Design Example Using STR5A464S:

3 W (15 V, 0.2 A)

Off-line Buck Converter

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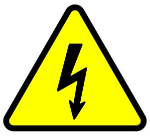
Precautions for High Voltage



Dangerously high voltages exist inside the demonstration board.
Mishandling the demonstration board may cause the death or serious injury of a person.
Before using the demonstration board, read the following cautions carefully, and then use the demonstration board correctly.

DO NOT touch the demonstration board being energized.

Dangerously high voltages that can cause death or serious injury exist inside the demonstration board being energized.

Electrical shock may be caused even by accidental short-time contact or by putting hands close to the demonstration board.

Electrical shock can result in death or serious injury.
Before touching the demonstration board, make sure that the capacitors have been discharged.

For safety purpose, an operator familiar with electrical knowledge must handle the demonstration board.

The demonstration board is for evaluation of all the features of the STR5A464S.
The demonstration board shall not be included or used in your mass-produced products.
Before using the demonstration board, see this document and refer to the STR5A464S data sheet.
Be sure to use the demonstration board within the ranges of the ratings for input voltage, frequency, output voltage, and output current.
Be sure to strictly maintain the specified ambient environmental conditions, such as ambient temperature and humidity.

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1. Introduction

This document describes the design example of a power supply using the STR5A464S intended for the non-isolated buck converter that supports universal inputs and a 15 V/0.2 A output. The STR5A464S is a current mode PWM control IC with a built-in power MOSFET, developed for configuring non-isolated buck converters. In addition, the design example uses the EM1C as a half-wave rectifier diode for input, the SJPD-D5 as fast recovery diodes for the freewheeling and feedback diodes, the SJPB-D9 as a Schottky diode for the IC's power supply.

This document contains the following: the specifications of the design example, circuit diagrams, the bill of materials, the setting examples of component constants, a pattern layout example, and the evaluation results of the power supply characteristics. For more details on the parts listed in this document, refer to the corresponding data sheets.

2. Power Supply Features

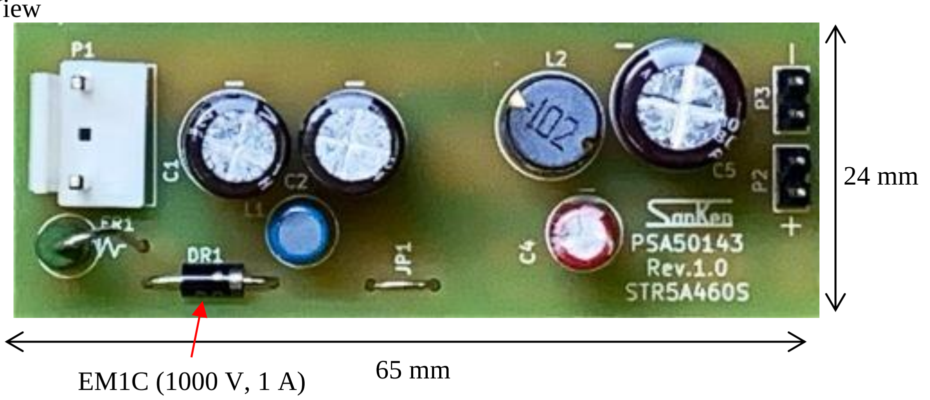
- Reduced Number of External Components (Built-in Startup Circuit and Current-sensing Resistor)
- High Efficiency in All Load Ranges Achieved by Load-based Auto-shifting Operation Modes
  - Normal Operation: PWM Mode, 60 kHz (Typ.)
  - Light-load Operation: Green Mode
  - Standby Operation: Burst Oscillation Mode
- Supplied in a Surface-mount SIOC Package
- Efficiency: 82.3% (230 VAC, 3 W)
- Input Power at No Load: 56.6 mW (230 VAC)
- Reduced EMI Noise (Random Switching Function)

3. Applications

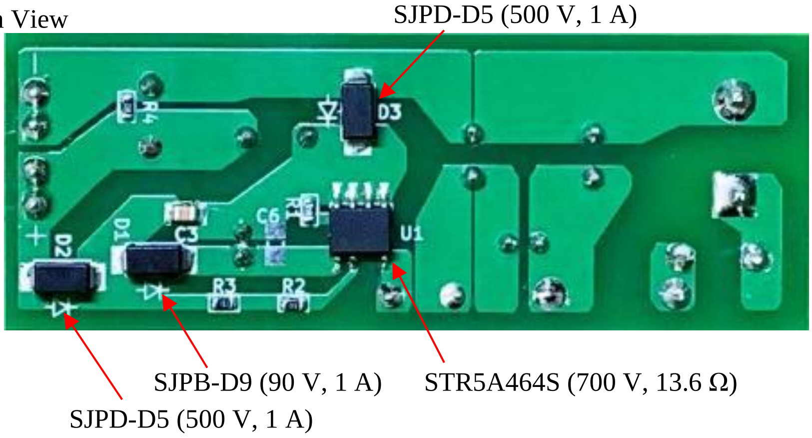
- Small Home Appliance
- Large Home Appliance
- Auxiliary Power Supply
- Power Supply for Motor Control
- Other SMPSs (Switching Mode Power Supplies)

4. Design Example: Appearance

Top View



Bottom View



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5. Design Example

5.1 Power Supply Specifications

Parameter	Symbol	Conditions	Min	Typ.	Max.	Unit
Input						
Input Voltage	V_{INAC}		85	—	265	V
Frequency	f_{LINE}		47	50/60	63	Hz
Output						
Rated Voltage	V_{NP}		13.5	15	16.5	V
Rated Current	I_{NP}		—	0.2	—	A
Output Ripple Voltage	V_{RIPPLE}	20 MHz bandwidth; filter added[(1)]	—	44	—	mV_{P_P}
Output Power	P_{OUT}		—	3.0	—	W
Efficiency	η	Rated load, T_A = 25 °C, 230 VAC	—	82.3	—	%
Environment						
Conduction Noise	—	T_A = 25 °C	As per CISPR22B/EN55022B			—
Temperature						
Power Supply IC Temperature Increase[(2)]	$\Delta T_{C\text{-}IC}$	265 VAC, I_O = 0.2 A	—	26.7	—	°C
Freewheeling Diode Temperature Increase[(3)]	$\Delta T_{C\text{-}DI}$	265 VAC, I_O = 0.2 A	—	23.1	—	°C
Inductor Temperature Increase	ΔT_L	265 VAC, I_O = 0.2 A	—	25.3	—	°C

(1) By connecting an electrolytic capacitor (50 V, 1 µF) and a ceramic capacitor (50 V, 0.1 µF) in parallel to the output connector of the PCB.

(2) Refers to a case temperature of the STR5A464S.

(3) Refers to a case temperature of the SJPD-D5.

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5.2 Circuit Diagram

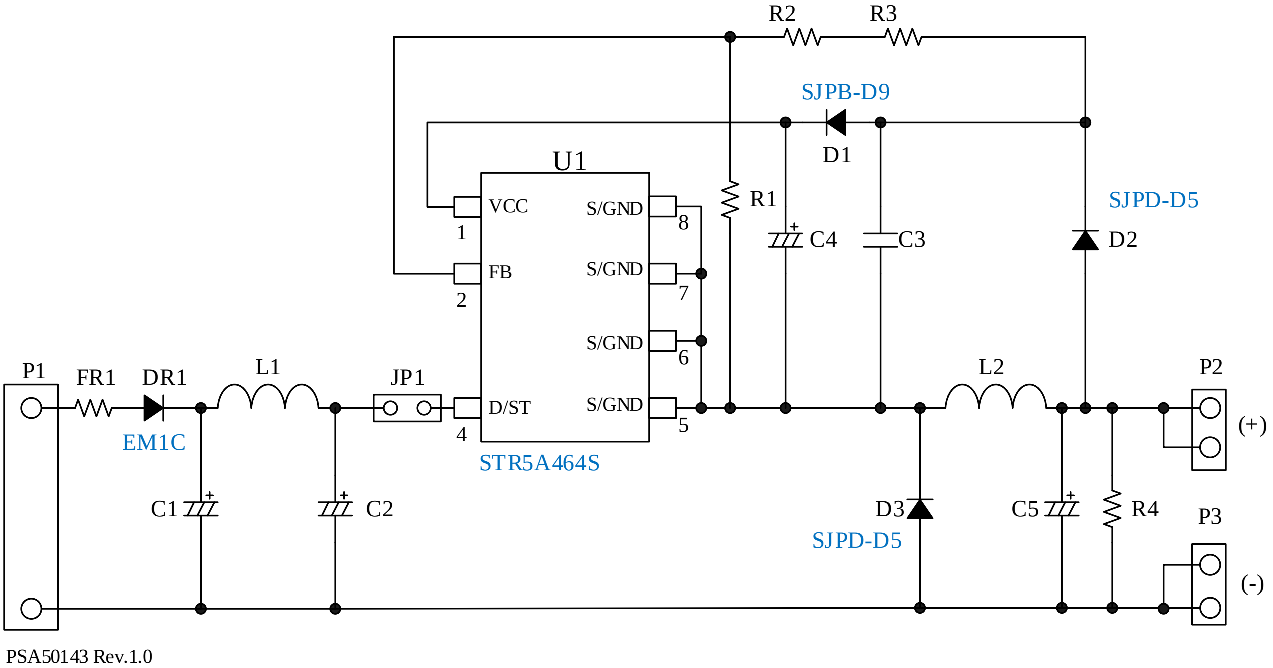

Figure 5-1. Circuit Diagram

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5.3 Bill of Materials

Part Symbol	Part Type	Ratings	Part Number*	Manufacturer
C1	Electrolytic capacitor	105 °C, 400 V, 8.2 µF	UVC2G8R2MPD	Nichicon
C2	Electrolytic capacitor	105 °C, 400 V, 8.2 µF	UVC2G8R2MPD	Nichicon
C3	Ceramic capacitor	50 V, 0.22 µF, 2012	885012207100	Wurth Electronics
C4	Electrolytic capacitor	105 °C, 50 V, 10 µF	860020672010 EKY-500E100ME11D	Wurth Electronics Nippon Chemi-Con
C5	Electrolytic capacitor	105 °C, 25 V, 470 µF	UPS1E471MPD 25ZL470MEFC10x16	Nichicon Rubycon
DR1	General-purpose rectifier diode	1000 V, 1 A	EM1C	Sanken
D1	Schottky diode	90 V, 1 A	SJPB-D9	Sanken
D2	Fast recovery diode	500 V, 1 A	SJPD-D5	Sanken
D3	Fast recovery diode	500 V, 1 A	SJPD-D5	Sanken
L1	Inductor	1 mH, 0.21 A	SBC1-102-211	TOKIN
L2	Inductor	1 mH, 0.5 A	768772102 RLB9012-102KL	Wurth Electronics BOURNS
FR1	Resistor	2 W, 10 Ω	RWF2B100J	Akahane Electronics
R1	Chip resistor	6.8 kΩ, 1/8 W, 1608	CR16TR682F	Akahane Electronics
R2	Chip resistor	33 kΩ, 1/8 W, 1608	CR16TR333F	Akahane Electronics
R3	Chip resistor	1.8 kΩ, 1/8 W, 1608	CR16TR182F	Akahane Electronics
R4	Chip resistor	6.8 kΩ, 1/8 W, 1608	CR16TR682J	Akahane Electronics
U1	PWM off-line converter IC	700 V, 13.6 Ω	STR5A464S	Sanken
JP1	Jumper wire	Plated wire	φ = 0.6, P = 5 mm	
P1	Connector	250 V	B2P3-VH	JST
P2	Connector	50 V	61300211121	Wurth Electronics
P3	Connector	50 V	61300211121	Wurth Electronics
—	PCB		PSA50143 Rev.1.0	Sanken

* When multiple parts are listed, any one of them is used.

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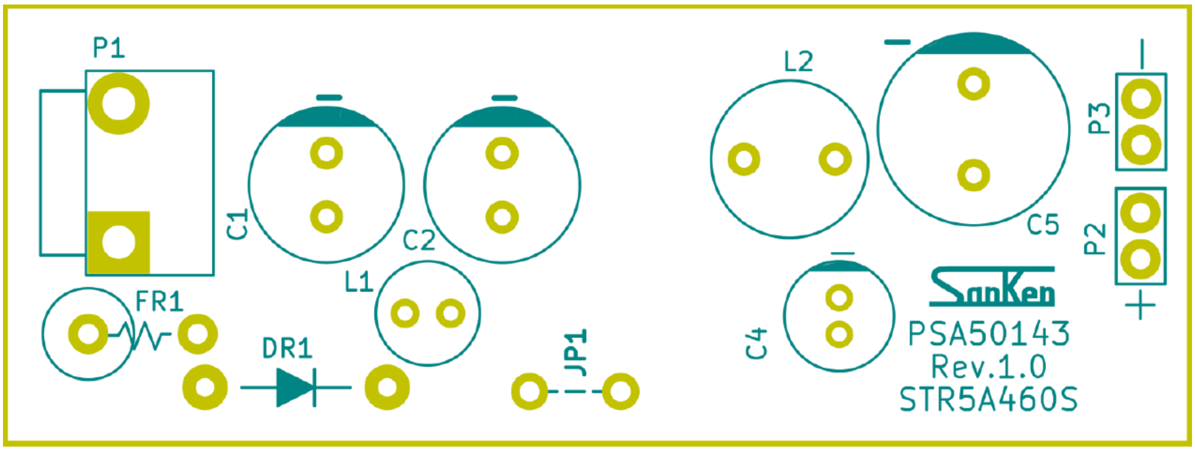
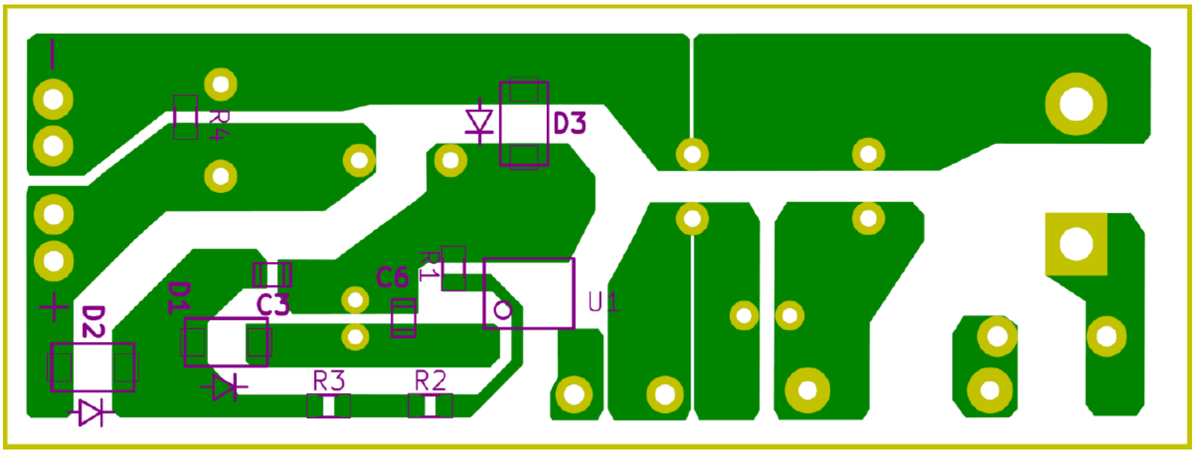
5.4 Pattern Layout Example

The design example uses only the parts listed in the circuit diagram and the bill of materials.
PCB dimensions: 65 mm × 24 mm



(a) Top View



(b) Bottom View

Figure 5-2. Pattern Layout Example

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6. Design Example: Basic Operations

The connector P1 is connected to an AC power supply. When an AC voltage is applied, the AC input voltage is rectified via the input filter and the rectifier diode DR1. The rectified voltage is then smoothed to a DC voltage by the electrolytic capacitors C1 and C2.

L1, C1, and C2 configure the π filter that removes normal-mode noise.

When a voltage is applied to the D/ST pin of the power supply IC (U1: STR5A464S), the internal startup circuit turns on. Consequently, a startup current flowing out of the VCC pin charges the electrolytic capacitor C4. When the VCC pin voltage increases to the IC operation start voltage, the IC control circuit starts to operate. Then, the internal power MOSFET starts its PMW switching operation. After the IC operation starts, the startup circuit turns off and the VCC pin power is then supplied from the output. The output voltage is smoothed by C3 via the fast recovery diode D2 and charges C4. This is how the VCC pin voltage maintains.

During a power MOSFET turn-on period, L2 stores energy with the I_{ON} current path (Figure 6-1) and charges the output electrolytic capacitor C5. In this design example, a low-ESR capacitor should be used for C5.

During a power MOSFET turn-off period, the energy stored in L2 generates back EMF, and the freewheeling diode D3 is then forward-biased and turned on. This allows currents to flow through the I_{OFF} current path (Figure 6-1). In the manner explained above, the internal power MOSFET repeats turning on and off to increase the output voltage to its target voltage level. A signal produced by the output voltage divided by the resistors R1 to R3 is input to the FB pin. With this signal, the power supply IC controls the duty cycle of the internal MOSFET to regulate output voltages to be constant. The bleeder resistor R5 is connected to both the ends of C5 for suppressing an increase in the output voltage at light load.

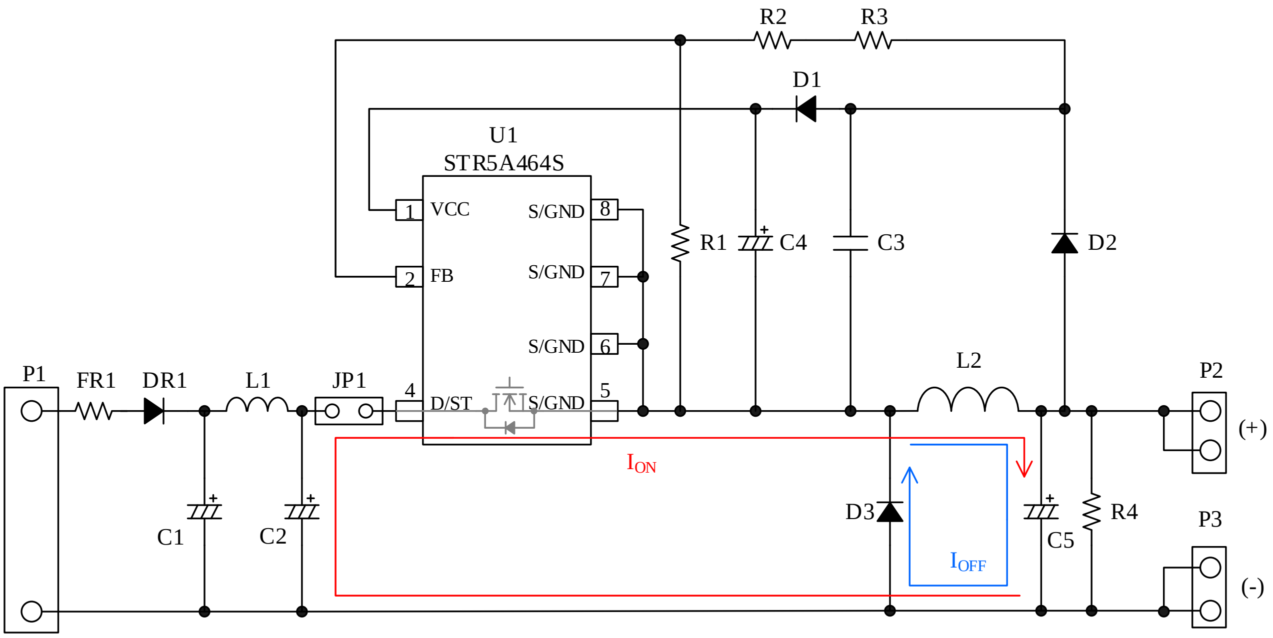

Figure 6-1. Circuit Diagram

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7. Designing the Power Supply

7.1 Setting an Output Voltage

The equation below defines the relation between the output voltage, V_{OUT}, and the resistors R1 to R3:

$$R2 + R3 = \left(\frac{|V_{OUT}| - V_{FD2} + V_{FD3}}{V_{FB(REF)}} - 1\right) \times R1\,. \qquad (7\text{-}1)$$

Where:
V_{FD2} is the forward voltage of D2,
V_{FD3} is the forward voltage of D3, and
$V_{FB(REF)}$ is the reference voltage of the FB pin.

Based on Equation (7-1), when V_{OUT} = 15 V, V_{FD2} = 0.5 V, V_{FD3} = 0.8 V, $V_{FB(REF)}$ = 2.5 V, example setting values for the resistors R1 to R3 are as follows:
R1 = 6.8 kΩ
R2 = 33 kΩ
R3 = 1.8 kΩ

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7.2 Setting an Inductance

7.2.1 PWM Switching Modes

As Figure 7-1 shows, the PWM control has three operation modes: the continuous conduction mode (CCM), the critical conduction mode (CRM), and the discontinuous conduction mode (DCM).

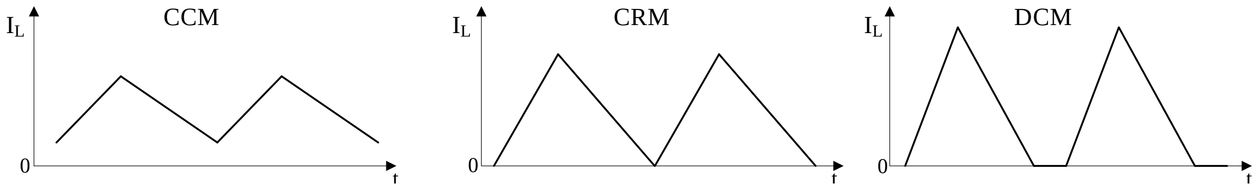

Figure 7-1. PWM Switching Modes

The CCM is a mode that reduces conduction losses in a power MOSFET but has a tendency to be noise-prone and switching-loss increasing because the power MOSFET turns on while a current flows through an inductor. In the CRM and DCM operations, the power MOSFET turns on even when an inductor current is zero, thus resulting in lower noise and switching losses.

The STR5A464S used in the design example has the drain current limit, I_{DLIM}, internally fixed by the IC. As a result, the output current and operation mode while the drain current is limited vary according to the inductance you use, as Figure 7-2 depicts.

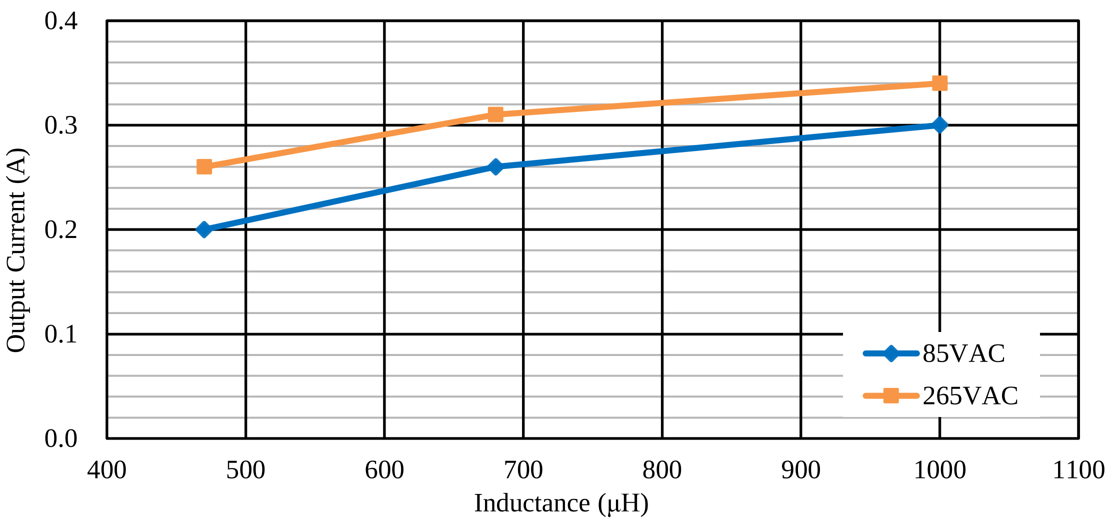

Figure 7-2. Output Current during Drain Current Limitation vs. Inductance (Reference)

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7.2.2 Parameter Definitions

When you set the output voltage, V_{OUT}, to ≥25.7 V, the STR5A464S requires the Zener diode DZ1 to be connected in series with D1, as in Figure 7-3. Be sure to perform operation checking so that the VCC pin voltage will not decrease to the startup current bias threshold voltage.

Assuming that a duty cycle settable during normal operation is up to 45%, V_{OUT} should be determined so that it can satisfy Equation (7-2), below. The design example can step down V_{OUT} to ≤45% of the the input voltage.

$$V_{CC(OFF)}(\mathrm{max.}) < V_{OUT} - (V_{DZ1} + V_{DF1} + V_{DF2}) + V_{DF3} < V_{CC(OVP)}(\mathrm{min.})\ . \qquad (7\text{-}2)$$

Where:

$V_{CC(OVP)}$ is the minimum OVP threshold voltage (27.5 V), and

V_{DZ1} is the Zener diode of DZ1.

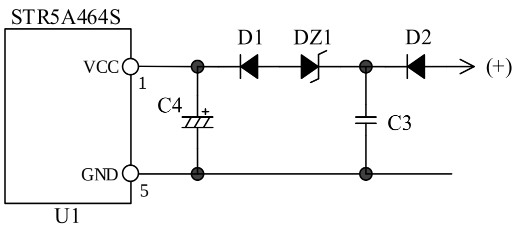

Figure 7-3. Circuit Configuration with Increased Output Voltage, V_{OUT}

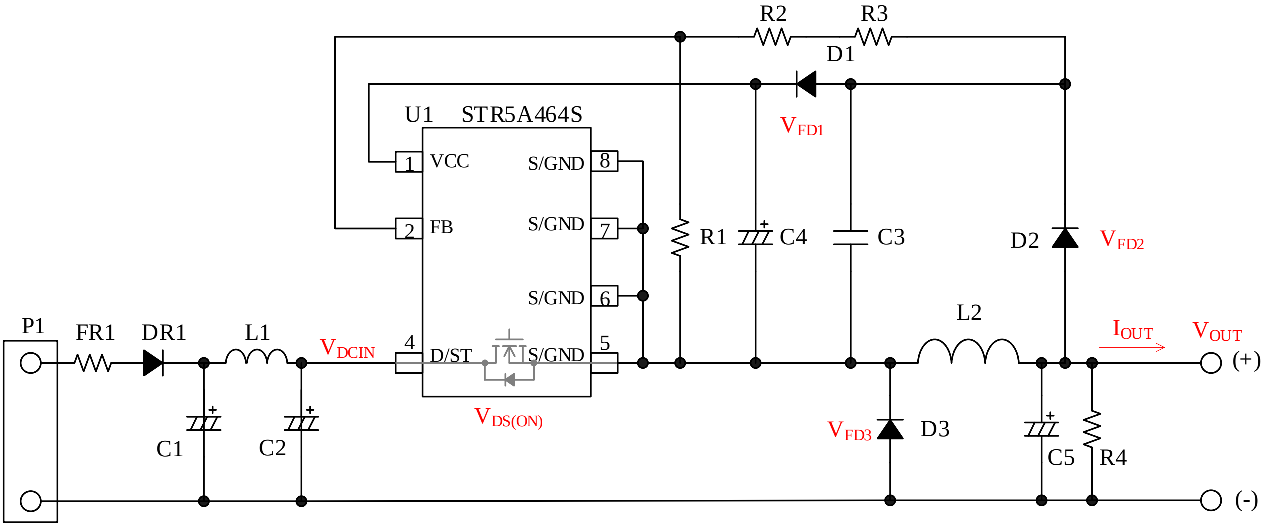

Figure 7-4. Circuit Diagram

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Table 7-1 explains the definitions for the symbols used as circuit parameters in Figure 7-4.

Table 7-1. Circuit Parameters

Symbol	Description
V_{DCIN_MIN}	C2 DC input voltage lower limit
V_{DCIN_MAX}	C2 DC input voltage upper limit
V_{OUT}	Output voltage
I_{OUT}	Output current
V_{RON}	Internal power MOSFET on-voltage: V_{RON} = drain current × $R_{DS(ON)}$
V_{FD3}	D3 forward voltage
V_{FD2}	D2 forward voltage
V_{FD1}	D1 forward voltage
V_{DZ1}	DZ1 Zener voltage (when $V_{OUT} \geq 27.5$ V, add a Zener diode or regulator; pay attention to losses)

Table 7-2 lists the characteristic parameters dependent on the power supply IC. For the values specified for the power supply IC, refer to the data sheet.

Table 7-2. Characteristic Parameters

Symbol	Description	Value Specified for STR5A464S
D_{ON_MAX}	Maximum settable duty cycle in normal operation	0.45
V_{ST_MAX}	Maximum startup circuit operating voltage, $V_{ST(ON)}$	39 V
$V_{DC(MAX)}$	Maximum DC input voltage	400 V (Recommended)
$V_{CC(OVP)\_MIN}$	Minimum OVP threshold voltage, $V_{CC(OVP)}$	27.5 V
I_{DLIM}	Minimum drain current limit, I_{DLIM}	0.37 A
f_{TYP}	Average oscillation frequency, $f_{OSC(AVG)}$	60 kHz

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Figure 7-5 shows the inductor current waveforms in the critical conduction mode (CRM) and the discontinuous conduction mode (DCM), respectively. Table 7-3 lists the definitions for the symbols used in Figure 7-5.

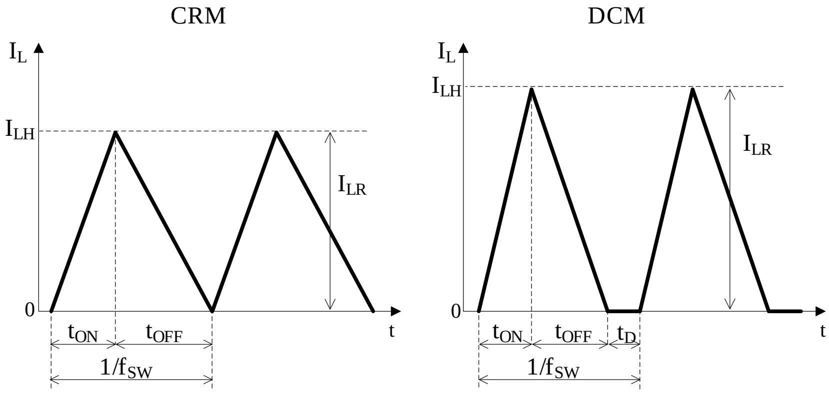

Figure 7-5. Operation Modes for PWM Control

Table 7-3. Inductor Current Waveform Parameters

Symbol	Description
f_{SW}	Switching frequency
t_{ON}	On-time
t_{OFF}	Off-time
t_D	Discontinuous time
I_{LH}	Inductor current upper limit
I_{LR}	Inductor ripple current

Table 7-4 provides the input/output conditions defined for the buck converter.

Table 7-4. Buck Converter Input/Output Conditions

Parameter	Conditions	
	Min.	Max.
V_{DCIN}	Will be the higher of the below: $\geq V_{ST\_MAX}$ $> 2.2 \times V_{OUT} + 1.2 \times V_{FD3} + V_{RON}$	$\leq V_{DC(MAX)}$
V_{OUT}	$> V_{CC\_MIN} + V_{DZ1} - V_{FD3} + V_{FD1} + V_{FD2}$	$< 0.45 \times (V_{DCIN\_MIN} - V_{RON}) - 0.55 \times V_{FD3}$
I_{OUT}	—	$< 0.5 \times I_{DLIM}$ (Depends on heat generated by the IC's on-resistance)
V_{DZ1}	Will be the higher of the below: ≥ 0 $> V_{OUT} + V_{FD3} - (V_{FD1} + V_{FD2} + V_{CC(OVP)\_MIN})$	$< V_{OUT} + V_{FD3} - (V_{FD1} + V_{FD2} + V_{CC(OFF)MAX})$

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7.2.3 Calculating an Inductance

The STR5A464S is developed to be used in a condition up to $I_{OUT} \approx 0.2$ A when $V_{OUT} = 15$ V. When an inductance is too low, a peak current during the drain current limitation becomes higher due to an internal propagation delay of the IC. The higher the peak current, the larger the core size is required, thus causing an increase in inductor's external dimensions. To avoid increasing the inductor's external dimensions more than needs, set an inductance to about 1 mH for the buck converter with outputs up to about 15 V/0.2 A.

Firstly, calculate an output current when L = 1 mH in the critical conduction mode (CRM). Then, select the operation mode appropriate for the rated current to be set. After that, calculate an inductor current in the operation mode, and verify that the inductance you set causes no problems.

The duty cycle, D_{ON}, in the CRM operation should be set within the range defined as:

$$D_{ON} = \frac{V_{OUT} + V_{FD3}}{V_{DCIN\_MIN} - V_{RON} + V_{FD3}} < 0.45 \,. \tag{7-3}$$

The parameters for the inductor current in the CRM operation can be obtained as follows (see Figure 7-5, the operational waveforms in CRM):

$I_{LH} = 2 \times I_{OUT}$, and

$I_{LR} = I_{LH}$.

The equation below defines I_{LH}:

$$I_{LH} = \frac{(V_{DCIN\_MIN} - V_{OUT} - V_{RON}) \times D_{CCM}}{f_{TYP} \times L} \,. \tag{7-4}$$

Then, the output current, I_{OUT_CRM}, in the CRM operation can be determined as:

$$I_{OUT\_CRM} = 0.5 \times I_{LH} \,. \tag{7-5}$$

Based on the relationship between the rated current value to be set, I_{OUT_USR}, and I_{OUT_CRM}, the operation mode should be:

- The continuous conduction mode (CCM) when $I_{OUT\_USER} > I_{OUT\_CRM}$
- The critical conduction mode (CRM) when $I_{OUT\_USER} \leq I_{OUT\_CRM}$

Using Equation (7-4), we found $I_{LH} \approx 0.23$ A for the design example when $V_{DCIN\_MIN} = 120$ V, $V_{OUT} = 15$ V, $I_{LH} = 0.37$ A, $V_{RON} = 13.6\ \Omega \times 0.37\ A \approx 5.0$ V, $V_{DF3} = 0.85$ V, $D_{ON} = 0.137$, $f_{TYP} = 60$ kHz, and L = 1 mH.

We finally obtained $I_{OUT\_CRM} \approx 0.105$ A from Equation (7-5); hence, the design example (15 V, 0.2 A) should be set to operate in the CCM.

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According to the operation mode confirmed by the procedures above, verify I_{LH} when L = 1 mH.

- **For the CCM operation**

When $I_{OUT\_USER} > I_{OUT\_CRM}$, the design example should operate in the CCM (Figure 7-6).
The duty cycle, D_{ON}, in the CCM operation should be set within the range defined as:

$$D_{ON} = \frac{V_{OUT} + V_{FD3}}{V_{DCIN\_MIN} - V_{RON} + V_{FD3}} < 0.45 . \quad (7\text{-}6)$$

The parameters for the inductor current in the CCM operation can be obtained as follows:

$$I_{LR} = \frac{(V_{DCIN\_MIN} - V_{OUT} - V_{RON}) \times D_{ON}}{f_{TYP} \times L} . \quad (7\text{-}7)$$

$$I_{LH} = I_{OUT} + 0.5 \times I_{LR} . \quad (7\text{-}8)$$

At this point, make certain that I_{LH} has a sufficient margin to I_{DLIM_MIN} when L = 1 mH.

Although we set L = 1 mH for the design example, you can increase the output current value by increasing the inductance to be set. Note that, however, increasing the inductance will raise concerns such as increases in an effective current value and in losses by on-resistance. When the output current becomes >0.2 A (V_{OUT} = 15 V) or I_{LH} can not ensure a margin to I_{DLIM_MIN}, please consider using the STR5A450 series.

- **For the DCM operation**

When $I_{OUT\_USER} \leq I_{OUT\_CRM}$, the design example should operate in the DCM (Figure 7-7).
The equation below defines I_{LH} when L = 1 mH:

$$I_{LH} = \sqrt{\frac{2 \times I_{OUT} \times (V_{DCIN\_MIN} - V_{OUT} - V_{RON}) \times (V_{OUT} + V_{FD3})}{f_{TYP} \times L \times (V_{DCIN\_MIN} - V_{OUT} - V_{RON})}} . \quad (7\text{-}9)$$

The power MOSFET on-time, t_{ON}, can be obtained as follows:

$$t_{ON} = \frac{L \times I_{LH}}{(V_{DCIN\_MIN} - V_{OUT} - V_{RON})} . \quad (7\text{-}10)$$

The duty cycle, D_{ON}, in the DCM operation should be set within the range defined as:

$$D_{ON} = \frac{V_{OUT} + V_{FD3}}{V_{DCIN\_MIN} - V_{RON} + V_{FD3}} < 0.45 . \quad (7\text{-}11)$$

Even when I_{LH} is low in normal operation, I_{LH} increases to I_{DLIM} at power-on or during the overcurrent protection (OCP) operation. Therefore, be sure to verify I_{LH} through checking actual operations.

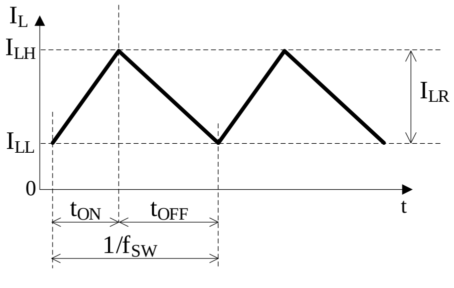

Figure 7-6. CCM Operation

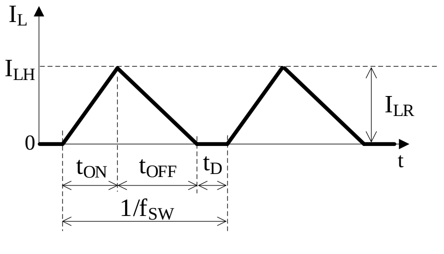

Figure 7-7. DCM Operation

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7.3 Selecting the Rectifier Diode DR1

For the rectifier diode DR1, select the one that has voltage and current ratings with sufficient margin to the upper limits of AC input voltage and current.

When the upper limit of an input voltage is 265 VAC, the voltage to be applied to DR1 is as follows: $V_P = 265\ (VAC) \times \sqrt{2} \times 2 \approx 750\ (VDC)$. When a derating of ≥80% is applied to the DR1 breakdown voltage, DR1 requires a breakdown voltage of ≥1000 V. The equation below defines the input current, I_{IN}:

$$I_{IN} = \frac{P_{OUT}}{V_{INAC(MIN)} \times \eta \times PF}. \qquad (7\text{-}12)$$

Where:

P_{OUT} is the output power,
$V_{INAC(MIN)}$ is the lower limit of the AC input voltage,
η is the efficiency, and
PF is the power factor.

From Equation (7-12), when P_{OUT} = 3 W, $V_{INAC(MIN)}$ = 85 VAC, η = 0.8, PF = 0.6, hence $I_{IN} \approx 74$ mA. When a derating of ≥80% is applied to the DR1 rated current, DR1 requires a rated current of ≥92 mA.

For the design example, we selected the general-purpose rectifier diode with a breakdown voltage of 1000 V and a rated current of 1 A, from the ones available in the market.

7.4 Selecting the VCC Power Supply Diode D1, Feedback Diode D2, and Freewheeling Diode D3

For D1, use a Schottky diode (SBD) for minimizing the effect of the forward voltage, VF, to output voltages. Moreover, select the breakdown voltage of D1 with setting a derating of ≥80% to the maximum OVP threshold voltage, $V_{CC(OVP)}$ = 31.3 V.

For D2 and D3, select a fast recovery diode (FRD) with a short recovery time because switching currents flow through them. Any of the diodes should have voltage and current ratings with sufficient margin to the upper limits of AC input voltage and current, and to peak currents that flow through the diodes. When the upper limit of an input voltage is 265 VAC, the voltage to be applied to the diodes is as follows: $V_P = 265\ (VAC) \times \sqrt{2} \approx 375\ (VDC)$. Note that a surge voltage during switching operation is also an important parameter to take into account. When a derating of ≥80% is applied to the breakdown voltages of the diodes, each diode requires a breakdown voltage of ≥500 V. The diodes should have sufficient margins as follows: D1 to the circuit current during power supply IC operation; D2 to the circuit and feedback currents during power supply IC operation; D3 to the current value that provides enough peak current, I_{LP}, flowing through the inductor L2.

For the design example, the L2 ripple current was approximately 0.23 A based on the operational waveforms in actual normal operation (Figure 9-15 to Figure 9-16). Given that a circuit current of up to 2 mA and a feedback current of up to 2.4 µA will run through while the STR5A464S operates, we selected the diodes with the following ratings from the ones available in the market:

- VCC power supply diode D1: SBD, 90 V, 1 A (SJPB-D9)
- Feedback diode D2: FRD, 500 V, 1 A (SJPD-D5)
- Freewheeling diode D3: FRD, 500 V, 1 A (SJPD-D5)

7.5 Selecting the Bleeder Resistor R4

For suppressing an increase in the output voltage at light load, the bleeder resistor R4 is connected to both the ends of C5. Select a resistance of R4 so that regulation characteristics can fall within a target range of ±10% to an output voltage of 15.0 V while checking actual operations. Note that the higher the regulation characteristics improve, the more the reactive power increases; therefore, be sure to select a well-balanced resistance value. For the design example, we selected the resistor of 6.8 kΩ.

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8. Performance Data

All the performance data contained in this document were measured at a room temperature, an AC line frequency of 50 Hz, and a load of 3 W (15 V, 0.2 A).

8.1 Efficiency

Figure 8-1 shows the characteristics of power supply efficiency vs. input voltage; Figure 8-2 shows the characteristics of power supply efficiency vs. output power.

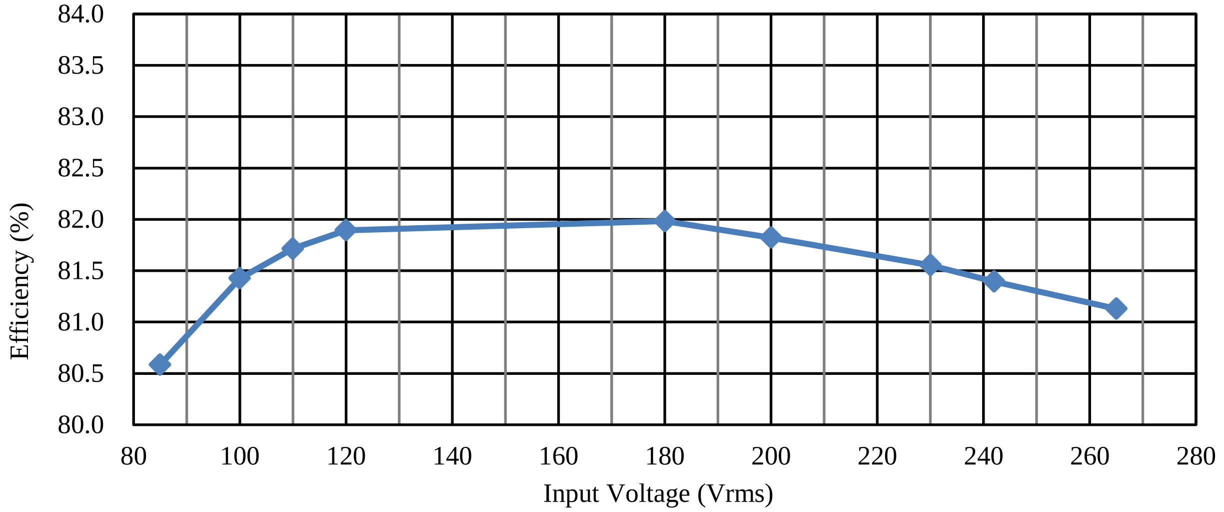

Figure 8-1. Efficiency vs. Input Voltage

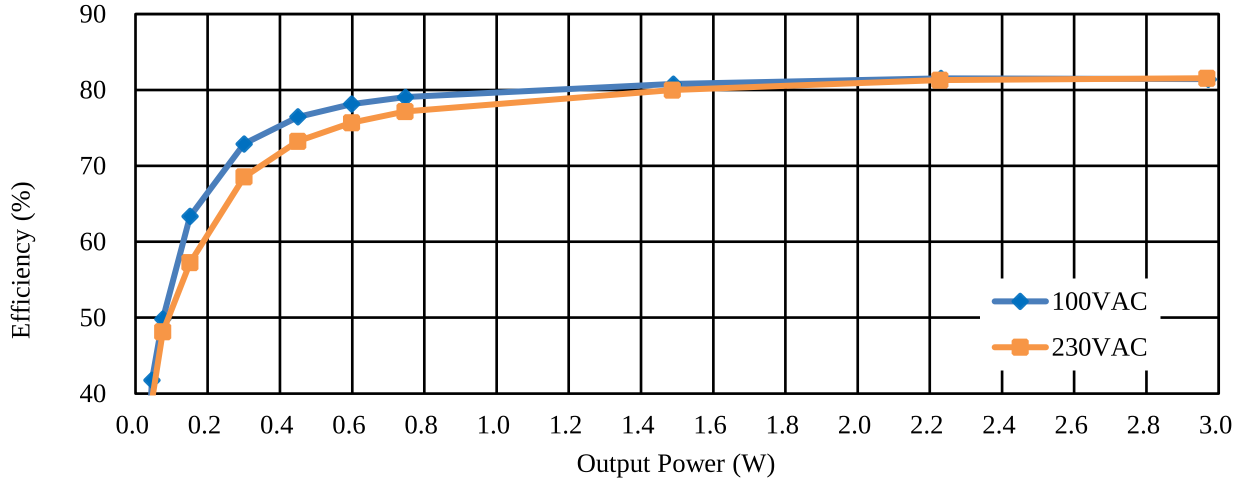

Figure 8-2. Efficiency vs. Output Power

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8.2 Standby Power

Table 8-1. Input Power at No Load

Input Voltage	Input Power
100 VAC	51.8 mW
230 VAC	56.6 mW

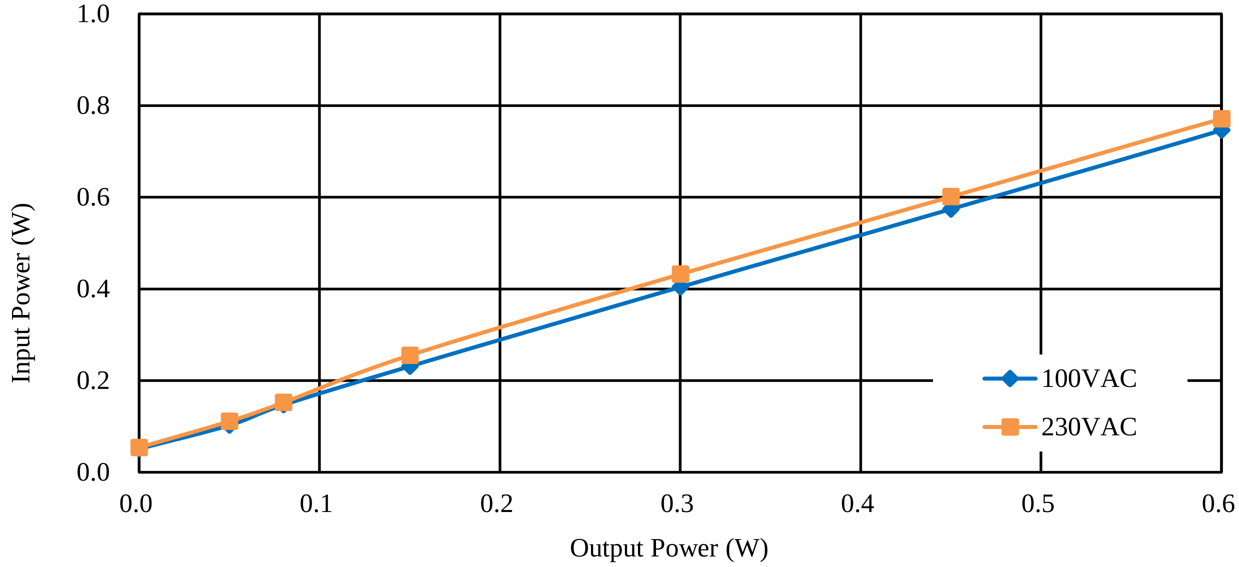

Figure 8-3. Input Power vs. Output Power

8.3 Line Regulation

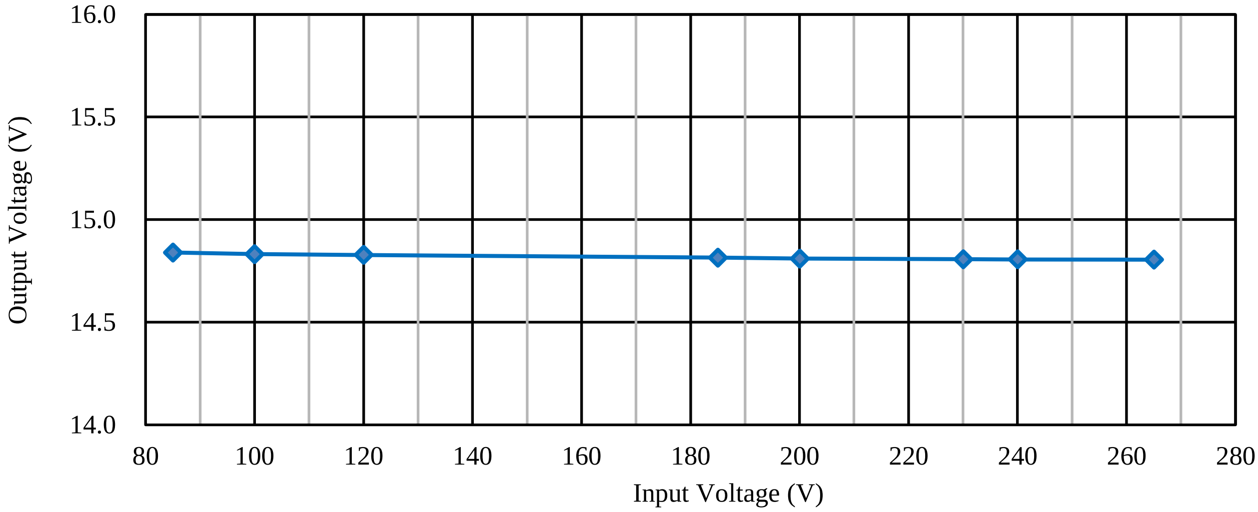

Figure 8-4. Output Voltage vs. Input Voltage

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8.4 Load Regulation

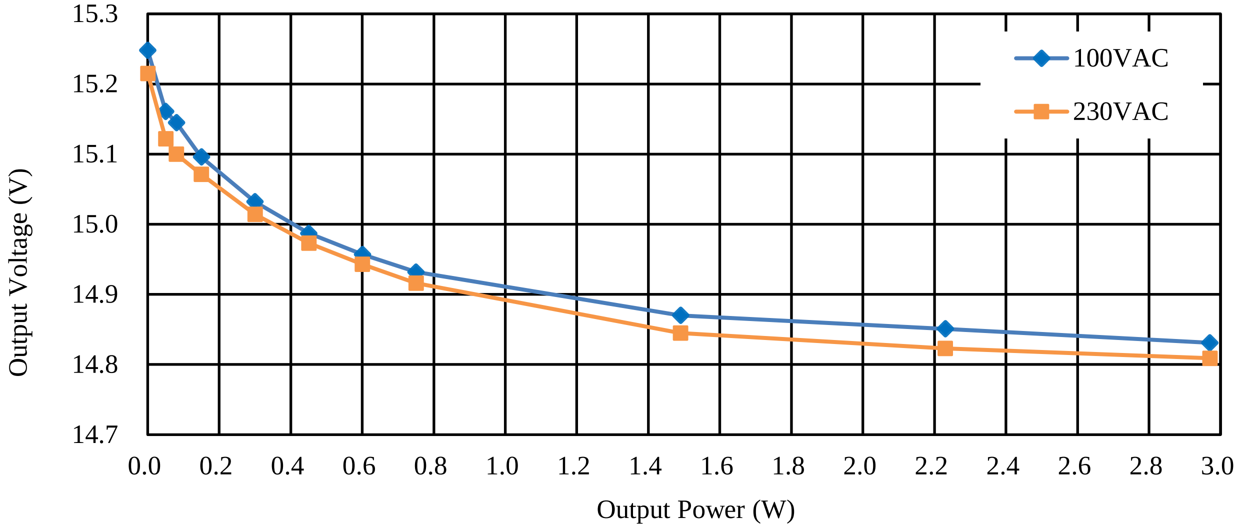

Figure 8-5. Output Voltage vs. Output Power

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9. Operation Check

All the performance data contained in this document were measured at a room temperature and an AC line frequency of 50 Hz.

The maximum continuous load is 3 W (15 V, 0.2 A).

For more details on the power supply IC (STR5A464S) such as electrical characteristics and operational descriptions, refer to the data sheet.

9.1 Startup Operation

9.1.1 Power Supply IC Switching Operation

When the soft start function is activated at power-on, the D/ST pin current, $I_{D/ST}$, of the power supply IC slowly increases. When $I_{D/ST}$ reaches the power supply IC drain current limit, I_{DLIM} = 0.41 A (typ.), the overcurrent protection (OCP) is activated to limit the output power.

Figure 9-1 shows the waveform of the D/ST pin voltage, $V_{D/ST}$. The pulsating part of the $V_{D/ST}$ waveform indicates a full-wave rectified input ripple component. The D/ST pin current, $I_{D/ST}$, is and remains limited by the OCP during the period until the output voltage becomes constant. When the output voltage becomes constant after the limitation, $I_{D/ST}$ decreases.

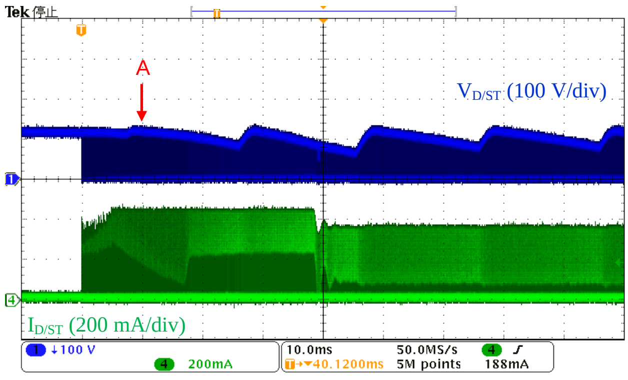

Figure 9-1. Operational Waveforms at Startup
(V_{IN} = 85 VAC, I_O = 0.2 A)

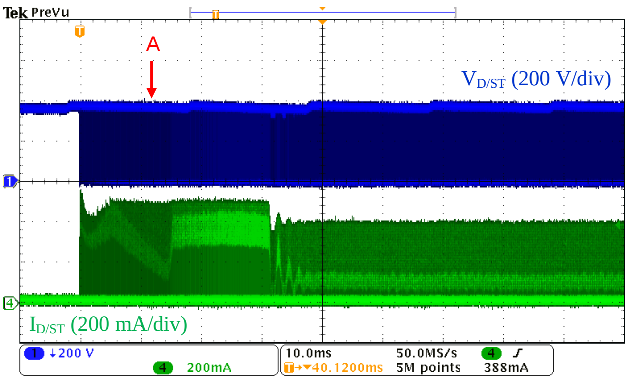

Figure 9-2. Operational Waveforms at Startup
(V_{IN} = 265 VAC, I_O = 0.2 A)

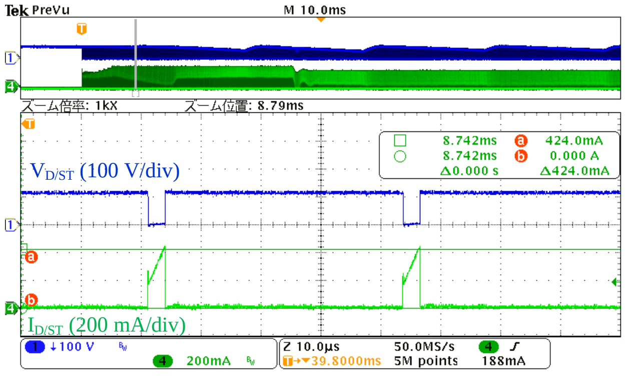

Figure 9-3. Operational Waveforms at Startup
(Expanded Scale of A in Figure 9-1)

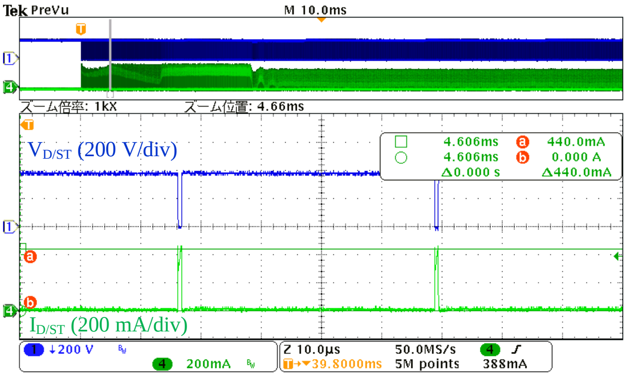

Figure 9-4. Operational Waveforms at Startup
(Expanded Scale of A in Figure 9-2)

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9.1.2 Output Voltage

When the soft start function is activated at power-on, the output voltage, V_{OUT}, gradually decreases. After V_{OUT} reaches its target voltage, V_{OUT} has no overshoot and shifts to the normal operation state within the power supply specifications.

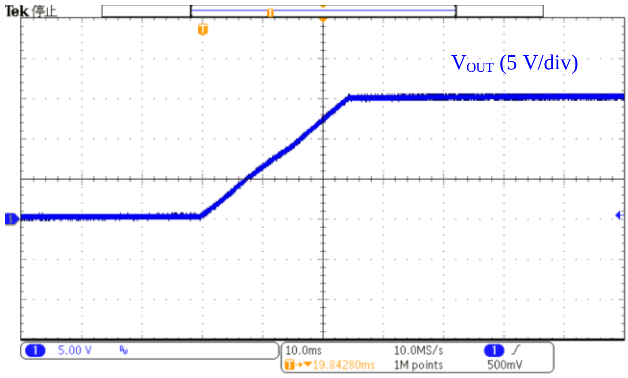

Figure 9-5. Output Voltage Waveform at Startup (V_{IN} = 85 VAC, I_O = 0 A)

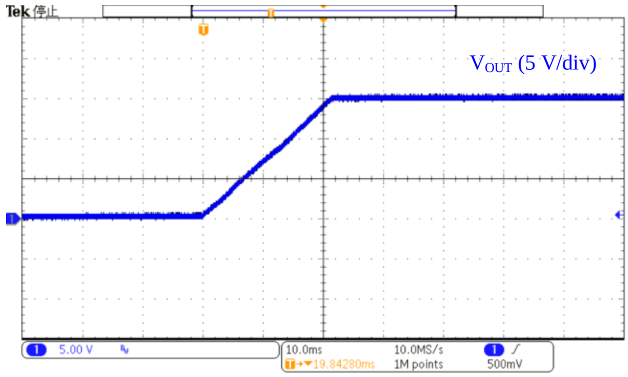

Figure 9-6. Output Voltage Waveform at Startup (V_{IN} = 265 VAC, I_O = 0 A)

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9.2 Power Supply IC Switching Operation

The STR5A464S automatically shifts its operation modes according to loads and enhances efficiency in all load ranges. Therefore, the power supply IC monitors not only its normal operation but also the operations in all load ranges.

9.2.1 Normal Operation

Figure 9-7 to Figure 9-10 provide the waveforms in normal operation. These waveforms show that the frequency is about 45 kHz when V_{IN} = 85 VAC and is about 40 kHz when V_{IN} = 265 VAC, revealing that the values are within the frequencies in the green mode. Each drain peak current setting has a margin to its overcurrent operating point.

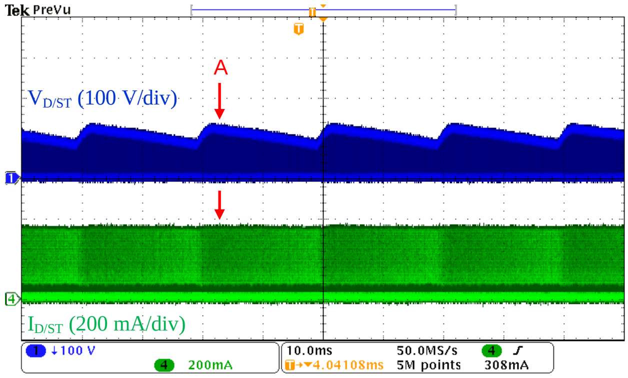

Figure 9-7. Operational Waveforms in Normal Operation (V_{IN} = 85 VAC, I_O = 0.2 A)

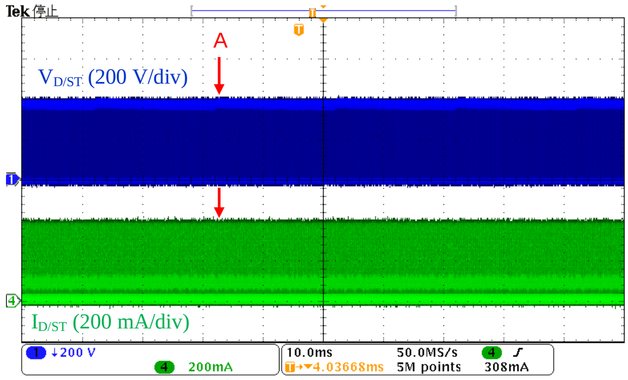

Figure 9-8. Operational Waveforms in Normal Operation (V_{IN} = 265 VAC, I_O = 0.2 A)

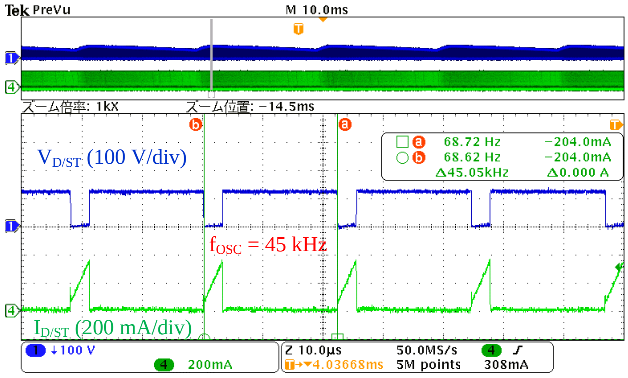

Figure 9-9. Operational Waveforms in Normal Operation (Expanded Scale of A in Figure 9-7)

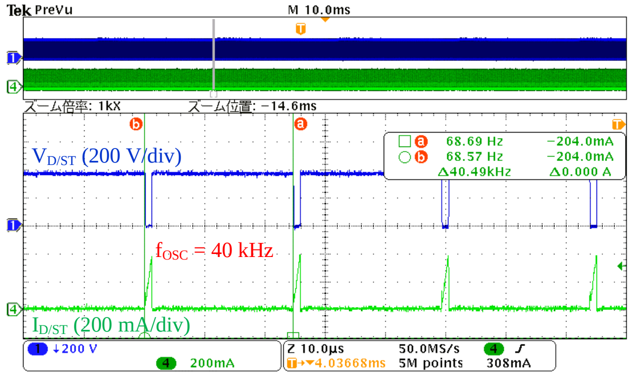

Figure 9-10. Operational Waveforms in Normal Operation (Expanded Scale of A in Figure 9-8)

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9.2.2 Light-load Operation (Green Mode)

In light-load operation, the power supply IC enters the green mode and reduces its oscillation frequency according to loads.

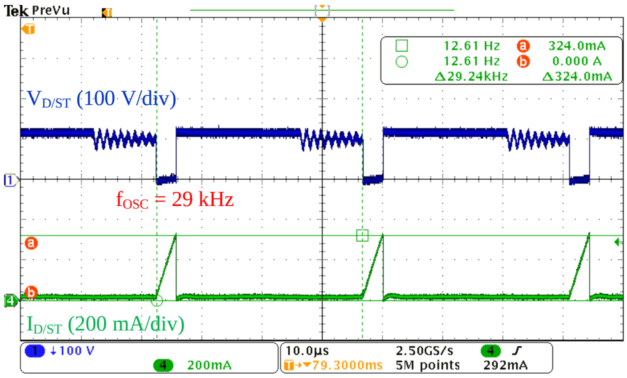

Figure 9-11. Operational Waveforms at Light Load (V_{IN} = 85 VAC, I_O = 0.1 A)

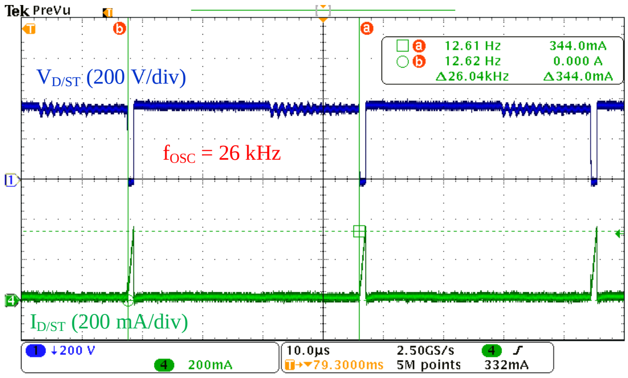

Figure 9-12. Operational Waveforms at Light Load (V_{IN} = 265 VAC, I_O = 0.1 A)

9.2.3 No-load Operation (Burst Oscillation)

In no-load operation, the power supply IC enters the burst oscillation operation. The burst oscillation period, T_{STBOP}, of the design example is 0.74 ms under any of the input voltages. The frequency during the burst oscillation operation is apploximately 23 kHz.

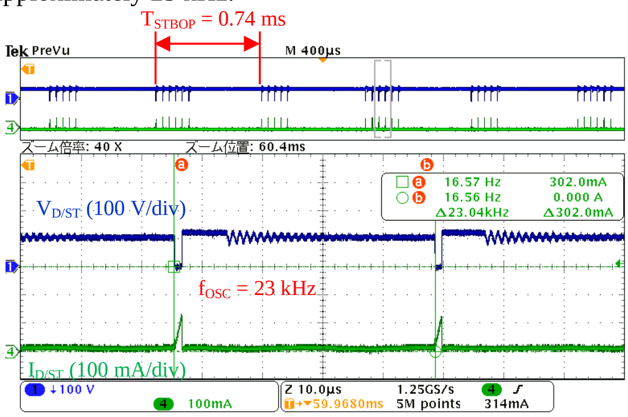

Figure 9-13. Operational Waveforms at No Load (V_{IN} = 85 VAC, I_O = 0 A)

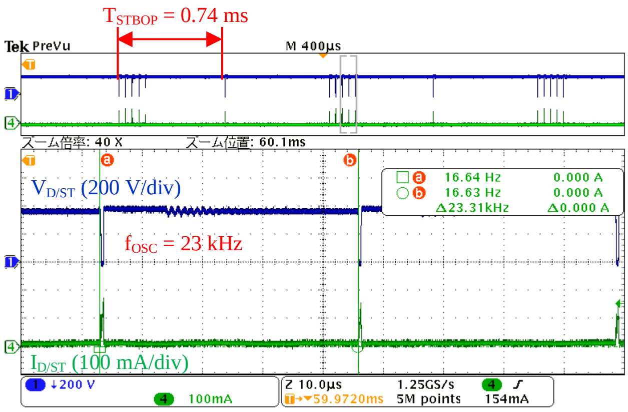

Figure 9-14. Operational Waveforms at No Load (V_{IN} = 265 VAC, I_O = 0 A)

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9.3 Output Ripple Voltage

The design example has output ripple voltages as follows: about 25 mV when V_{IN} = 85 VAC, and about 44 mV when V_{IN} = 265 VAC. Below are the measurement conditions:

- Added a filter to the output connector of the PCB (by connecting a 50 V, 1 µF electrolytic capacitor and a 50 V, 0.1 µF ceramic capacitor in parallel)
- Set a bandwidth of the oscilloscope to 20 MHz

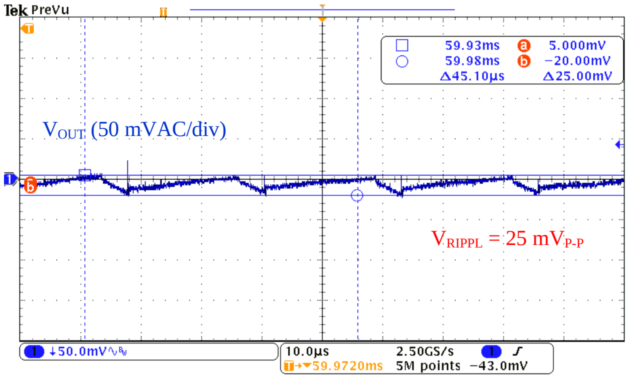

Figure 9-15. Output Ripple Voltage Waveform (V_{IN} = 85 VAC, I_O = 0.2 A)

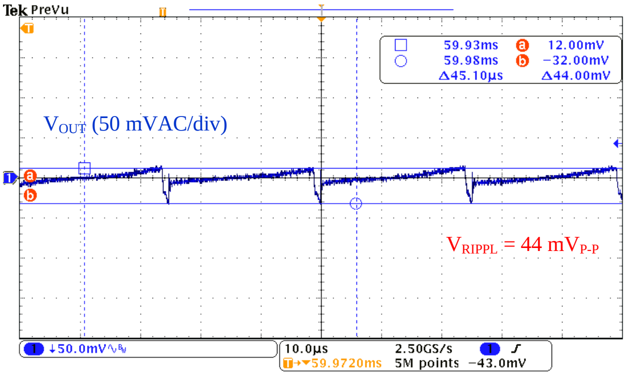

Figure 9-16. Output Ripple Voltage Waveform (V_{IN} = 265 VAC, I_O = 0.2 A)

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9.4 OCP and OLP Operations

When the power supply IC reaches a certain load level, the overcurrent protection (OCP) limits the internal power MOSFET drain current, $I_{D/ST}$, to the drain current limit, I_{DLIM} = 0.41 A (typ.).

When an overload condition limited by I_{DLIM} persists for the delay time, t_{OLP} = 72 ms (typ.) or longer, the overload protection (OLP) is activated to stop switching operations. The bias assist function is disabled during the OLP operation. After the switching operations stopped, when the VCC pin voltage decreases to $V_{CC(OFF)}$ = 8.0 V (typ.), the control circuit stops operating. In the OLP operation, such intermittent operation is repeated by the UVLO function. And this suppresses an increase in the temperature of the power MOSFET. When the causes of the overload condition are eliminated, the power supply IC automatically returns to its normal operation.

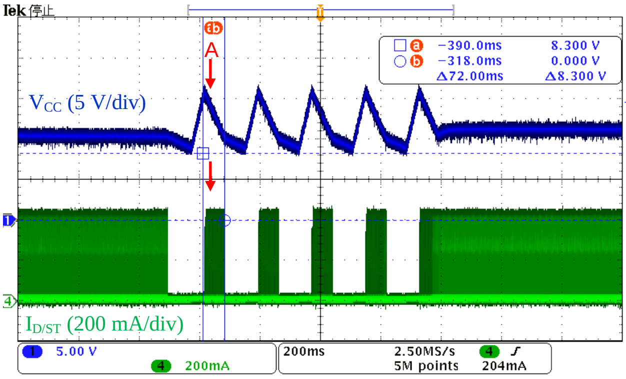

Figure 9-17. OCP and OLP Operational Waveforms (V_{IN} = 85 VAC, I_O > 0.2 A)

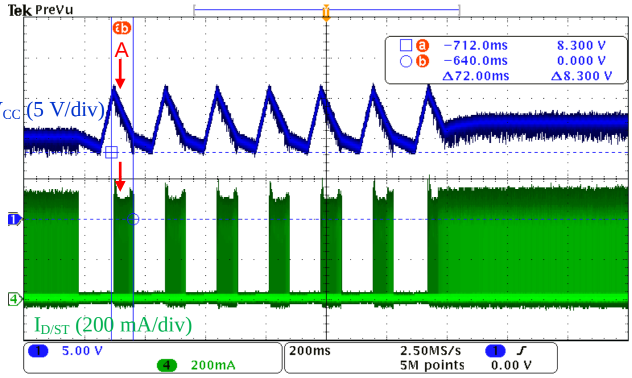

Figure 9-18. OCP and OLP Operational Waveforms (V_{IN} = 265 VAC, I_O > 0.2 A)

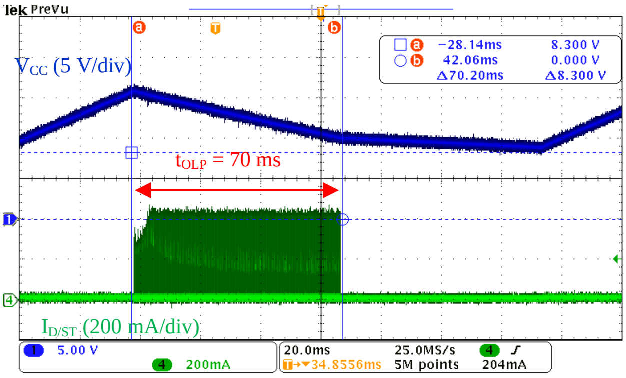

Figure 9-19. OCP and OLP Operational Waveforms (Expanded Scale of A in Figure 9-17)

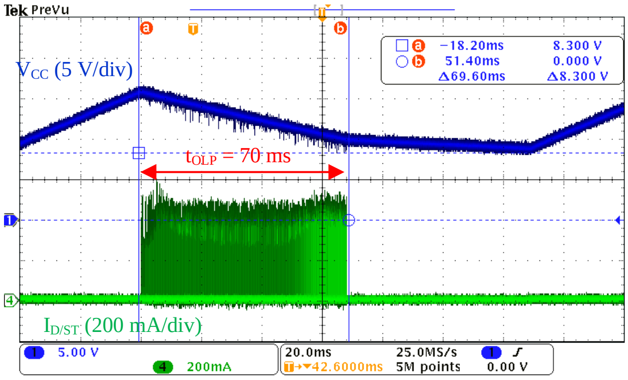

Figure 9-20. OCP and OLP Operational Waveforms (Expanded Scale of A in Figure 9-18)

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9.5 OVP Operation

When the voltage between the VCC and S/GND pins of the power supply IC increases to the OVP threshold voltage, $V_{CC(OVP)}$ = 29.3 V (typ.) or more, the overvoltage protection (OVP) is activated and power supply IC shifts to the OVP operation. In the OVP operation, an intermittent oscillation operation is repeated by the UVLO function of the VCC pin. When the causes of the overvoltage condition are eliminated, the power supply IC automatically returns to its normal operation.

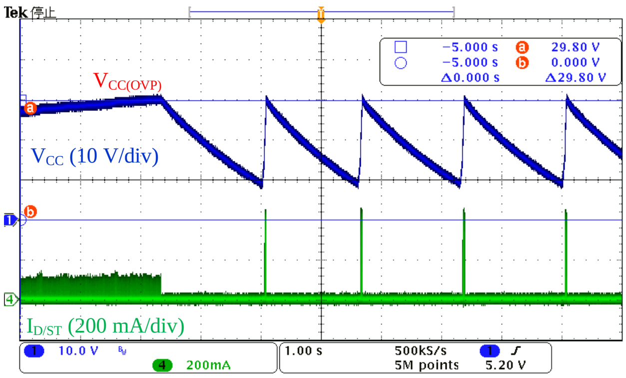

Figure 9-21. OVP Operational Waveforms (V_{IN} = 85 VAC, I_O = 0 A)

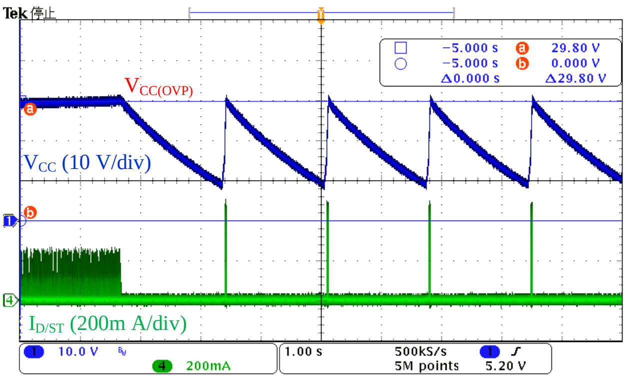

Figure 9-22. OVP Operational Waveforms (V_{IN} = 265 VAC, I_O = 0 A)

9.6 Shutdown Operation

When an AC power supply is cut off, the output voltage, V_{OUT}, will have an overshoot. Even though the dummy resistor R4 can adjust an increase in the output voltage, be sure to conduct actual board operation checking because R4 also affects the power loss during standby operation. As we set R4 = 6.8 kΩ for the design example, the output voltage has an overshoot of about 0.5 V at shutdown.

After the AC power supply cutoff, the reason V_{OUT} continues to occur for about 2.2 seconds is due to the residual charge of C5.

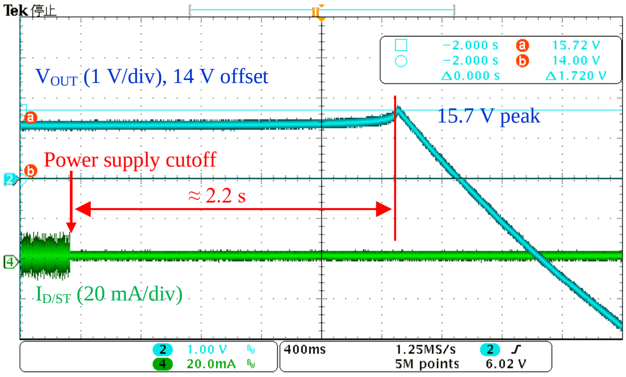

Figure 9-23. Operational Waveforms at Shutdown (V_{IN} = 85 VAC, I_O = 0 A)

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9.7 Case Temperature

Table 9-1 lists the individual component case temperatures at input voltage upper and lower limits, measured under the ambient temperatures 25 °C and 50 °C respectively.

Table 9-1. Input Voltage vs. Component Case Temperature (I_O = 0.2 A)

Ambient Temperature (°C)	Input Voltage (VAC)	Care Temperatures in Normal Operation (°C)		
		Power Supply IC (U1)	Freewheeling Diode (D3)	Inductor (L2)
25	85	49.8	45.5	44.5
	265	51.7	48.1	50.3
50*	85	74.8	70.5	69.5
	265	76.7	73.1	75.3

* Refers to case temperatures converted from the ones at an ambient temperature of 25 °C.

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10. Conducted Emission Test

Figure 10-1 to Figure 10-4 show the measurement results of mains terminal disturbance voltage (EMI).
Measurement conditions: I_O = 0.7 A, FG = open
Test mode: Average

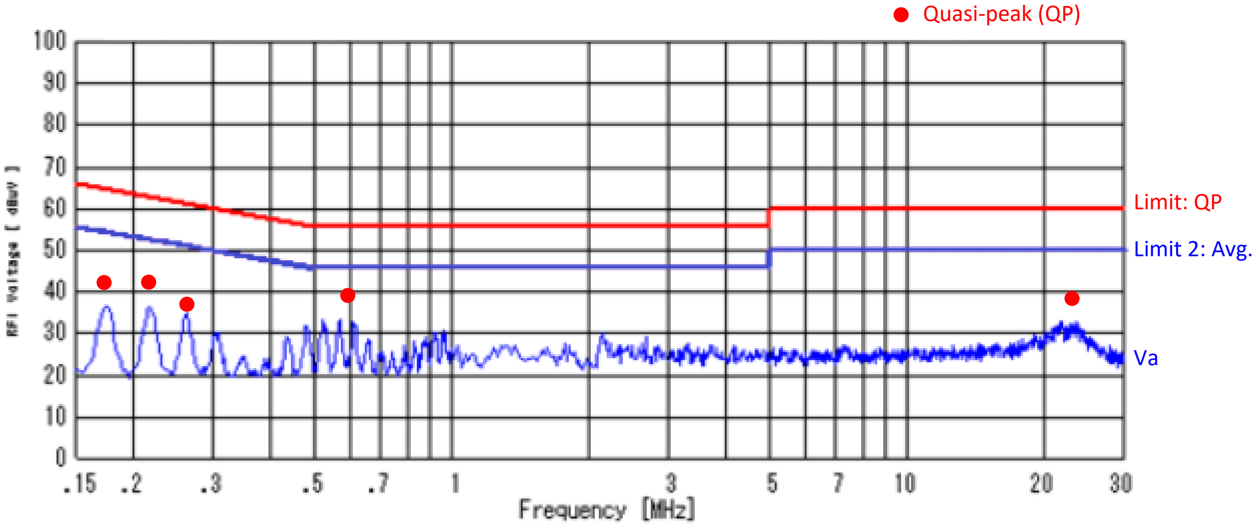

Figure 10-1. EMI Measurement Result (Line, V_{IN} = 100 VAC)

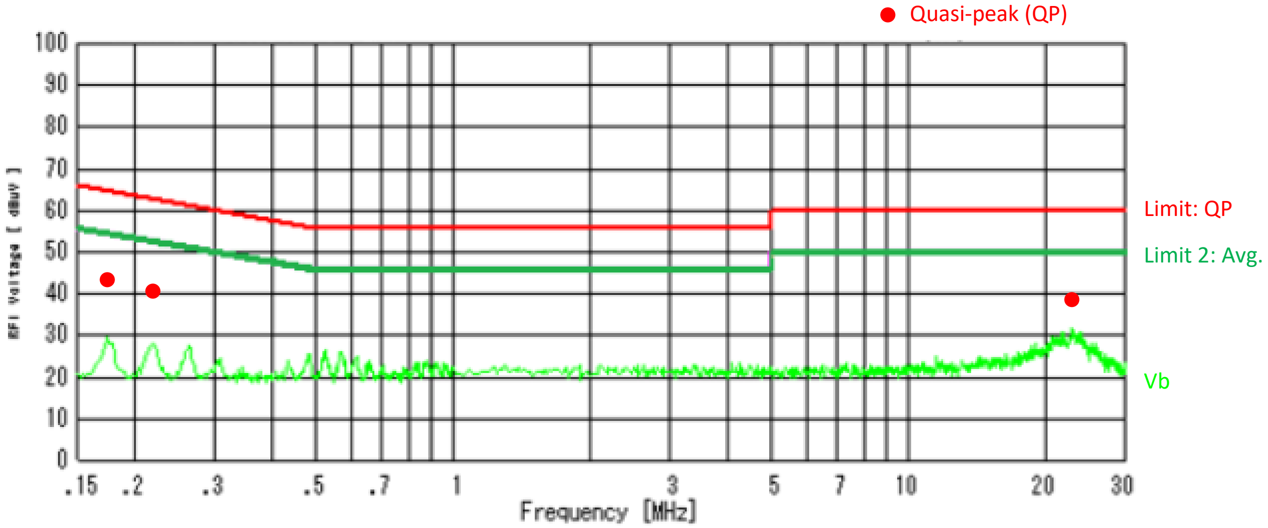

Figure 10-2. EMI Measurement Result (Neutral, V_{IN} = 100 VAC)

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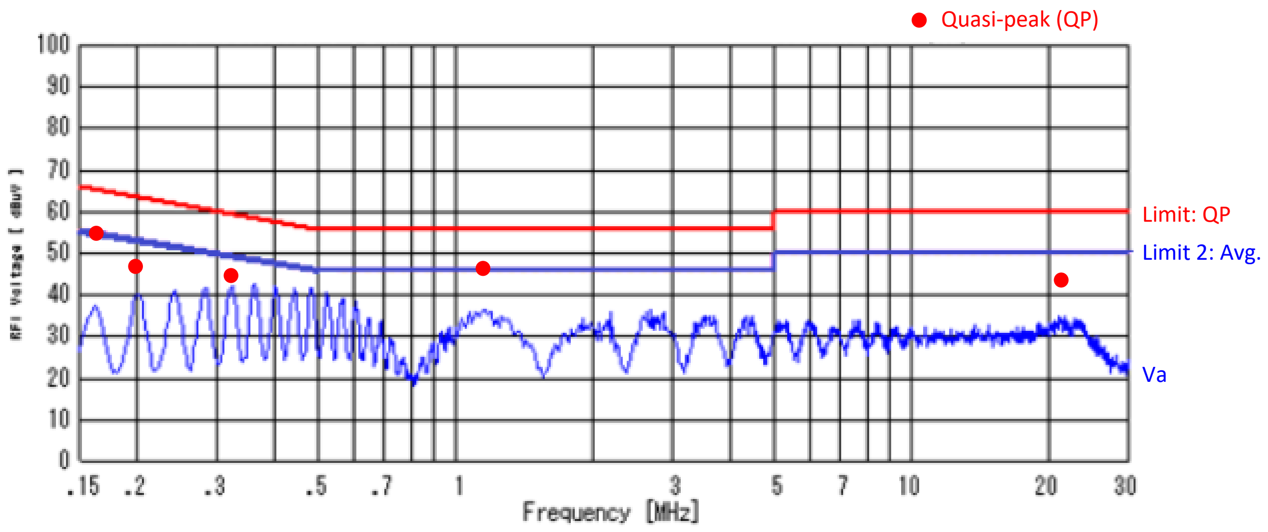

Figure 10-3. EMI Measurement Result (Line, V_{IN} = 230 VAC)

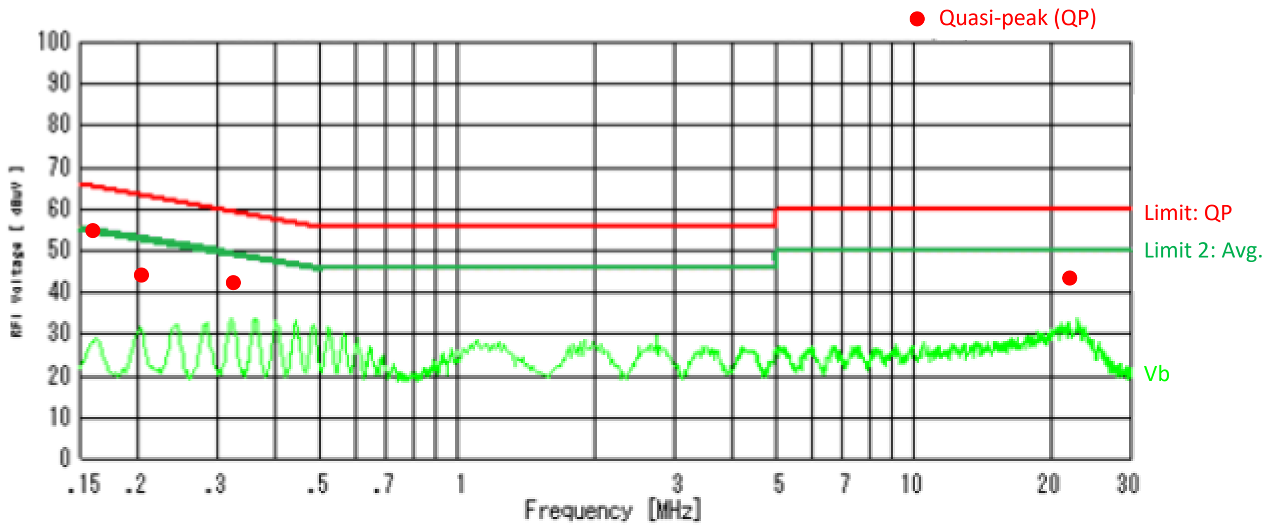

Figure 10-4. EMI Measurement Result (Neutral, V_{IN} = 230 VAC)

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