag{32}$$

I_{LED}	: Target value of LED current
$I_{L2}(t)$	: Current in transformer secondary coil at time t
f	: Commercial power frequency 50Hz/60Hz

7-11. Output Capacitor (C4)

This capacitor limits LED ripple current and ripple voltage.

In this example, the A type is used to improve the power factor in an isolated flyback circuit, and thus the input current and current through the transformer secondary coil are in phase with the AC input as shown in Fig. 42. For this reason, the ripple voltage in the LED voltage fluctuates due to the cycles of two frequencies, the commercial frequency and the switching frequency.

However, in this example the fluctuation in LED voltage due to the cycle of the commercial frequency is far larger than the fluctuation due to the cycle of the switching frequency, and thus the component due to the switching frequency cycle can be disregarded when calculating the output capacitance.

The value of the output capacitance is determined by the ripple current ratio of the LED current. Here we decide the capacitance value taking a ripple current ratio of 0.8 as the target value.

If the ripple current ratio is to be kept under 0.8 when ILED = 350mA (ripple current 350mA ×0.8 = 280mA), we first calculate the allowed Vripple from the IV characteristic of the LED to be used. Here, 0.35V×6=2.1V from Fig. 43.

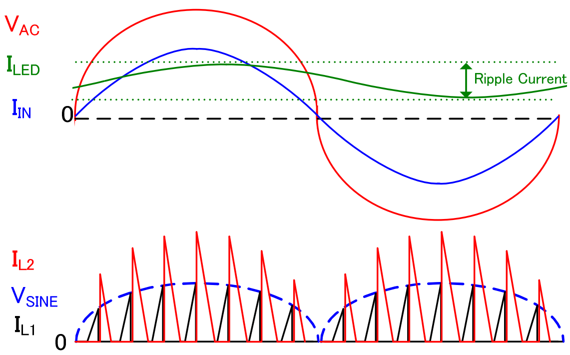


Fig.42 Transformer current and LED current

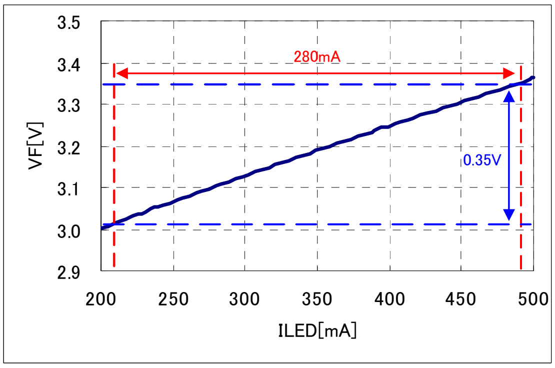


Fig.43 LED IV characteristic

The ripple voltage can be expressed by Equation (33) as a relation of the transformer secondary coil current, LED current, and output capacitance. Use this to select a capacitance value that gives a ripple voltage of 2.1V.

If an electrolytic capacitor will be used for the output capacitance, select a product with sufficient allowance for ripple current.

$$V_{ripple} > \int_{t_1}^{t_2} \{I_{L2}(t) - I_{LED}(t)\}dt \Big/ C \qquad (33)$$

Vripple	: Allowed ripple voltage in LED voltage
I_{L2}(t)	: Value of current in transformer secondary coil at time t
I_{LED}(t)	: LED current value at time t
C	: Effective capacitance value of output capacitance C4
t_1,t_2	: Time t_1 to t_2 over which I_{L2}(t) and I_{LED}(t) equalize

The actual calculation is complex, so please check in the calculation file.

In addition, the actual ESR effects of the capacitor and IV characteristics of the LED are non-linear, and thus the value may vary in the actual equipment. Test in the actual equipment before selecting the capacitance value.

8. Examples of solutions and characteristics

By changing the external components, the XC9401 can be used for a variety of applications in addition to the typical circuits shown in section 4. Examples of typical XC9401 solutions are shown in Table 1.

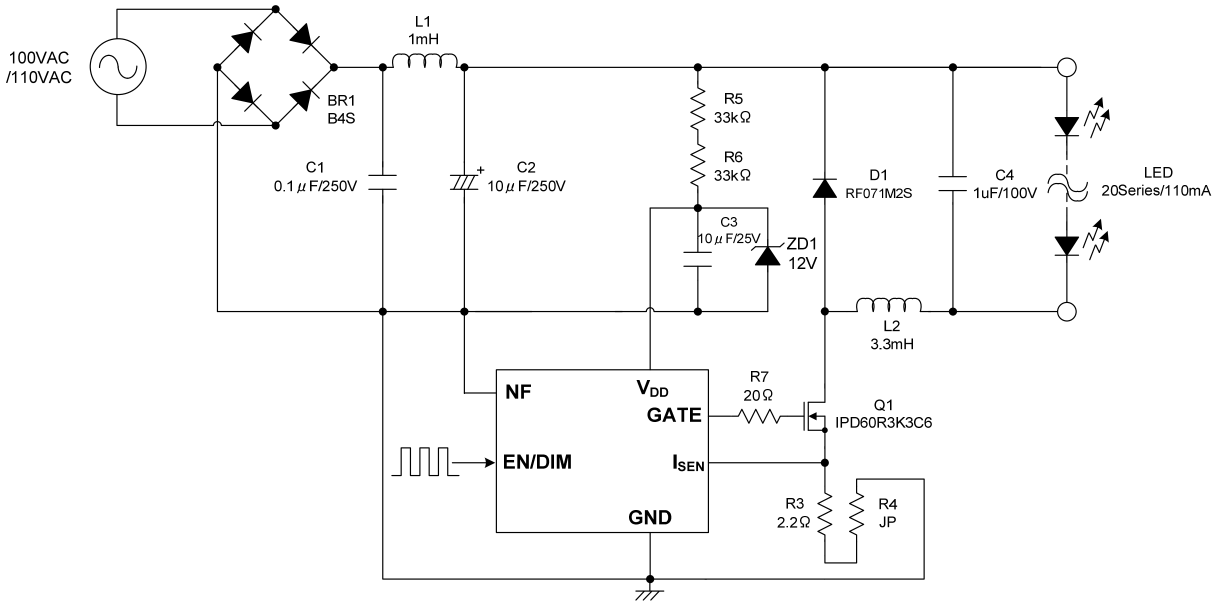
Circuit schematics, external components, and characteristics of some of the typical solutions in Table 1 are provided in the next section. Refer to this section for details.

Table 1: XC9401 Solution Examples

<table>
<tr><th>No.</th><th>Input Voltage</th><th>Type</th><th>Isolation/ Non-Isolation</th><th>Topology</th><th>Efficiency</th><th>Power Factor</th><th>Line Regulation (*1)</th><th>EVB Size</th></tr>
<tr><td>1-1</td><td rowspan="2">100VAC /110VAC</td><td>B</td><td rowspan="2">Non-Isolation</td><td rowspan="2">Buck</td><td>91%</td><td>0.5 ~0.65</td><td>≦3%</td><td>Ultra Small</td></tr>
<tr><td>1-2</td><td>A</td><td>88%</td><td>0.95~</td><td>Same As Input</td><td>Small</td></tr>
<tr><td>2-1</td><td rowspan="4">220VAC /240VAC</td><td>B</td><td rowspan="2">Isolation</td><td rowspan="2">Flyback</td><td>83%</td><td>0.5 ~0.65</td><td>≦3%</td><td>Standard</td></tr>
<tr><td>2-2</td><td>A</td><td>82%</td><td>0.9~</td><td>Same As Input×1.2</td><td>Standard</td></tr>
<tr><td>2-3</td><td>B</td><td rowspan="2">Non-Isolation</td><td rowspan="2">Buck</td><td>87%</td><td>0.5 ~0.65</td><td>≦2%</td><td>Ultra Small</td></tr>
<tr><td>2-4</td><td>B</td><td>88%</td><td>0.75 ~0.85</td><td>≦2%</td><td>Small</td></tr>
<tr><td>3-1</td><td rowspan="2">DC /12VAC</td><td>B</td><td rowspan="2">-</td><td>Buck</td><td>88%</td><td rowspan="2">-</td><td>≦1%</td><td>Ultra Small</td></tr>
<tr><td>3-2</td><td>B</td><td>Buck-Boost</td><td>86%</td><td>≦5%</td><td>Ultra Small</td></tr>
</table>

(*1) Line regulation can be improved by adjusting with an external resistance.
(For details, refer to section 6-11.)

<<1-1: Example of 100VAC / 110VAC non-isolated step-down B type solution>>



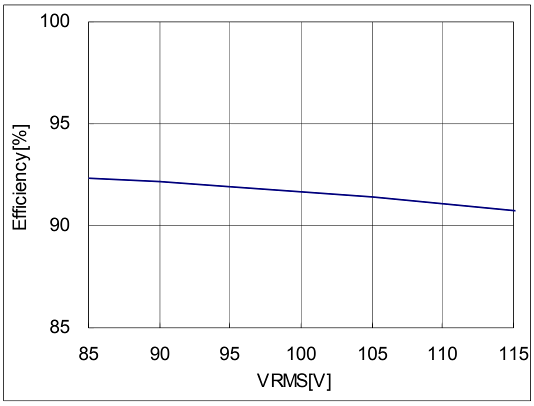
Typical Application Circuit

Item	Q'ty	Value	Description	Size/PKG	Part Number	Manufacture
IC	1	-	LED Driver IC	SOT-26	XC9401B605MR-G	TOREX
C1	1	0.1μF	Capacitor, Ceramic,250V,JB,±10%	3216	QMK316BJ104KL-T	Taiyo Yuden
C2	1	10μF	Capacitor, Alminium,250V,±20%	φ10.0x20.0	UCS2E100MPD	Nichicon
C3	1	10μF	Capacitor, Ceramic,25V,X5R,±10%	3216	TMK316BJ106KL-T	Taiyo Yuden
C4	1	1μF	Capacitor, Ceramic,100V,X7R,±10%	3216	GRM31CR72A105A01L	Murata
L1	1	1mH	Inductor, 0.50A(Isat), 1.84Ω	φ7.8x9.5	744772102	Würth Elektronik
L2	1	3.3mH	Inductor, SMD, 0.35A, 6.4Ω	12.7x12.7	SRR1208-332KL	BOURNS
D1	1	-	Diode, Fast Rec., 0.7A, 200V	SOD-123	RF071M2S	Rohm
ZD1	1	-	Zener Diode, 12V	Smin2-F5-B	DZ2J120M0L	Panasonic
R3	1	2.2Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16-2R2F	Kamaya
R4	-	Jumper	-	-	-	-
R5	1	33kΩ	Resistor, Chip, 0.33W, 200V	3225	RK73B2ETTD333J	KOA
R6	1	33kΩ	Resistor, Chip, 0.33W, 200V	3225	RK73B2ETTD333J	KOA
R7	1	20Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K200F	Kamaya
Q1	1	-	MOSFET, Nch, 600V, 1.7A, 2.97Ω	TO-252	IPD60R3K3C6	Infineon
BR1	1	-	Bridge Rectifier, 0.8A, 400V	MDI	B4S	PANJIT

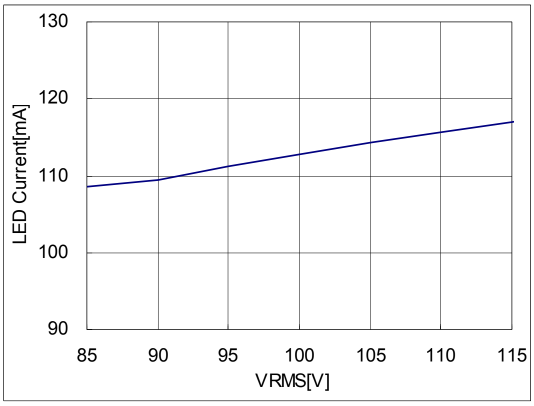
※LED: VLED=3.0V x 20, ILED Target = 110mA (Both average value)

■Evaluation Result

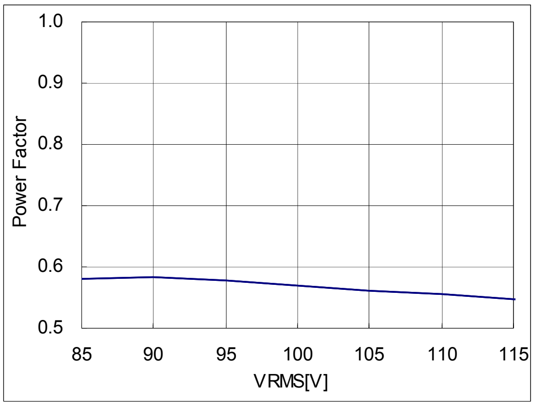
(1)Efficiency vs Input Voltage(RMS) Ta=25℃



(2)LED Current vs Input Voltage(RMS) Ta=25℃

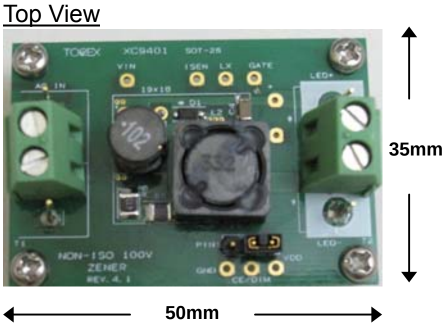


(3)Power Factor vs Input Voltage(RMS) Ta=25℃



■Test board　Photo of exterior

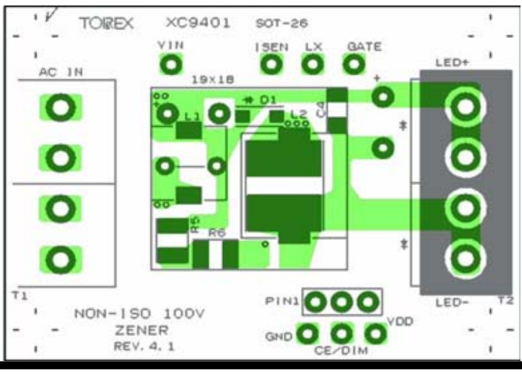
Top View



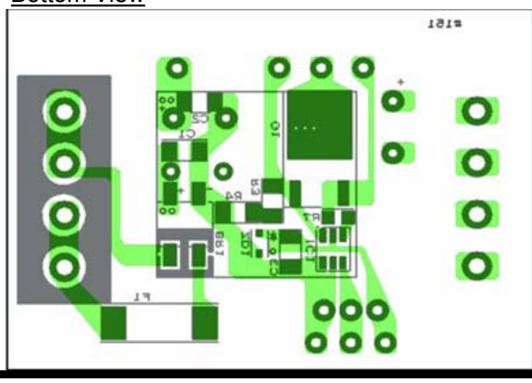
Bottom View

■Test board layout

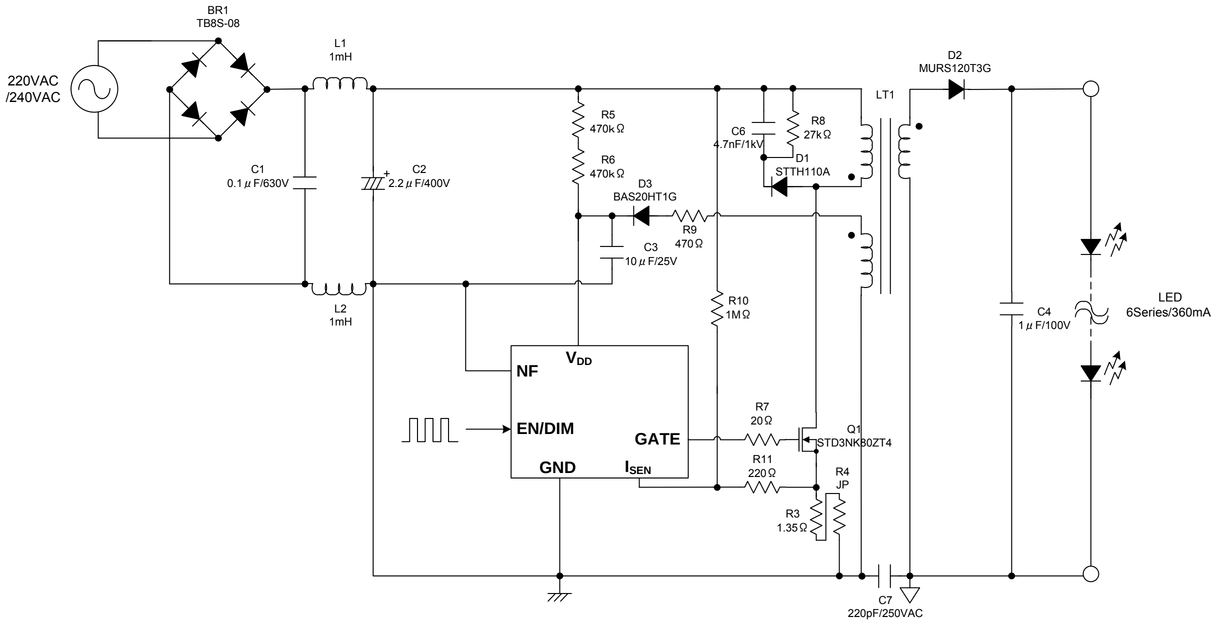
Top View



Bottom View



<<2-1: Example of 220VAC / 240VAC isolated flyback B type solution>>



Typical Application Circuit

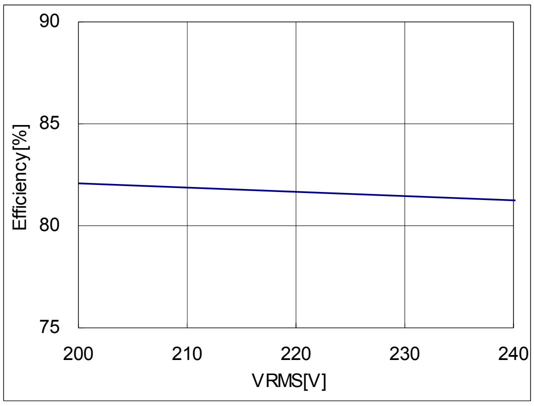
Item	Q'ty	Value	Description	Size/PKG	Part Number	Manufacture
IC	1	-	LED Driver IC	SOT-26	XC9401B605MR-G	TOREX
C1	1	0.1μF	Capacitor, Ceramic,630V,JB,±10%	4532	C4532JB2J104K	TDK-EPC
C2	1	2.2μF	Capacitor, Aluminum,400V,±20%	φ10.0x12.5	400BXC2R2MEFC10X12.5	Rubycon
C3	1	10μF	Capacitor, Ceramic,25V,X5R,±10%	3216	TMK316BJ106KL-T	Taiyo Yuden
C4	1	1μF	Capacitor, Ceramic,100V,X7R,±10%	3216	GRM31CR72A105KA01L	Murata
C6	1	4.7nF	Capacitor,Ceramic,1kV,X7R	3216	GRM31BR73A472KW01L	Murata
C7	1	220pF	Safety Capacitor Y1,250VAC,B	-	DE1B3KX221KN5AL01	Murata
L1,2	1	1mH	Inductor, 0.40A(Isat), 2.2Ω	-	5800-102-RC	BOURNS
LT1	1	-	transformer	-	750813551	Würth Elektronik
D1	1	-	Diode, Fast Rec., 1.0A, 1000V	SMA	STTH110A	STMicroelectronics
D2	1	-	Diode, Fast Rec., 1.0A, 200V	SMB	MURS120T3G	On semiconductor
D3	1	-	Diode, Fast Rec., 0.2A, 200V	SOD-323	BAS20HT1G	On semiconductor
R3(*1)	2	2.7Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16-2R7F	Kamaya
R4	-	Jumper	-	-	-	-
R5	1	470kΩ	Resistor, Chip, 0.25W, 500V	3216	HV732BTBK474J	KOA
R6	1	470kΩ	Resistor, Chip, 0.25W, 500V	3216	HV732BTBK474J	KOA
R7	1	20Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K200F	Kamaya
R8	1	27kΩ	Resistor, Chip, 0.5W, 200V	3225	ERJT14J273U	Panasonic
R9	1	470Ω	Resistor, Chip, 0.25W, 150V	2012	ERJT06J471V	Panasonic
R10	1	1MΩ	Resistor, Chip, 0.25W, 400V	2012	RVC20K105F	Kamaya
R11	1	220Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K201F	Kamaya
Q1	1	-	MOSFET, Nch, 800V, 2.5A, 3.8Ω	D-PAK	STD3NK80ZT4	STMicroelectronics
BR1	1	-	Bridge Rectifier, 0.8A, 800V	MICRO DIP	TB8S-08	PANJIT

(*1) R3 is connected in paralell.

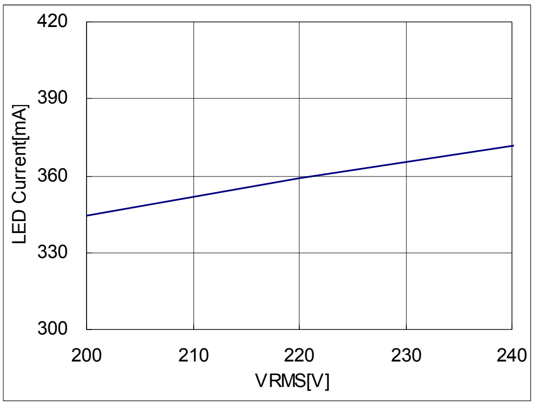
※LED: VLED=3.2V x 6, ILED Target = 360mA (Both average value)

■Evaluation Result

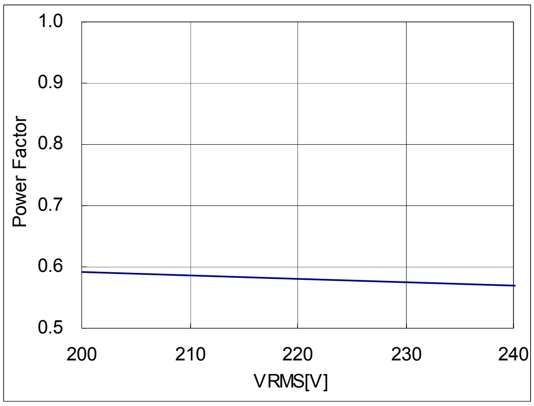
(1)Efficiency vs Input Voltage(RMS) Ta=25℃



(2)LED Current vs Input Voltage(RMS) Ta=25℃

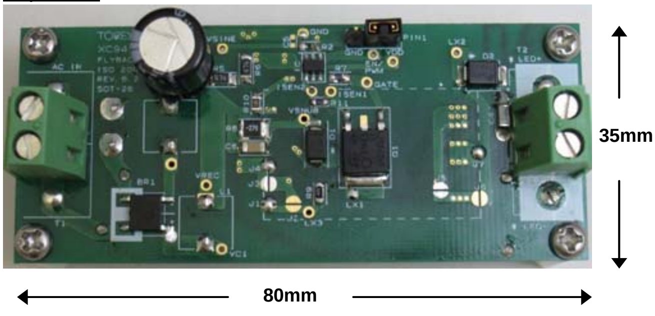


(3)Power Factor vs Input Voltage(RMS) Ta=25℃



■Test board　Photo of exterior

Top View

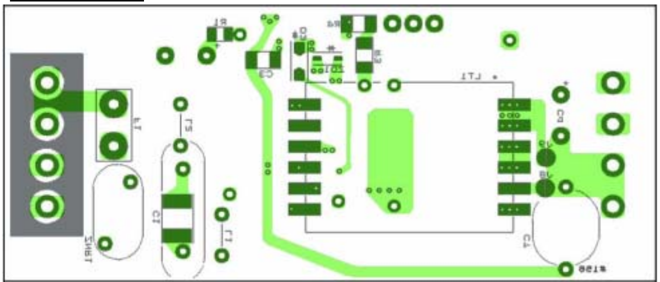


Bottom View

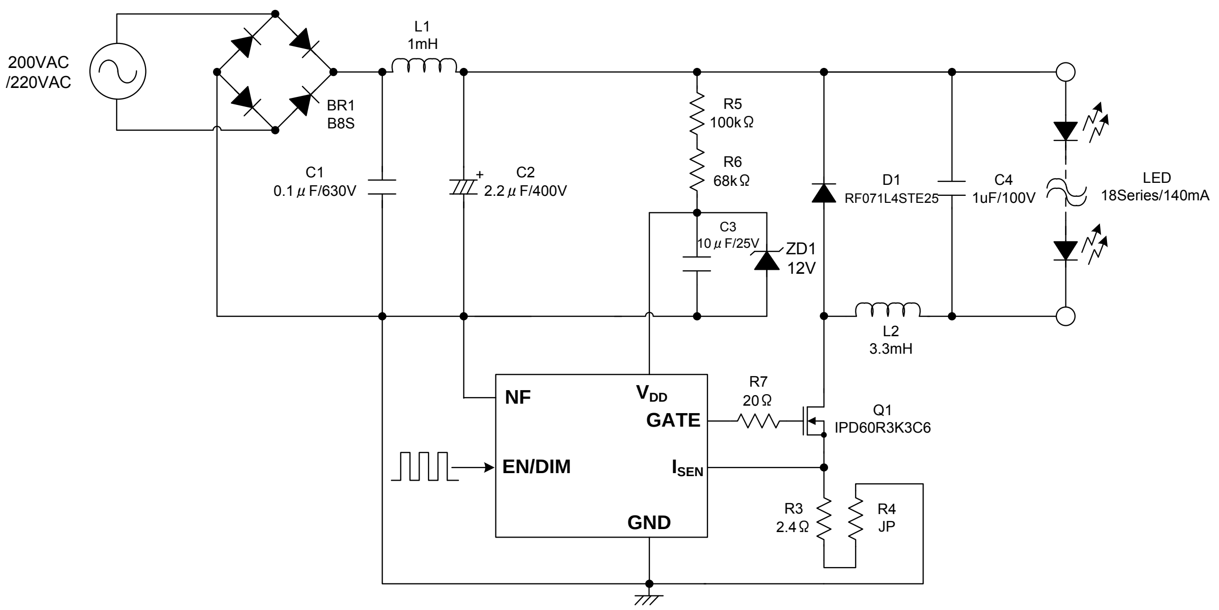
■Test board layout

Top View

Bottom View



<<2-3: Example of 220VAC / 240VAC non-isolated step-down B type solution>>



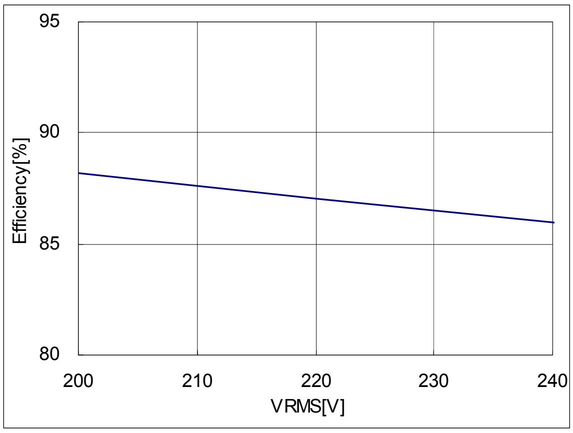
Typical Application Circuit

Item	Q'ty	Value	Description	Size/PKG	Part Number	Manufacture
IC	1	-	LED Driver IC	SOT-26	XC9401B605MR-G	TOREX
C1	1	0.1μF	Capacitor, Ceramic,630V,JB,±10%	4532	C4532JB2J104K	TDK-EPC
C2	1	2.2μF	Capacitor, Aluminum,400V,±20%	φ10.0x12.5	400BXC2R2MEFC10X12.5	Rubycon
C3	1	10μF	Capacitor, Ceramic,25V,X5R,±10%	3216	TMK316BJ106KL-T	Taiyo Yuden
C4	1	1μF	Capacitor, Ceramic,100V,X7R,±10%	3216	GRM31CR72A105A01L	Murata
L1	1	1mH	Inductor, 0.40A(Isat), 2.2Ω	-	5800-102-RC	BOURNS
L2	1	3.3mH	Inductor, SMD, 0.35A, 6.4Ω	12.7x12.7	SRR1208-332KL	BOURNS
D1	1	-	Diode, Fast Rec., 1.0A, 400V	SOD-106	RF071L4STE25	Rohm
ZD1	1	-	Zener Diode, 12V	Smin2-F5-B	DZ2J120M0L	Panasonic
R3	1	2.4Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16-2R4F	Kamaya
R4	-	Jumper	-	-	-	-
R5	1	100kΩ	Resistor, Chip, 0.5W, 500V	5025	RVC50K104F	Kamaya
R6	1	68kΩ	Resistor, Chip, 0.5W, 500V	5025	RVC50K104F	Kamaya
R7	1	20Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K200F	Kamaya
Q1	1	-	MOSFET, Nch, 600V, 1.7A, 2.97Ω	TO-252	IPD60R3K3C6	Infineon
BR1	1	-	Bridge Rectifier, 0.8A, 800V	MDI	B8S	PANJIT

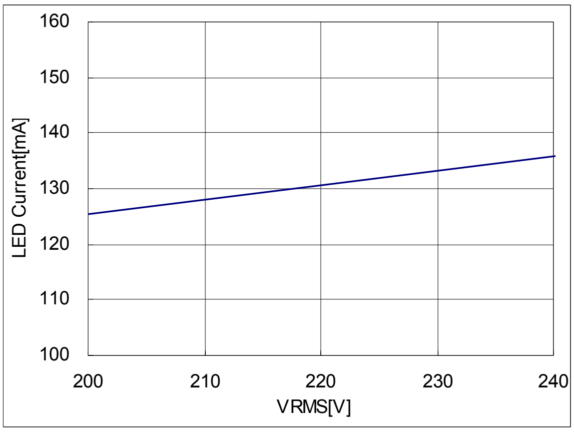
※LED: VLED=3.2V x 20, ILED Target = 130mA (Both average value)

■Evaluation Result

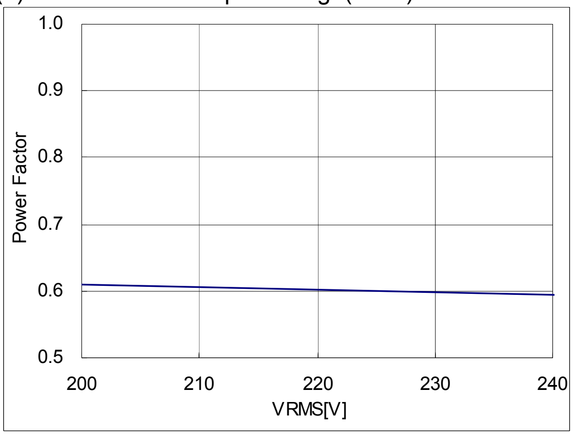
(1)Efficiency vs Input Voltage(RMS) Ta=25℃



(2)LED Current vs Input Voltage(RMS) Ta=25℃

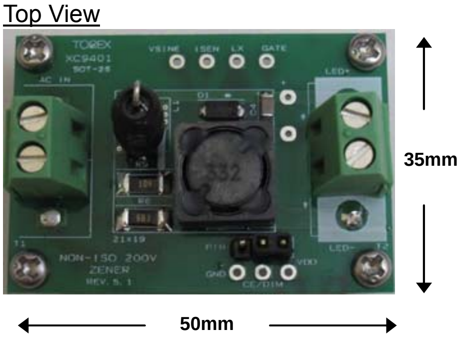


(3)Power Factor vs Input Voltage(RMS) Ta=25℃



■Test board　Photo of exterior

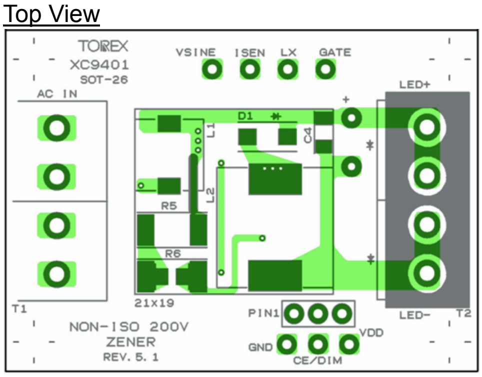
Top View



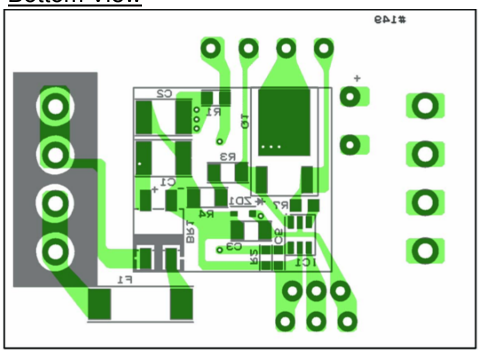
Bottom View

■Test board layout

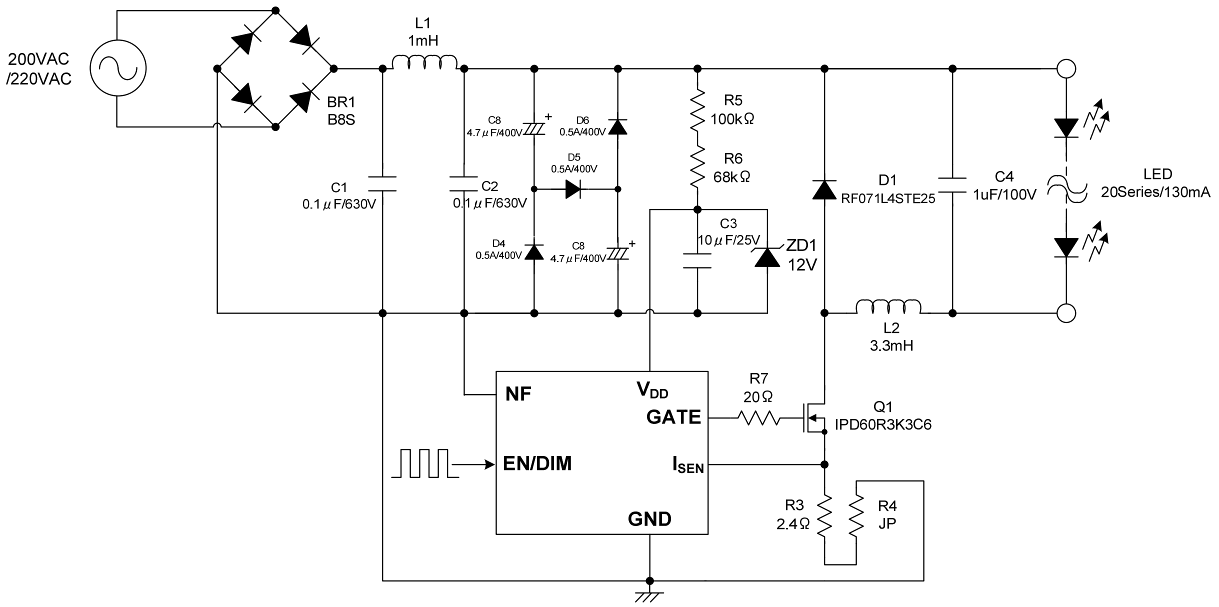
Top View



Bottom View



<<2-4: Example of 220VAC / 240VAC non-isolated step-down B type (Valley-Fill) solution>>



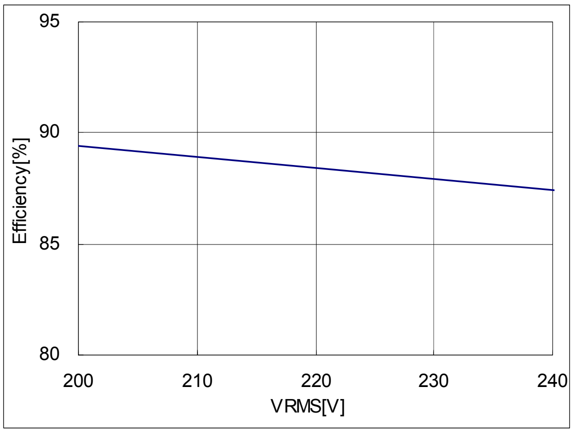
Typical Application Circuit

Item	Q'ty	Value	Description	Size/PKG	Part Number	Manufacture
IC	1	-	LED Driver IC	SOT-26	XC9401B605MR-G	TOREX
C1,2	1	0.1μF	Capacitor, Ceramic,630V,JB,±10%	4532	C4532JB2J104K	TDK-EPC
C3	1	10μF	Capacitor, Ceramic,25V,X5R,±10%	3216	TMK316BJ106KL-T	Taiyo Yuden
C4	1	1μF	Capacitor, Ceramic,100V,X7R,±10%	3216	GRM31CR72A105A01L	Murata
C5,6	1	4.7μF	Capacitor, Ceramic,100V,X7R,±10%	φ10.0x16.0	400BXC4R7MEFC10X16	Rubycon
L1	1	1mH	Inductor, 0.40A(Isat), 2.2Ω	-	5800-102-RC	BOURNS
L2	1	3.3mH	Inductor, SMD, 0.35A, 6.4Ω	12.7x12.7	SRR1208-332KL	BOURNS
D1	1	-	Diode, Fast Rec., 1.0A, 400V	SOD-106	RF071L4STE25	Rohm
D2-4	1	-	Diode, 0.5A, 400V	DO-213AA	GL34G-E3/98	Vishay
ZD1	1	-	Zener Diode, 12V	Smin2-F5-B	DZ2J120M0L	Panasonic
R3	1	2.4Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16-2R4F	Kamaya
R4	-	Jumper	-	-	-	-
R5	1	100kΩ	Resistor, Chip, 0.5W, 500V	5025	RVC50K104F	Kamaya
R6	1	68kΩ	Resistor, Chip, 0.5W, 500V	5025	RVC50K104F	Kamaya
R7	1	20Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K200F	Kamaya
Q1	1	-	MOSFET, Nch, 600V, 1.7A, 2.97Ω	TO-252	IPD60R3K3C6	Infineon
BR1	1	-	Bridge Rectifier, 0.8A, 800V	MDI	B8S	PANJIT

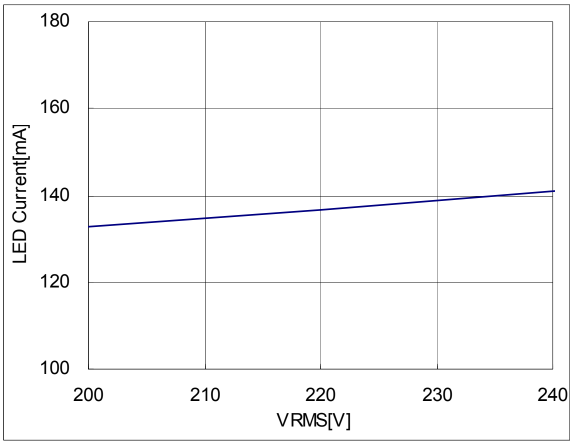
※LED: VLED=3.2V x 18, ILED Target = 140mA (Both average value)

■Evaluation Result

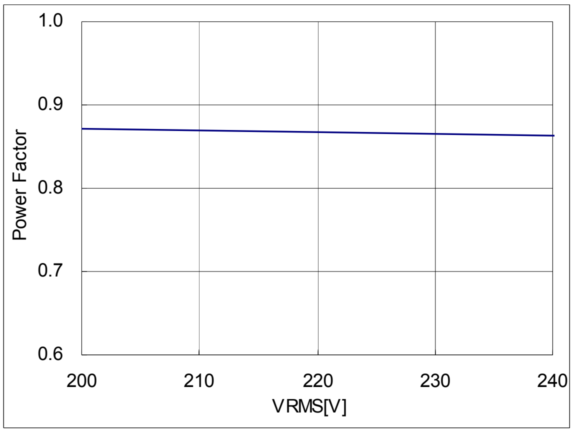
(1)Efficiency vs Input Voltage(RMS) Ta=25℃



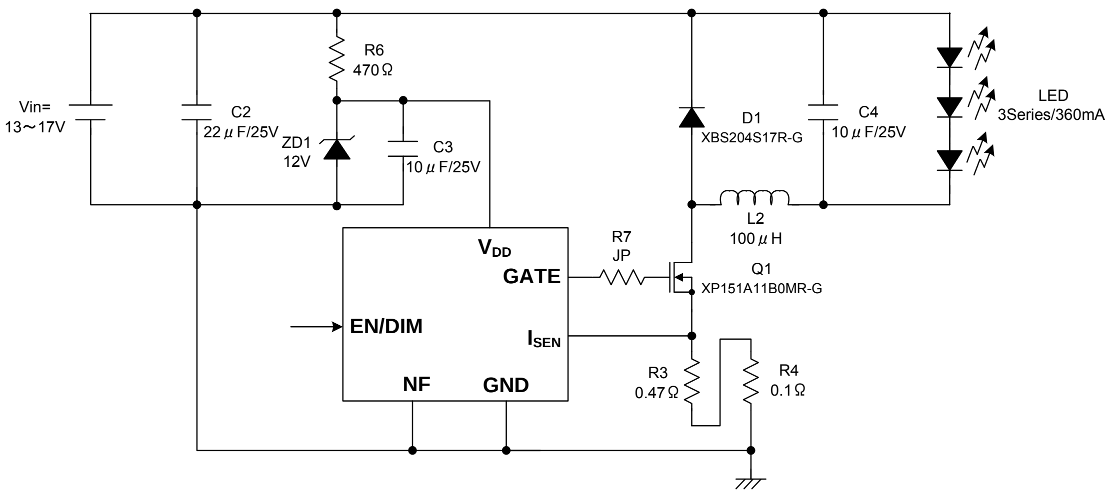
(2)LED Current vs Input Voltage(RMS) Ta=25℃



(3)Power Factor vs Input Voltage(RMS) Ta=25℃



<<3-1: Example of 15VDC input step-down B type solution>>



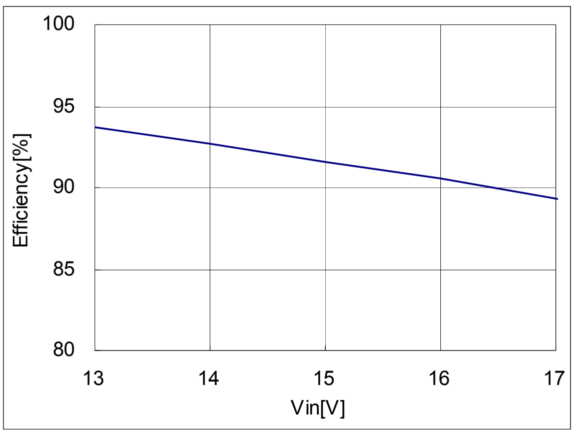
Typical Application Circuit

Item	Q'ty	Value	Description	Size/PKG	Part Number	Manufacture
IC	1	-	LED Driver IC	SOT-26	XC9401B605MR-G	TOREX
C2	1	22μF	Capacitor, Ceramic,25V,B,±20%	3216	GRM32EB31E226ME15	Murata
C3	1	1μF	Capacitor, Ceramic,25V,B,±10%	1608	TMK107BJ105KA	Taiyo Yuden
C4	1	10μF	Capacitor, Ceramic,25V,X5R,±10%	3216	TMK316BJ106KL	Taiyo Yuden
L2	1	100μH	Inductor, SMD, 1A, 0.28Ω	7.7x8.0	VLP8040T-101M	TDK-EPC
D1	1	-	Diode, Schottky, 2A, 40V	SMA	XBS204S17R-G	TOREX
ZD1	1	-	Zener Diode, 12V	Smin2-F5-B	DZ2J120M0L	Panasonic
R3	1	0.47Ω	Resistor, Chip, 0.5W	3216	RLC32KR470F	Kamaya
R4	1	0.1Ω	Resistor, Chip, 0.5W	3216	RLC32-R100F	Kamaya
R6	1	470Ω	Resistor, Chip, 0.1W, 50V	1608	RMC1/16K471F	Kamaya
R7	-	Jumper	-	-	-	-
Q1	1	-	MOSFET, Nch, 30V, 0.09Ω	SOT-23	XP151A11B0MR-G	TOREX

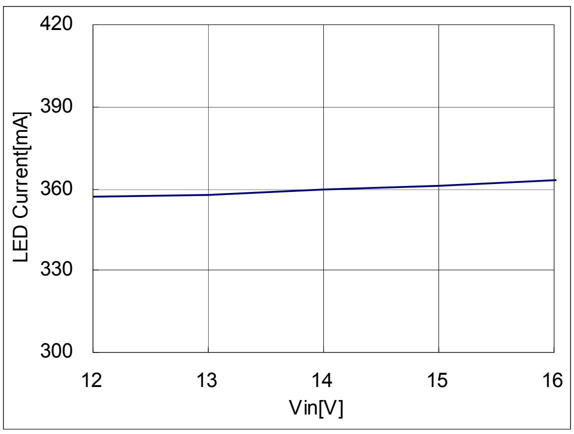
※LED: VLED=3.2V x 3, ILED Target = 360mA

■Evaluation Result

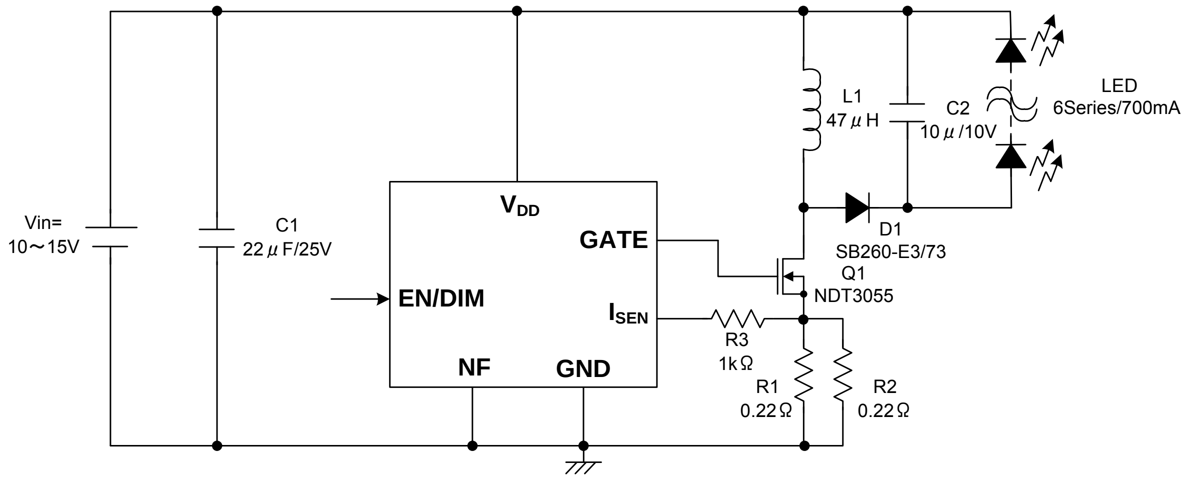
(1)Efficiency vs Input Voltage(RMS) Ta=25℃



(2)LED Current vs Input Voltage(RMS) Ta=25℃



<<3-2: Example of 10VDC~15VDC input, buck-boost B type solution>>



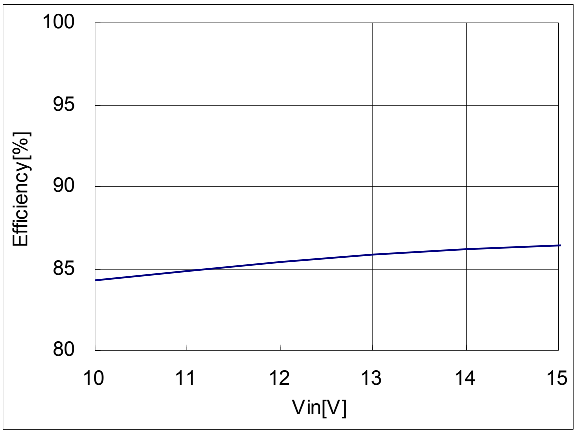
Typical Application Circuit

Item	Q'ty	Value	Description	Size/PKG	Part Number	Manufacture
IC	1	-	LED Driver IC	SOT-26	XC9401B605MR-G	TOREX
C1	1	22μF	Capacitor, Ceramic,25V,B,±20%	3225	GRM32EB31E226ME15	Murata
C2	1	10μF	Capacitor, Ceramic,35V,B,±10%	3225	GRM32EB3YA106KA12L	Murata
L1	1	47μF	Inductor, SMD, 5.28A(Sat), 72mΩ	12.5 x 12.5	DR127-470-R	Cooper Bussmann
R1,2	1	0.22Ω	Resistor, Chip	3216	RLC32-R220F	Kamaya
R3	1	1kΩ	Resistor, Chip	1608	RMC1/16K102F	Kamaya
D1	1	-	Diode, Schottky, 2A, 60V	DO-15	SB260-E3/73	Vishay
Q1	1	-	MOSFET, Nch, 60V, 84mΩ	SOT-223	NDT3055	Fairchild

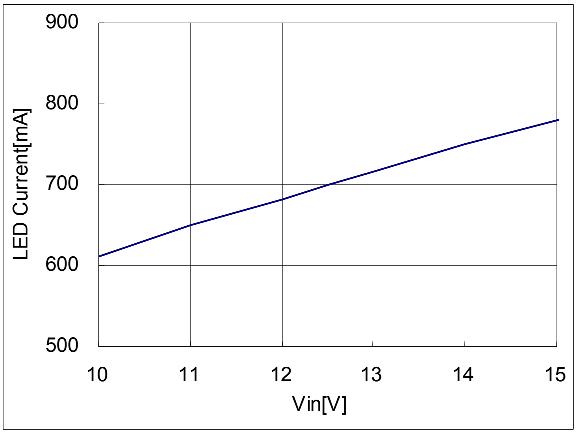
※LED: VLED=3.4V x 6, ILED Target = 700mA

■Evaluation Result

(1)Efficiency vs Input Voltage(RMS) Ta=25℃



(2)LED Current vs Input Voltage(RMS) Ta=25℃



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) Spike voltages and ripple voltage occur in switching controllers such as the XC9401 series and in peripheral circuits controlled by a switching controller. This is highly dependent on the peripheral components (coil inductance values, capacitors, and peripheral component board layout). Test sufficiently in the actual equipment when designing.

3) A delay time of about 140μs after the UVLO release voltage and after the EN/DIM "H" voltage has been established in this IC. Take this into consideration in sequence design.

4) The NF pin of the XC9401B605MR-G is not N.C. Although it does not operate in the circuit, it is connected to the internal circuit and thus must be connected to GND when used.

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

6) Please pay attention not to exceed absolute maximum ratings of this IC and external components.

7) To minimize V_{DD} fluctuations, connect a bypass capacitor (C_{VDD}) between V_{DD} and GND along the shortest path. If there is too much distance between the IC and C_{VDD}, operation may become unstable.

8) Mount peripheral components as close as possible to the IC. Use thick and short wiring to lower the wiring impedance of the peripheral components.

9) Use sufficiently reinforced wiring between V_{DD} and GND. Noise from V_{DD} and GND during switching may cause IC operation to become unstable.

10) When selecting actual components, take into consideration factors such as deviations in external component characteristics, deterioration over time, and temperature characteristics. In particular, the temperature of external components will rise due to heat generated by the LED. Take these factors into consideration when selecting external components, and design for heat dissipation.

11) Select external components and design test boards so that applicable regulations and standards are satisfied.

12) 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.

1. The products and product specifications contained herein are subject to change without notice to improve performance characteristics. Consult us, or our representatives before use, to confirm that the information in this application notes is up to date.
2. We assume no responsibility for any infringement of patents, patent rights, or other rights arising from the use of any information and circuitry in this application notes.
3. Please ensure suitable shipping controls (including fail-safe designs and aging protection) are in force for equipment employing products listed in this application notes.
4. The products in this application notes are not developed, designed, or approved for use with such equipment whose failure of malfunction can be reasonably expected to directly endanger the life of, or cause significant injury to, the user.
   (e.g. Atomic energy; aerospace; transport; combustion and associated safety equipment thereof.)
5. Please use the products listed in this application notes within the specified ranges.
   Should you wish to use the products under conditions exceeding the specifications, please consult us or our representatives.
6. We assume no responsibility for damage or loss due to abnormal use.
7.

TOREX SEMICONDUCTOR LTD.