

**100 W Power Supply
for LED Lighting
Design Guide**

RD034-DGUIDE-01

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

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1. Introduction

This Design Guide describes how to design the circuitry and layout of the 100 W Power Supply for LED Lighting (hereafter referred to as "this Power Supply"). Refer to the reference guide for the specifications, usage, and characteristic data of this power supply.

Even if the part number is indicated in the circuit diagram, it is not mounted on PCBs if it is indicated as "Not Mounted" in the bill of materials. A mounting location is provided on the PCB for constant value adjustment at the time of circuit design.

1.1. Onboard Power MOSFET

This power supply is expected to be used in lighting fixtures that require a larger amount of light and require more power than residential lighting, such as commercial facilities.

Such Lighting generally has a configuration where the power supply unit is independent of the lamp, and there is no need to reduce the thickness of the power supply unit to incorporate it into the lamp as in the case of home lighting, but a heat sink must be installed for heat dissipation. In view of the convenience of mounting the heat sink, we have chosen a through-hole type insulation package that eliminates the need for an insulating sheet and allows direct mounting of the heat sink.

This power supply consists of a PFC circuit and a flyback circuit. After boosting the input AC voltage to DC390 V (designed value), flyback circuit outputs a constant current of DC1.04 A. This section explains the reasons for selecting MOSFET used in the PFC-circuit and the flyback-circuit.

•MOSFET for PFCs

The PFC output voltage is 390 V. An element with the maximum rating of 600V is selected considering the surge voltage during switching caused by the effect of inductive component of the board and wiring and the derating with respect to the maximum rated voltage of MOSFET.

The loss caused by MOSFET has a steady-state loss caused by the on-resistance and a switching loss caused by the switching operation, and the steady-state loss depends on the on-resistance and the current of MOSFET. Generally, when a MOSFET with a lower on-resistance is selected, the steady-state loss can be reduced, but the switching loss has a trade-off relation and thus it increases.

The input current of the PFC-circuit of this power supply becomes maximum when the input voltage is the smallest i.e. AC90 V within the operating range and the output power is the largest i.e. 100 W. Since the input current (RMS value) at this time is approximately 1.34 A, therefore TK290A60Y is selected because of its on-resistance of 0.29 Ω (max.) with an emphasis on reducing switching loss.

•MOSFET for flyback circuitry

The PFC output voltage of 390 V is the input voltage of the flyback circuit. A voltage obtained by adding a flyback voltage of about 100 V to this 390 V is applied to the MOSFET. An element with the maximum rating of 650 V is selected considering the surge voltage at switching generated by the effect of inductive component of the board and wiring and the derating with respect to the maximum rated voltage of MOSFET. The input current of the flyback circuit is maximum when the output power is maximum i.e. 100 W. At this time, the input current is about 0.3 A, and therefore TK290A65Y is

selected because of its on-resistance of 0.29Ω (max.) with an emphasis on reducing the switching loss as in the PFC-circuit.

[TK290A60Y](#)

Used in PFC circuit

$V_{DSS} = 600 \text{ V}$, $R_{DS(ON)} (\text{Max}) = 0.29 \Omega @ V_{GS} = 10 \text{ V}$, TO-220SIS package (TO-220 insulated package)

A superjunction structure is adopted to achieve both high withstand voltage and low on-resistance.

[TK290A65Y](#)

Used in flyback circuit

$V_{DSS} = 650 \text{ V}$, $R_{DS(ON)} (\text{Max}) = 0.29 \Omega @ V_{GS} = 10 \text{ V}$, TO-220SIS package (TO-220 insulated package)

A superjunction structure is adopted to achieve both high withstand voltage and low on-resistance.

An insulated package product is selected this time, although a non-insulated package can be selected if heat dissipation performance is of more importance. When mounting a non-insulated package on a heat sink, it is necessary to electrically insulate the heat sink by inserting an insulating sheet, etc., between the heat sink and the element. Please also refer to the following application notes for heat sink mounting.

For Application Notes regarding Mounting MOSFET Heatsinks →

[Click Here](#)

Toshiba has commercialized the high-voltage superjunction structural DT MOS series suitable for PFCs in AC-DC converters and primary-side switches. Products with the optimum on-resistance can be selected according to the power supply specifications, such as the output power. In addition to the through-hole type insulation packages used in this power supply, surface-mount type packages and through-hole type non-insulation packages are also available, therefore allowing the design of power supply unit with a height that meets the application specifications. Following is the line-up of 600 V and 650 V max. rated voltage (V_{DSS}) devices which are optimal for this type of application.

Max. Rated Voltage 600 V DT MOS Series Product Lineup →

[Click Here](#)

Max. Rated Voltage 650 V DT MOS Series Product Lineup →

[Click Here](#)

2. Circuit Design

This section describes the key-points in circuit design of this power supply.

2.1. AC Line Circuit Design

Fig. 2.1 shows the AC line circuit and explains the basic design method.

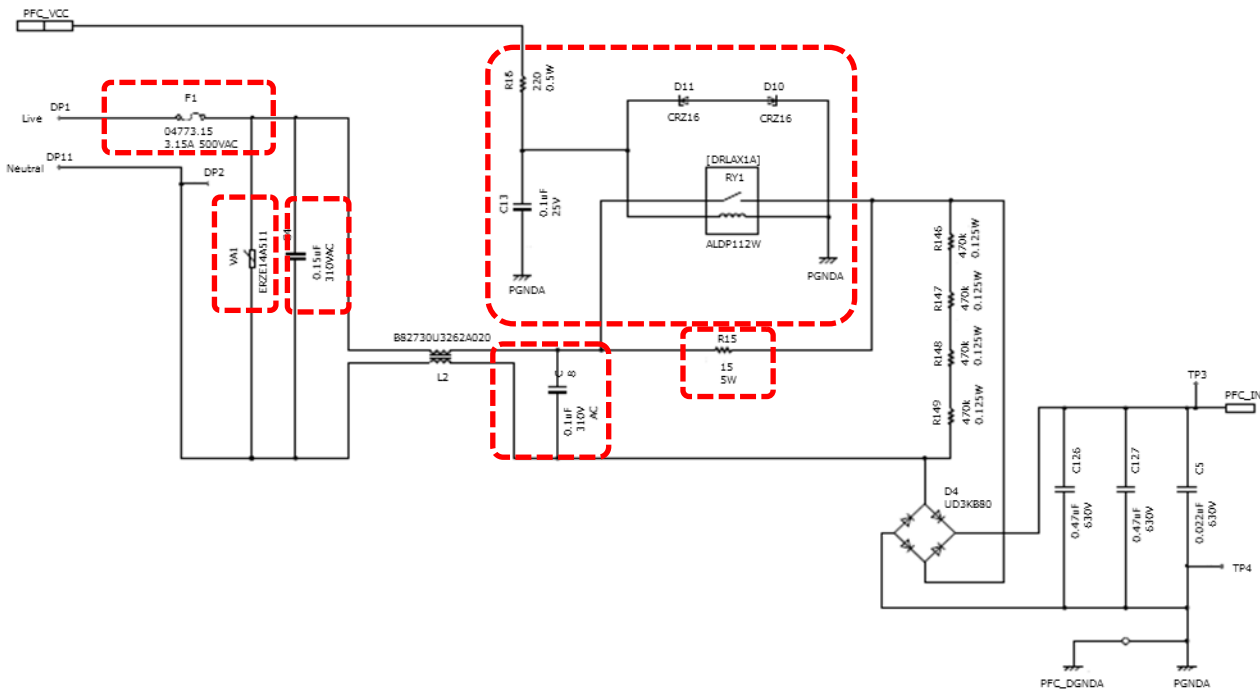


Fig. 2.1 AC Line Circuit

Fuse

Fuse (F1) is used to shut off the AC line when an excessive current flows through the AC line. Select a fuse using the AC line current RMS value (max). Calculate the AC line current RMS value (max) using the following equation.

$$\text{AC Line Current RMS (max)} = \text{Maximum Power} / \text{Power Supply Efficiency} / \text{Power Factor} / \text{AC Line Voltage RMS (min)}$$

The output specification of this power supply is 100 W output. Since the power supply efficiency of the PFC decreases when the AC line voltage is low, the AC line current RMS value (max) is calculated by setting the AC line voltage RMS value (min) to 90 V of the minimum value of the 100 V system.

Assuming that the input voltage (min RMS value) = 90 V, the maximum power = 100 W, the PFC power supply efficiency (η_1) = 93 %, the flyback power supply efficiency (η_2) = 90 %, and the power factor = 0.99, the AC line maximum current value (RMS value) of this power supply is approximately 1.34 A. Add margin to this power supply and use a 3.15 A fuse. When selecting a fuse, in addition to the above maximum current, it is necessary to consider the inrush current

when the AC power is turned on, and whether the product has obtained the safety standards to be complied with, etc.

Varistor

Ceramic varistor (RV1) is used to protect the circuit from surge voltages due to inductive lightning, etc., are applied to the AC line. Select a varistor using the voltage value of the AC line. Since the maximum AC line voltage of this power supply is 264 V (RMS value) and 373 V (instantaneous value), a varistor with a maximum allowable circuit voltage of 320 V (AC RMS value) and a varistor voltage of 510 V is used with an added margin.

Select the product considering not only the maximum allowable circuit voltage and varistor voltage, but also the surge current withstand capacity and energy withstand capacity. In addition, since the varistor failure mode has many short modes, a fuse is used in front (input side of the AC line) of the varistor.

X Capacitor Discharge Resistance

X Capacitor (Cx) uses a resistor Rdis (R146-R149) for discharging. Set the resistance value to meet the safety standards. For example, if the safety standard that the system should comply with requires that the safety standard be less than or equal to the safety voltage (Vsafe) within t seconds after the AC plug is unplugged, to satisfy the standard even if the AC plug is unplugged when the AC line voltage is peaked, set the discharge resistance value that satisfies the following equation.

$$R_{dis} < \frac{t}{C_x \times \ln\left(\frac{V_{inAC} \times \sqrt{2}}{V_{safe}}\right)}$$

Rdis is 3.6 MΩ or less when Cx is 0.3 μF, VinAC is the largest 264 V, Vsafe is 60 V, and t is 2 seconds. Rdis is assumed to be 1.88 MΩ (470 kΩ for R146-R149), taking into account variations in capacitance and resistances, and designed margins. In addition, the loss of resistance is as follows.

$$R_{loss} = \frac{V_{inAC}^2}{R_{dis}}$$

In this case, the power loss (Rloss) in the discharging resistor Rdis is 148 mW. Reducing the resistance of the discharging resistor makes it easier to satisfy the safety standards, but care must be taken because the power loss (Rloss) of the resistor increases.

EMI Countermeasure Parts

Common mode choke (L2) is used to suppress common mode noise. In addition, X capacitors (C4, C8) are used to prevent differential noise. Since each noise level is affected by the PCB layout and the enclosure structure, change, delete, or add the aforementioned parts as necessary. Since this power supply does not have an enclosure, a Y capacitor is not installed. However, when designing a system with an enclosure, install a Y capacitor as a countermeasure against common mode noise. Note that while installing a Y capacitor, if the capacitance value is increased, the leakage current will increase. Therefore, confirm that safety standards are satisfied.

Inrush Current Suppressing Components

Resistor (R15) and relay (RY1) are used to suppress inrush current when AC power is turned on. When the AC power is turned on, the relay (RY1) is opened and the AC line current flows to the resistor (R15), thereby suppressing inrush current. After the AC power is turned on, the primary side 12 V power supply of the external power supply is detected and the relay (RY1) becomes conductive. When the relay (RY1) becomes conductive, the resistor (R15) is short-circuited, which reduces power loss during operation. The resistor (R15) must be selected to withstand inrush current. Also, check that the conditions and timing for opening and continuity of the relay (RY1) satisfy the required specifications.

Bridge Diode

A bridge diode (D4) is used for the rectifier diode. For selecting match the product ratings with the inrush current value and the maximum applied voltage.

2.2. Power Factor Collection (PFC) Circuit Design

To improve the power factor, PFC circuitry using Texas Instruments Critical Mode PFC Controller UCC28051 (PFC controller) is used. Fig. 2.2 shows the PFC circuit (PFC controller-peripheral) and explains the basic design method. For detailed designs of the surroundings, refer to the data sheet of the UCC28051 datasheet, related documents, etc.

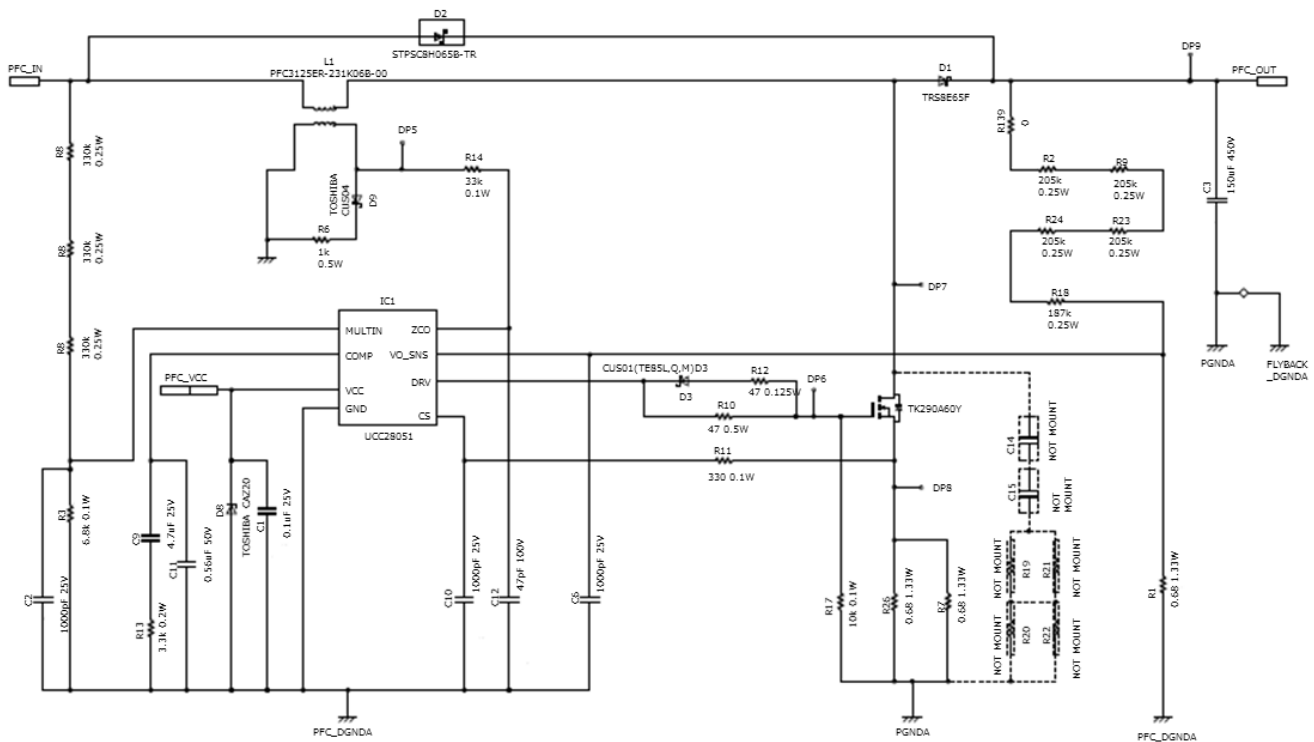


Fig. 2.2 PFC Circuit (PFC Controller-Peripheral)

Output Voltage

Set the output voltage (PFC_OUT) using the resistance values (of R1, R2, R9, R18, R23, R24, and R139). The PFC controller controls the output voltage (PFC_OUT) so that the output pin sense voltage (VO_SNS) divided by these resistors matches the internally referenced voltage (2.5 V) of the PFC controller. Calculate the output voltage (PFC_OUT) using the following equation. Fig. 2.3 shows the output voltage setting circuit.

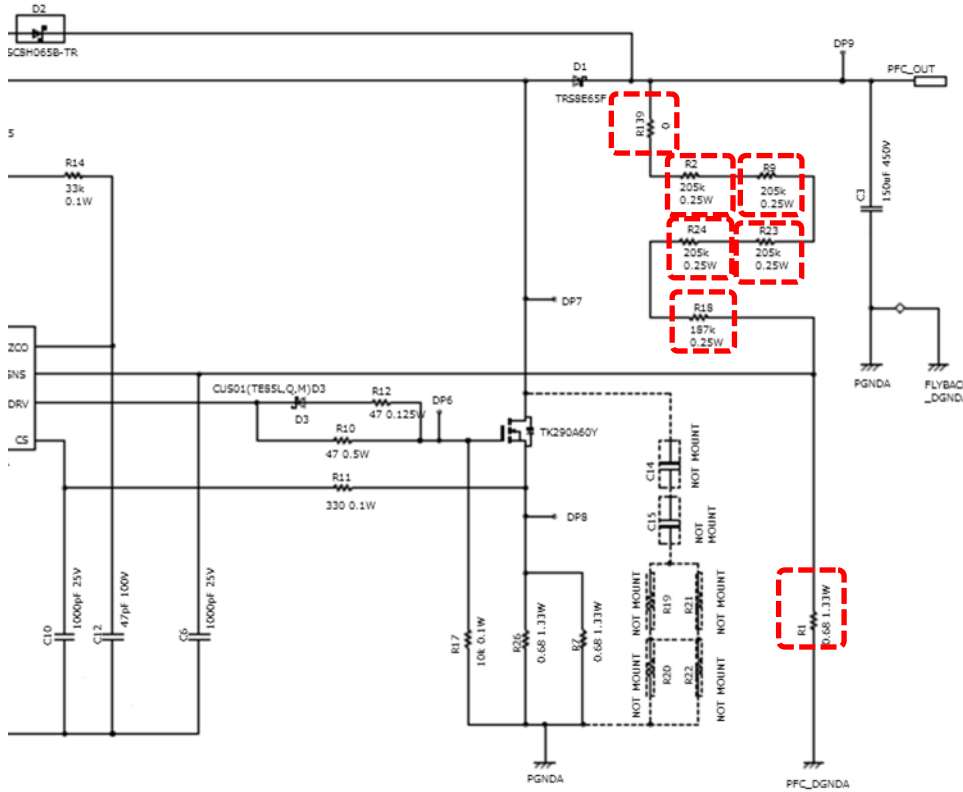


Fig. 2.3 Output Voltage Setting Circuit

$$PFC_OUT(V) = \frac{2.5 \times (R1 + R2 + R9 + R18 + R23 + R24 + R139)}{R1}$$

The set value of the output voltage (PFC_OUT) is approximately 390 V. In this case, the resistance value of R1 is 6.49 kΩ, the resistance value of R2, R9, R23, and R24 is 205 kΩ, the resistance value of R18 is 187 kΩ, and the resistance value R139 is 0 Ω.

Current Limiter

Set the current limiter level of the PFC circuit with the current detection resistors (R7 and R26). The PFC controller disables the gate drive signal (DRV) when the load current increases and the voltage value at the CS pin reaches the current limit threshold V_limit1. Fig. 2.4 shows the current limiter circuit.

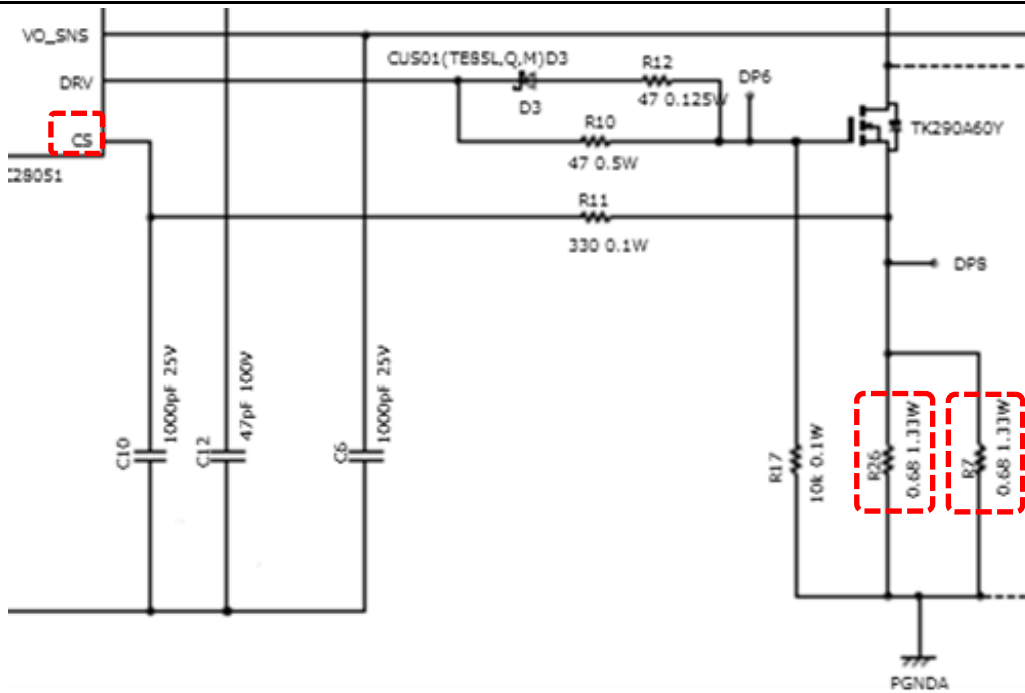


Fig. 2.4 Current Limiter Circuit

Calculate the target set point (I_{limit1}) of the current limiter using the following equation.

$$I_{limit1} = \frac{V_{limit1}}{R7 \parallel R26}$$

Here ($R7 \parallel R26$) is the equivalent resistance of two parallel resistor $R7$ and $R26$. If the current limit threshold V_{limit1} is 1.7 V and the current detection resistance ($R7 \parallel R26$) is 0.68 Ω , the current limiter level setting is 5.0 A.

Gate Drive Circuit

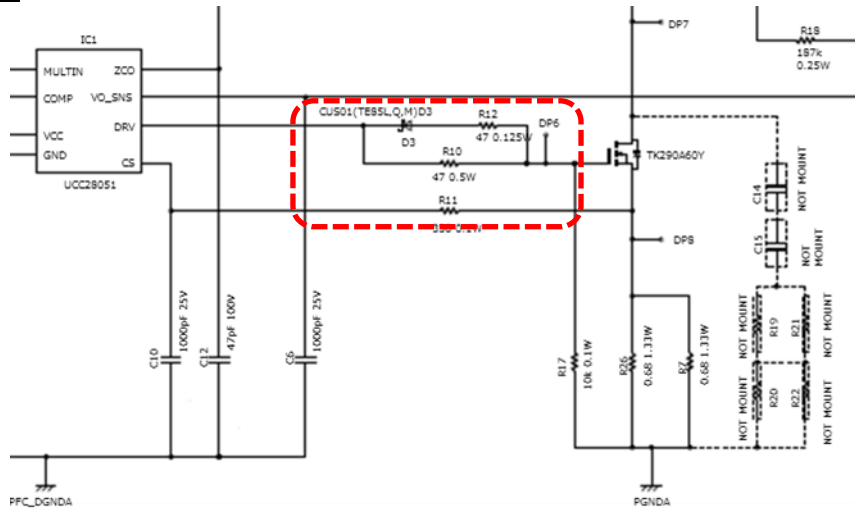


Fig. 2.5 Gate Drive Circuit

Fig. 2.5 shows the gate drive circuit. Gate drive design affects power supply efficiency and EMI (noise). Generally, there is a trade-off between power efficiency and EMI (noise), and a balanced design is required.

To reduce EMI (noise), it is better to increase the resistance of the gate series resistors (R10, R12). The turn-on speed and turn-off speed of the MOSFET can be adjusted individually in the gate drive circuit, but if EMI (noise) is generated in either the turn-on or the turn-off, it is not necessary to change the resistance value of all the gate series resistors. To make the turn-on time slower, increase resistance R10 and to make the turn-off time slower, increase resistance R12.

Note that increasing the value of resistors (R10, R12) will reduce the switching speed of MOSFET, which may result in poor power-supply efficiency. Check that the power supply efficiency specification and heat dissipation specification satisfy the required specification.

Output Capacitor

The capacitance (C3, Cout1) of the output capacitor is calculated based on the hold-up time requirement. Fig. 2.6 shows the peripheral circuits of the output capacitor.

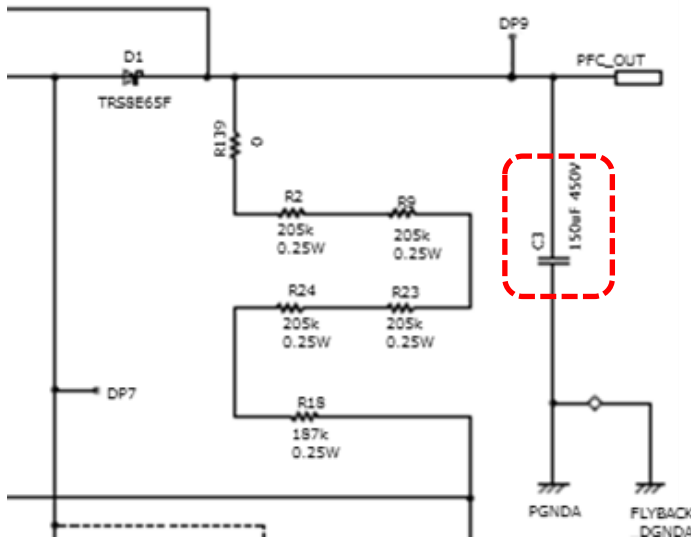


Fig. 2.6 Output Capacitor Peripheral Circuit

The hold-up time (T_{hold}) is calculated by C_{out1} and output voltage (V_{out_PFC}), the output voltage low limit voltage (V_{min}), the maximum output power (P_{out}), and the flyback power efficiency (η_2).

$$T_{hold} = C_{out1} \times \frac{(V_{out_PFC}^2 - V_{min}^2) \times \eta_2}{2 \times P_{out}}$$

When the capacitance (C_{out1}) is 150 μ F, the output voltage (V_{out_PFC}) is 382 V, the output voltage low limit voltage (V_{min}) is 300 V, the flyback power supply efficiency (η_2) is 90 %, and the maximum output power (P_{out}) is 100 W, the hold-up time (T_{hold}) is 37.7 ms.

In addition, when there is a required specification for the output ripple, set it by the following method.

1. Determine the capacitance of the output capacitor (C_{out1}) that meets the output ripple specifications.
2. Determine the capacitance of the output capacitor (C_{out1}) that satisfies the hold-up time.
3. Compare the capacitance values and use the larger value.

When selecting an output capacitor (C_{out1}), consider the tolerances and aging.

Inductor

The inductance (L) of inductor L1 is set using the following data.

1. Max. Output Power (Pout)
2. AC-Line Voltage RMS (VinAC)
3. Total power conversion efficiency of this power supply ($\eta_1 \times \eta_2$)
4. PFC output voltage (Vout_PFC)
5. Switching frequency (f_{PWM1})

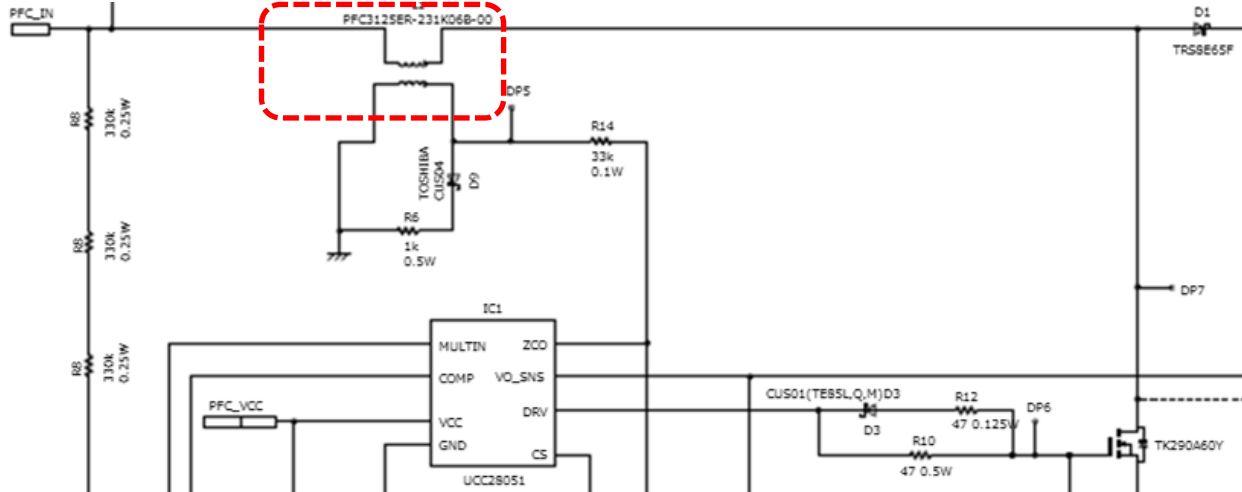


Fig. 2.7 Inductor Peripheral Circuit

Fig. 2.7 shows the inductor peripheral circuit. Calculate the inductance (L) using the following equation. Ripple current of the inductor (ΔI) is twice the AC line peak input current (ACin_peak).

$$ACin_peak = \frac{P_{out} \times \sqrt{2}}{V_{inAC} \times \eta_1 \times \eta_2}$$

$$\Delta I = ACin_peak \times 2$$

$$L = \frac{(V_{out_PFC} - \sqrt{2} \times V_{inAC}) \times \eta_1 \times \eta_2 \times V_{in}^2}{2 \times f_{PWM1} \times V_{out_PFC} \times P_{out}}$$

When the maximum output power (Pout) is 100 W, the AC line voltage RMS (VinAC) is 90 V, the PFC power supply efficiency (η_1) is 93%, the flyback power supply efficiency (η_2) is 90%, the PFC output voltage (Vout_PFC) is 390 V, and the switching frequency (f_{PWM1}) is 65 kHz, the inductance (L) is calculated as 351 μ H. Set to 230 μ H in consideration of magnetic saturation caused by load current.

The peak current (IL_peak) flowing through the inductor is calculated using the AC line peak input current (ACin_peak) from the following equation:

$$IL_peak = ACin_peak \times 2$$

Because the AC line peak input current (ACin_peak) is 1.88 A, the peak current (IL_peak) setting is 3.76 A. Select an inductor that can allow at least 3.76 A.

Switching Frequency

Because the PFC controller is used for critical-mode control, the switching frequency (F_{pwm1}) is not fixed. The switching frequency (F_{pwm1}) is calculated by the following equation.

$$F_{pwm1} = \frac{V_{inAC}^2 \times \eta_1 \times \eta_2 \times (PFC_OUT - \sqrt{2} \times V_{inAC})}{2 \times L \times P_{out} \times V_{out_PFC}}$$

Because the switching frequency (F_{pwm1}) increases as the load becomes lighter, the switching frequency (F_{pwm1}) becomes maximum when the output power supply is minimum (50 W). In this case, the switching frequency (F_{pwm1}) is 396 kHz, V_{inAC} is 220 V, V_{OUT_PFC} is 390 V, P_{out} is 50 W, η_1 is 93 %, and η_2 is 90 %.

MOSFET Surge-Voltage Reduction Circuitry

If surge voltage at turn-off of MOSFET (Q1) is an issue, install Snubber circuitry to reduce surge voltage (Fig. 2.8).

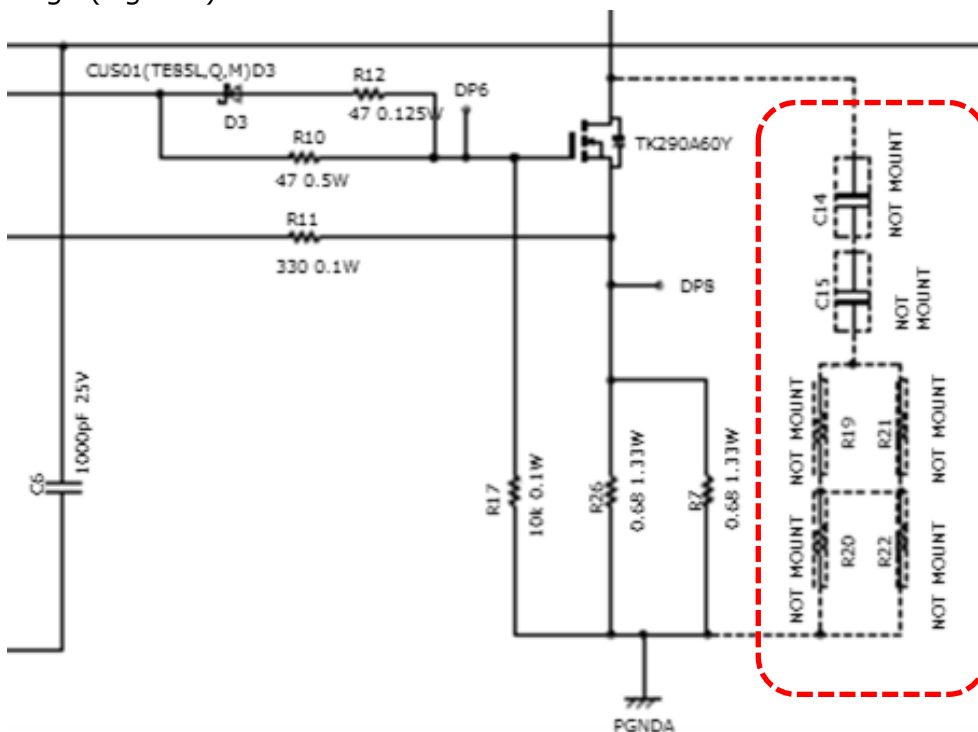


Fig. 2.8 Snubber Circuitry

Snubber circuitry is realized by R19-R22, C14, and C15. Snubber circuit absorbs the surge-voltage (V_{srg}) generated between the drain-source of Q1. At this time, the loss P_{d_Rsnb} generated by the resistor R19-R22 is as follows. $(C14 \parallel C15)$ is the equivalent capacitance of two serial capacitors C14 and C15.

$$P_{d_Rsnb} = (C14 \parallel C15) \times (V_{srg})^2 \times \left(\frac{f_{PWM1}}{2}\right)$$

Snubber circuitry is not installed in this power supply. Check the surge voltage on the actual device and mount it as necessary.

2.3. Constant Current Circuit Design

Texas Instruments flyback controller UCC28600 (flyback controller) is used to implement 100 W constant-current circuitry. Basic design method is explained using the Fig. 2.9 which shows the constant current circuit (flyback controller peripheral). For detailed design of the surroundings, refer to the UCC28600 datasheet, related documents, etc.

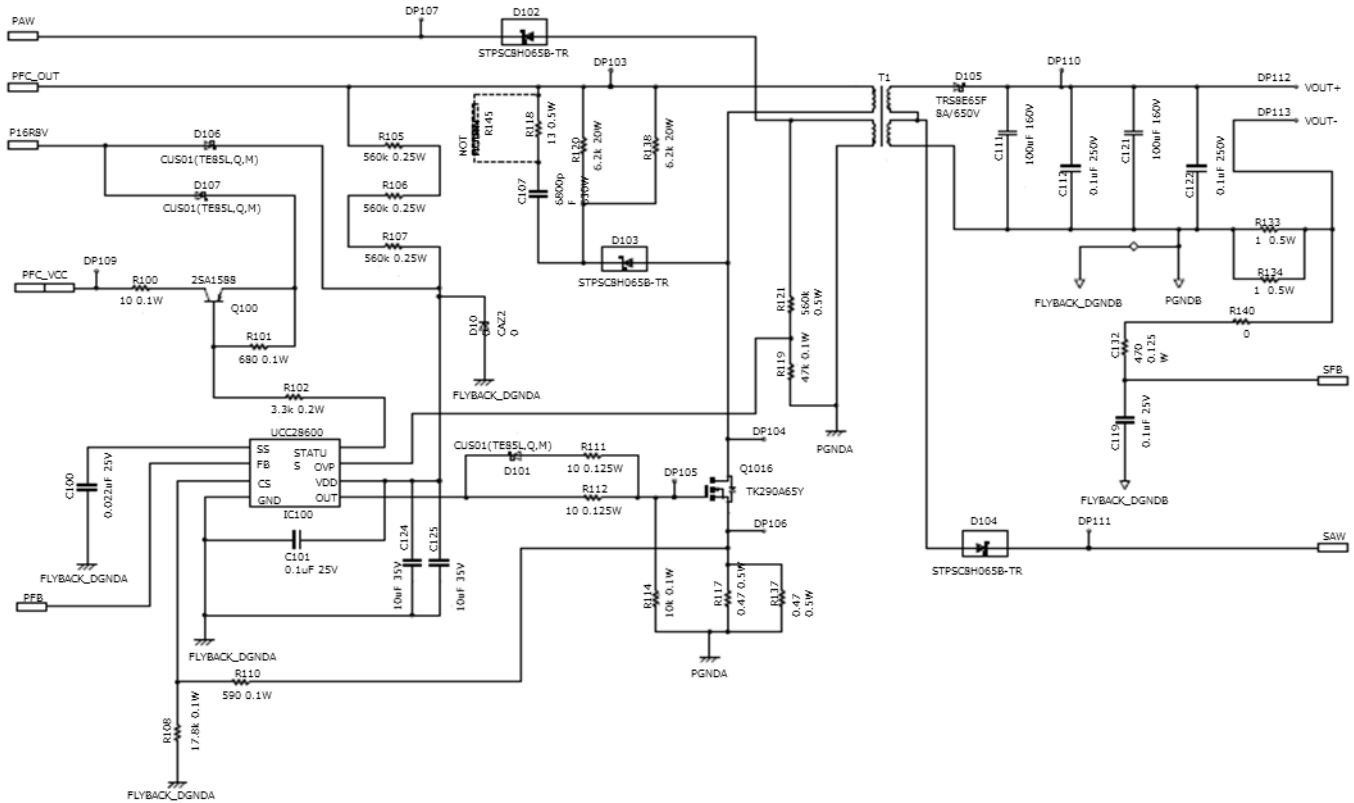


Fig. 2.9 Constant Current Circuit (Flyback Controller Peripheral)

Output Current Setting

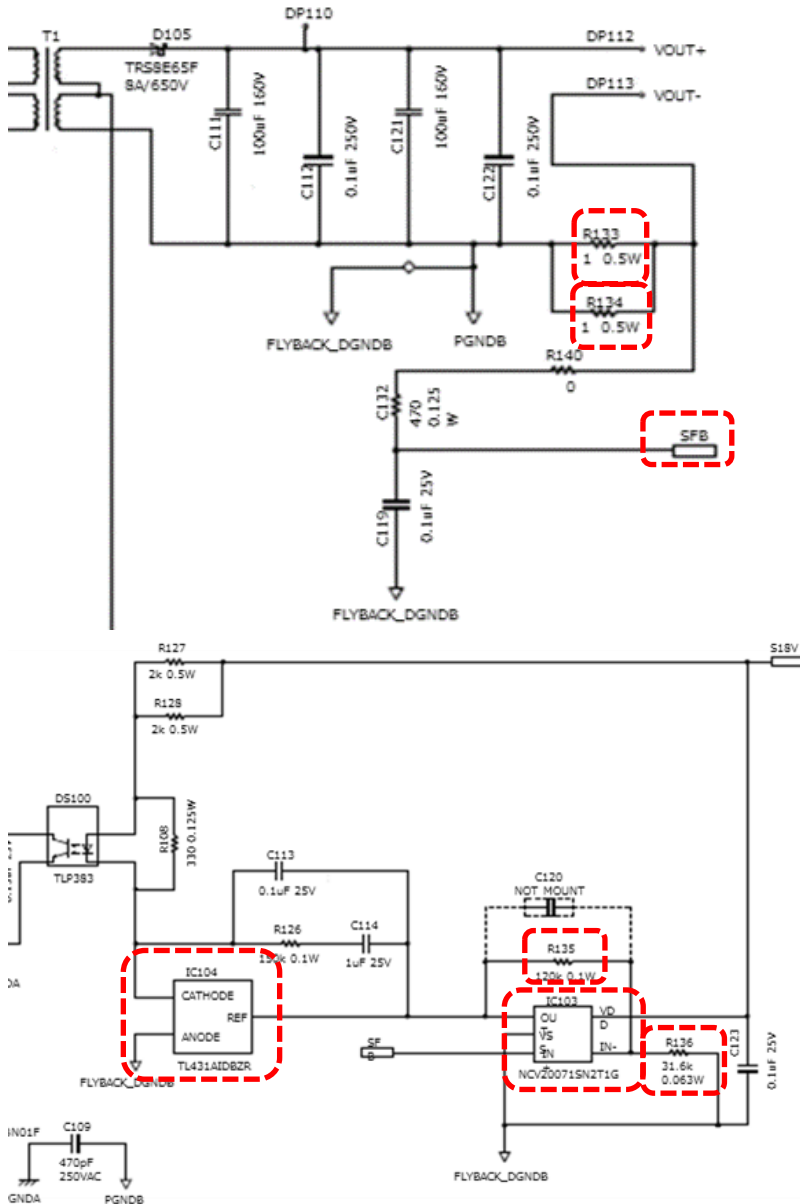


Fig. 2.10 Output Current Setting Circuit

Fig. 2.10 shows the output current setting circuit. Set the output current (I_{out}) of the constant current circuit with the resistor value of the external resistors (R133-R136), operational amplifier (IC103), and voltage reference (IC104). The operational amplifier (IC103) and R135 and R136 amplifies the voltage generated by the output current, R133 and R134. Then, flyback controller controls the current of the Photocoupler (DS100) so as to match this output voltage of IC103 and the reference voltage (VREF). The PWM controller controls MOSFET (Q101) depending on the amount of current fed back from the photocoupler (DS100) to keep the output current (I_{out}) constant. Calculate the output current (I_{out}) using the following equation.

$$I_{out} (V) = \frac{V_{REF}(V)}{R133 \parallel R134} \times \frac{R136}{R135 + R136}$$

Here (R133 || R134) is the equivalent resistance of two parallel resistor R133 and R134. The output current (I_{out}) is 1.04 A, when the resistance of (R133 || R134) is 0.5 Ω , the resistance of R135 is 120 k Ω , the resistance of R136 of 31.6 k Ω , and the reference voltage (V_{ref}) is 2.495 V.

Current Limiter

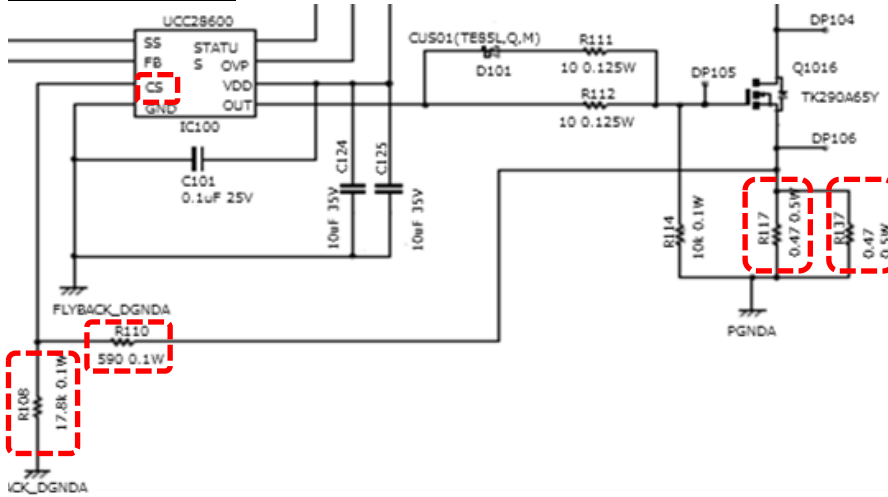


Fig. 2.11 Current Limiter Circuit

Fig. 2.11 shows the current limiter circuit. When the voltage at the CS pin of the flyback controller reaches the current limit threshold (1.25 V), the flyback controller controls the input-side bridge MOSFET to apply the current limit. The current limiter level I_{limit} is set by the current limit threshold (1.25 V), the resistance of the current sense resistors (R117, R137) and the external resistors (R108, R110). I_{limit} is calculated by the following equation.

$$I_{limit} = \frac{1.25}{R117 \parallel R137} \times \frac{R108 + R110}{R108}$$

Here (R117 || R137) is the equivalent resistance of two parallel resistor R117 and R137. The current limiter level is 5.49 A, when the resistance of (R117 || R137) is 0.47 Ω , the resistance of R108 is 17.8 k Ω , and the resistance of R110 is 590 Ω .

Gate Drive Circuit

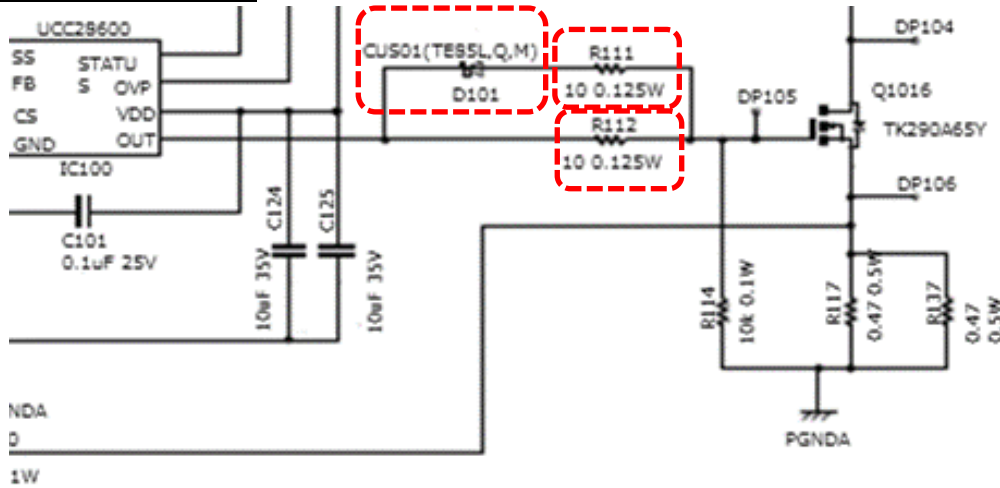


Fig. 2.12 Gate Drive Circuit

To reduce EMI (noise), it is better to increase the resistance (R111, R112) of the gate-series resistors. The turn-on and turn-off speeds of MOSFET can be individually adjusted by the gate drive circuitry, therefore if EMI (noise) is present either on turn-on or turn-off, there is no need to change the resistances of all gate series resistors. Increase the resistance value of R112 to make the turn-on time slower, and increase the resistance value of R111 to make the turn-off time slower.

Note that increasing the resistor value (R111, R112) will reduce the switching speed of MOSFET, which may result in deterioration of the power supply efficiency. Check that the power supply efficiency specification and heat dissipation specification satisfy the required specification.

Transformer

The number of turns of the transformer is determined from the flyback voltage. Since a 650 V breakdown voltage product is being used for the switching element this time, thus after taking margin we take 80 % of this voltage to be the peak voltage value i.e. 520 V. Assuming that the PFC power supply output voltage is V_{out_PFC} , the output voltage is V_{out} , the number of turns on the primary side is N_p , the number of turns on the secondary side is N_s , the forward voltage of the diode is V_f , and the margin on the secondary side is 150 %, the turn ratio (N_p/N_s) is calculated by the following equation.

$$\frac{N_p}{N_s} = \frac{650 \times 80\% - V_{out_PFC}}{(V_{out} + V_f) \times 150\%}$$

If the maximum value of the PFC power supply output voltage (V_{out_PFC}) is 410 V, the output voltage (V_{out}) is 100 V, and the forward voltage (V_f) of the diode is 1.2 V, then the winding ratio (N_p/N_s) is 0.72.

Since this power supply generates an auxiliary power supply using a transformer, the ratio of turns of the auxiliary power supply is also calculated. Assuming that the auxiliary power supply voltage is V_{aux} and the transformer winding number for the auxiliary power supply is N_b , the winding ratio (N_p/N_b) is calculated by the following equation.

$$\frac{N_p}{N_b} = \frac{N_p}{N_s} \times \frac{V_{out} + V_f}{V_{aux}}$$

If the auxiliary power supply voltage (V_{aux}) is 42 V, the winding ratio (N_p/N_b) is 1.75.

Let's assume that the number of turns ratio (N_p/N_s) is 0.8, the number of turns ratio (N_p/N_b) is 1.8, and the number of turns $N_p:N_s:N_b$ is 40:50:22. Note that the secondary side has a total of 50 turns i.e. N_s , but the secondary side also needs to generate an auxiliary power supply in the same way as the input side, thus the secondary side winding outputs an auxiliary power generation signal from the 22 turns (the number of turns same as N_b). In addition, primary-secondary dielectric strength, winding temperature rise, magnetic flux saturation, core loss, etc. must be sufficiently considered. Refer to the Bill of Materials (RD034-BOM-01) for the specifications of the transformer used in this power supply.

Output Overvoltage Detection Circuit

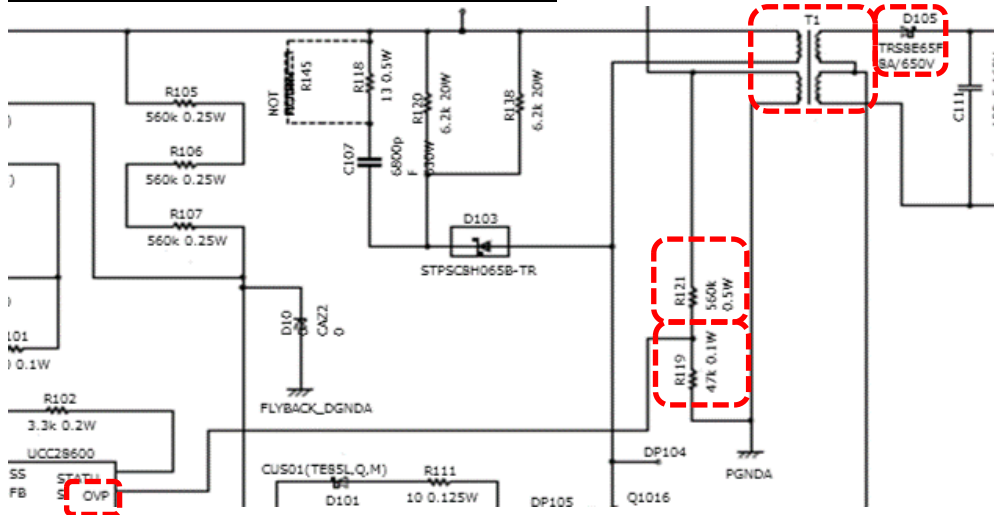


Fig. 2.13 Output Overvoltage Detection Circuit

Fig. 2.13 shows the output overvoltage detection circuit. Set the overvoltage detection value (V_{ovp}) of the output using the turns N_s on the secondary side of the transformer (T1), the transformer turns N_b for the auxiliary power supply, the resistance value of the external resistors (R119, R121), and the V_f value of the rectifier diode (D105). The output voltage is monitored indirectly using the voltage generated in the auxiliary power supply generating winding. When the voltage value obtained by dividing the voltage generated in the auxiliary power generation winding by an external resistor reaches the overvoltage detection value ($V_{det}=3.75\text{ V}$), the flyback controller stops switching operation. Output overvoltage (V_{ovp}) value can be calculated using the following equation:

$$V_{ovp} = V_{det} \times \frac{R119 + R121}{R119} \times \frac{N_s}{N_b} - V_f$$

If the resistance (R119) is 560 k Ω , the resistance (R121) is 56 k Ω , the number of turns N_s on the secondary side is 50, the transformer turns N_b for the auxiliary power supply is 22, and the V_f of the rectifier diode is 1.2 V, then the set value of overvoltage detection value V_{ovp} is 108.9 V.

Note that when directly monitoring the output voltage, an overvoltage detection circuit must be installed on the output side.

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