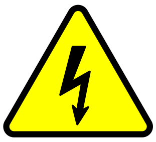
Design Example Using STR6S161HXD:

21.8 W (15 V, 1.45 A)

Isolated Flyback Converter

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 STR6S161HXD.
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 STR6S161HXD 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.

Contents

1. Introduction

This document describes the design example of a power supply using the STR6S161HXD intended for the isolated flyback converter that supports universal inputs and a 15 V/1.45 A output. The STR6S161HXD is a current mode PWM control IC with a built-in power MOSFET. In addition, the design example uses the SARS05 as a diode for the resistor-capacitor-diode (RCD) snubber, the SJPX-F2 as a fast recovery diode for the IC's power supply, and the FMEN-220B as a Schottky diode for the secondary rectifier.

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

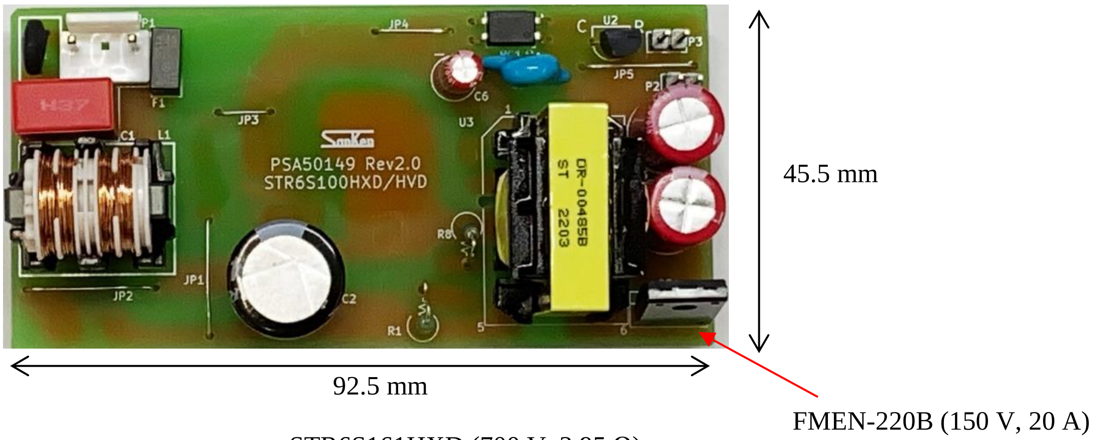
- Improved Circuit Efficiency (Secondary Rectifier Diodes with Lower V_{RM} and V_F Characteristics Achieved by Step Drive Control Circuit)
- High-voltage Protection (HVP)
- Brown-in and Brown-out Function
- Reduced Number of External Components (Built-in Startup Circuit)
- High Efficiency in All Load Ranges Achieved by Load-based Auto-shifting Operation Modes
  - Rated Load Operation: PWM Mode, 100 kHz (Typ.)
  - Light-load Operation: Green Mode
  - Standby Operation: Burst Oscillation Mode
- Efficiency: 89.2% (230 VAC, 21.8 W)
- Input Power at No Load: 59 mW (230 VAC)
- Reduced EMI Noise (Random Switching Function)

3. Applications

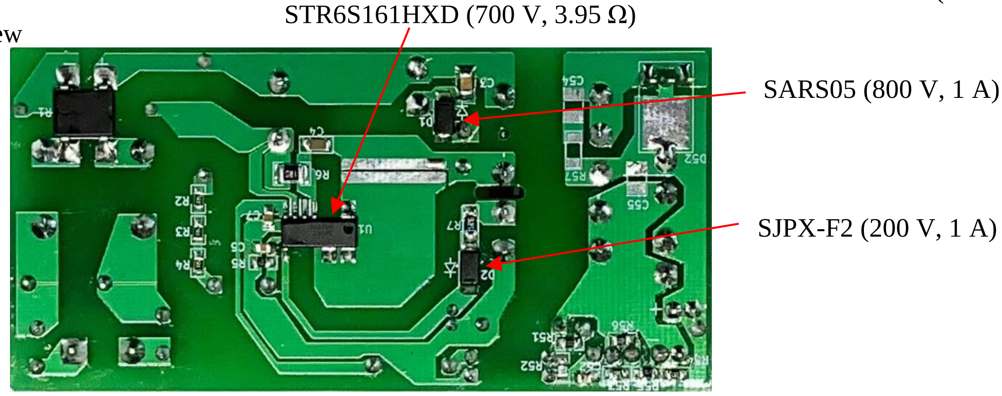
- Small Home Appliance
- Large Home Appliance
- Auxiliary Power Supply
- Power Supply for Motor Control
- Other SMPSs (Switching Mode Power Supplies)

4. Design Example: Appearance

Top View



Bottom View



5. Design Example

5.1 Power Supply Specifications

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Input						
Input Voltage	V_{INAC}		90	—	288	V
Frequency	f_{LINE}		47	50/60	63	Hz
Output						
Rated Voltage	V_{NP}		14.25	15	15.75	V
Rated Current	I_{NP}		—	1.45	—	A
Output Ripple Voltage	V_{RIPPLE}	20 MHz bandwidth; filter added(1)	—	370	—	mV_{P_P}
Output Power	P_{OUT}		—	21.8	—	W
Efficiency	η	Rated load, T_A = 25 °C, 230 VAC	—	89.2	—	%
Environment						
Conduction Noise	—	T_A = 25 °C	As per CISPR22B/EN55022B			—
Temperature						
Power Supply IC Temperature Increase(2)	$\Delta T_{C\text{-}IC}$	90 VAC, I_O = 1.45 A	—	48.5	—	°C
Secondary Rectifier Diode Temperature Increase(3)	$\Delta T_{C\text{-}DI}$	288 VAC, I_O = 1.45 A	—	49.6	—	°C
Transformer Temperature Increase	ΔT_L	90 VAC, I_O = 1.45 A	—	23.3	—	°C

5.2 Circuit Diagram

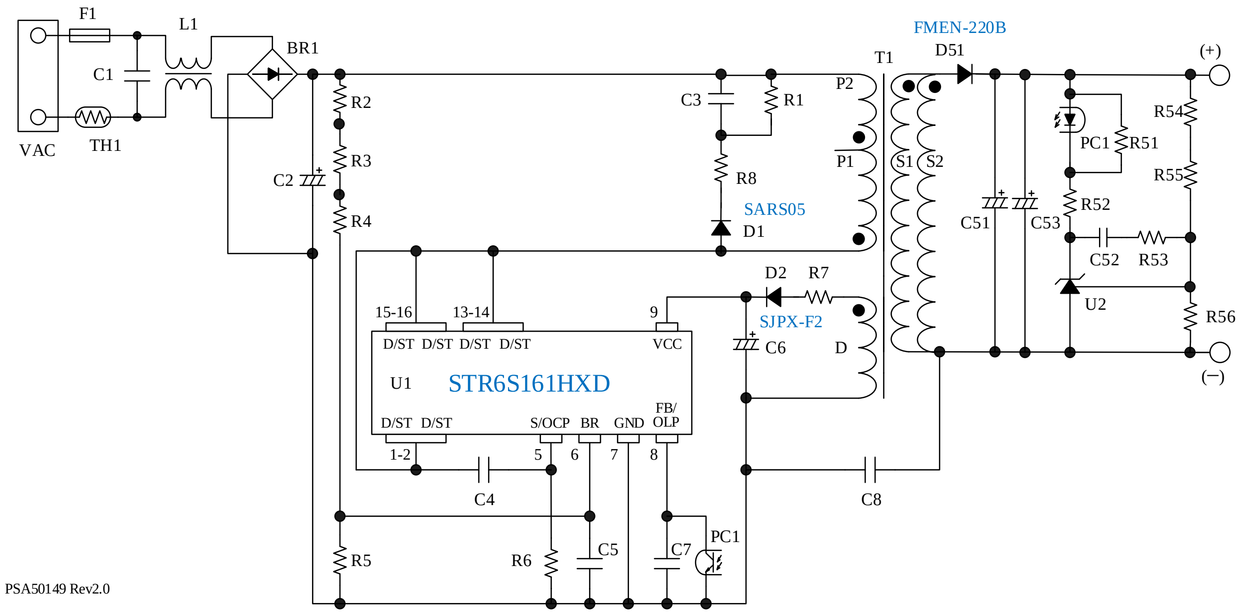


Figure 5-1. Circuit Diagram

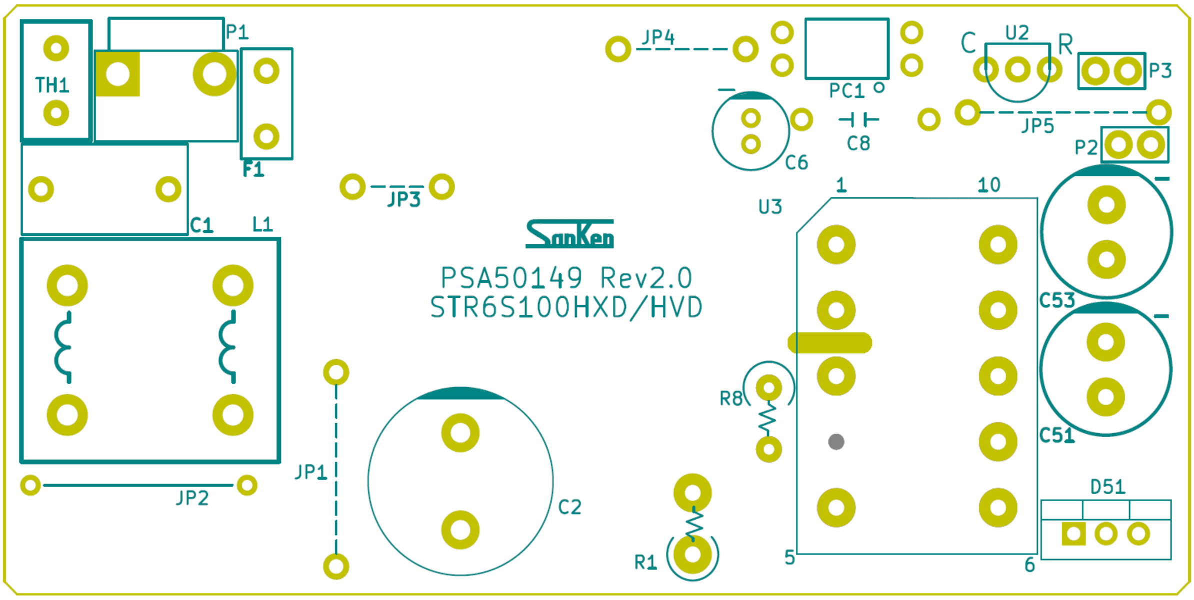
(1) By connecting an electrolytic capacitor (50 V, 1 µF) and a ceramic capacitor (50 V, 0.1 µF) in parallel to the output connector of the PCB.
(2) Refers to a case temperature of the STR6S161HXD.
(3) Refers to a case temperature of the FMEN-220B.

5.3 Bill of Materials

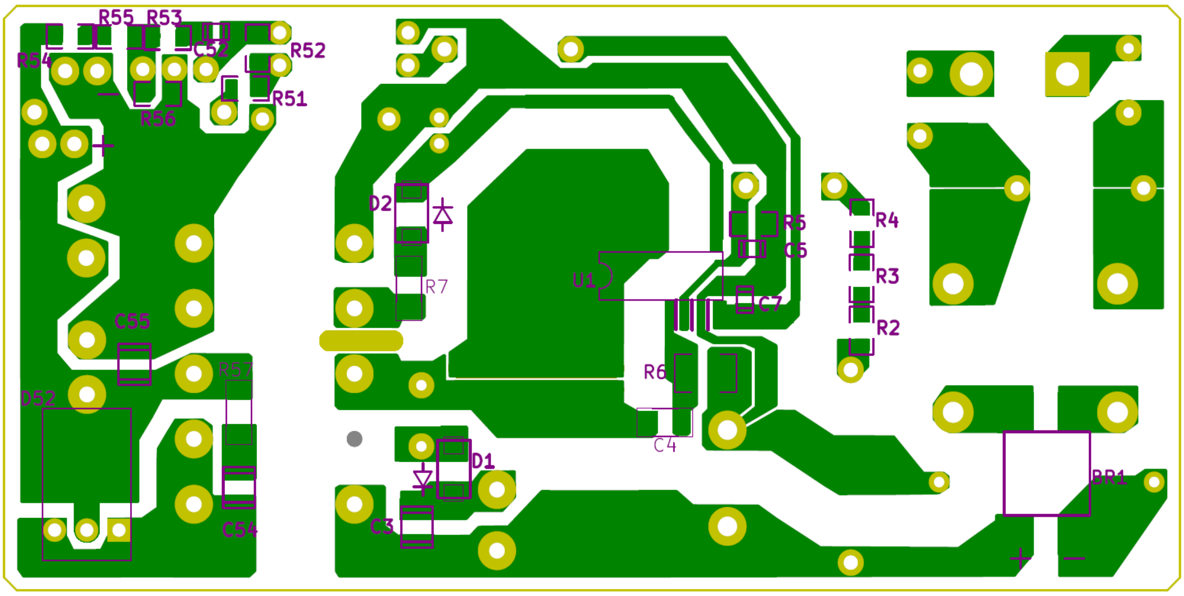
Part Symbol	Part Type	Ratings	Part Number*	Manufacturer
F1	Hues	2 A, 250 V	RSTA 2 BULK	BELLEFUSE
TH1	Power thermistor	4.7 Ω, 3 A	B57153S0479M000	TDKEPCOS
C1	Film capacitor	0.1 µF, 310 VAC	FTX2(890334023023CS)	Wurth Electronics
C2	Electrolytic capacitor	56 µF, 450 V	450LXW56MEFR14.5×25	Rubycon
C3	Chip ceramic capacitor	1500 pF, 1 kV, 3216	GRM31BR73A152KW01L	Murata
C4	Ceramic capacitor	10 pF, 2 kV	GRM31A7U3D100JW31D	Murata
C5	Chip ceramic capacitor	1000 pF, 50 V, 2012	885012207086	Wurth Electronics
C6	Electrolytic capacitor	22 µF, 50 V	860020672011	Wurth Electronics
C7	Chip ceramic capacitor	2200 pF, 50 V, 2012	885012207088	Wurth Electronics
C8	Y-capacitor	1500 pF, 250 VAC	DE1E3RA152MA4BP01F	Murata
C51	Electrolytic capacitor	560 µF, 25 V	860080475017	Wurth Electronics
C53	Electrolytic capacitor	560 µF, 25 V	860080475017	Wurth Electronics
C52	Chip ceramic capacitor	0.068 µF, 50 V, 2012	885012207097	Wurth Electronics
BR1	Bridge rectifier diode	1.5 A, 1000 V	DF10S	ON Semiconductor
D1	Snubber diode	1.0 A, 800 V	SARS05	Sanken
D51	Schottky diode	20 A, 150 V	FMEN-220B	Sanken
D2	Fast recovery diode	1.5 A, 200 V	SJPX-F2	Sanken
L1	Inductor	18 mH, 0.5 A	7448640416	Wurth Electronics
T1	Transformer	EE25/25B	DR-00485B	Sanshin
R1	Resistor	470 kΩ, 1/2 W	RN12S474JK	Akahane Electronics
R2	Chip resistor	3.3 MΩ, 1/4 W, 2012	CR0805-JW-335ELF	Bourns
R3	Chip resistor	3.3 MΩ, 1/4 W, 2012	CR0805-JW-335ELF	Bourns
R4	Chip resistor	3.3 MΩ, 1/4 W, 2012	CR0805-JW-335ELF	Bourns
R5	Chip resistor	120 kΩ, 1/4 W, 2012	RK73B2ATTD124J	KOA
R6	Chip resistor	1 Ω, 1/2 W , 3226	RK73B2ETTD1R0J	KOA
R7	Chip resistor	5.6 Ω, 1/4 W, 3216	RK73B2BTTD5R6J	KOA
R8	Resistor	68 Ω, 1/2 W	RSMF12B680J	Akahane Electronics
R51	Chip resistor	2.2 kΩ, 1/4 W, 2012	RK73B2ATTD222J	KOA
R52	Chip resistor	1.5 kΩ, 1/4 W, 2012	RK73B2ATTD682J	KOA
R53	Chip resistor	56 kΩ, 1/4 W, 2012	RK73B2ATTD682J	KOA
R54	Chip resistor	3.9 kΩ, 1/4 W, 2012	RK73B2ATTD392J	KOA
R55	Chip resistor	47 kΩ, 1/4 W, 2012	RK73B2ATTD473J	KOA
R56	Chip resistor	10 kΩ, 1/4 W, 2012	RK73B2ATTD103J	KOA
U1	PWM off-line converter IC	700 V, 3.95 Ω	STR6S161HXD	Sanken
U2	Shunt regulator	V_{REF} = 2.5V	TL431AILPRE3	Texas Instruments
PC1	Optocoupler		TLP781F	Toshiba
P1	Connector	250V, 10A	B2P3-VH	J.S.T.Mfg.
P2	Connector	50V	WR-WTB (64800611622)	Wurth Electronics
P3	Connector	50V	WR-WTB (64800611622)	Wurth Electronics
—	PCB		PSA50149, Rev.2.0	Sanken

5.4 Pattern Layout Example

The design example uses only the parts listed in the circuit diagram and the bill of materials.
PCB dimensions: 92.5 mm × 45.5 mm



(a) Top View



(b) Bottom View

Figure 5-2. Pattern Layout Example

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 full-wave rectified via the input filter and the bridge rectifier diode BR1. The rectified voltage is then smoothed to a DC voltage by the electrolytic capacitor, C2. The input filter part includes the following components: C1 for a normal-mode noise filter; L1 for a common-mode noise filter; the power thermistor TH1 for an inrush current limiter.

When a voltage is applied to the D/ST pin of the power supply IC (U1: STR6S161HXD), the internal startup circuit turns on. Consequently, a startup current flowing out of the VCC pin charges the electrolytic capacitor C6. 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 switching operation starts, a voltage is induced across the auxiliary winding D of the transformer T1. This induced voltage is rectified by D2 and C6 and is applied to the VCC pin. At this time, the internal startup circuit automatically turns off and the VCC pin power is supplied from the auxiliary winding D afterward. Note that the VCC pin voltage may be increased due to C6, which is charged by the surge voltage induced across the auxiliary winding D. For suppressing such voltage increase, R7 should be connected.

When the internal power MOSFET turns off, a ringing voltage is caused between the drain and source. For reducing such ringing voltage, the clamp snubber circuit (D1, C3, R1, and R8) should be connected across the winding P of the transformer T1. The SARS05, which is used for the diode D1, is a diode dedicated for snubber circuits and is contributory to not only ringing voltage reduction but also to better power supply efficiency by utilizing ringing energy effectively.

The current-sensing resistor R6 connected to the S/OCP pin is for overcurrent detection. The light-receiving element of the optocoupler PC1 is connected to the FB/OLP pin, and a feedback signal is input for controlling the output voltage to be constant. The feedback current, I_{FB}, according to the load runs through PC1. Also, the capacitor C7 is connected to the FB/OLP pin, for high-frequency noise filtering and phase compensation. The input volage detection resistors R2 to R5 and the noise filter capacitor C5 are connected to the BR pin.

In flyback converter design, the transformer T1 should consist of the primary and secondary sides whose polarities are connected oppositely. Energy is transferred from the primary side to the secondary side as follows. When the internal power MOSFET turns on, the input voltage, V_{INDC}, is applied to the winding P of the transformer T1. The transformer T1 then starts to store energy. As the secondary winding S has the reverse polarity, the secondary rectifier diode D51 does not become conductive at this time. Consequently, no power is transmitted from the primary side to the secondary side. When the internal power MOSFET turns off, the winding P generates a back EMF that conducts electricity to D51 and charges the electrolytic capacitors C51 and C53. Then, the energy stored in the transformer T1 is discharged to the secondary side.

The light-emitting element of the optocoupler PC1 is configured as follows: the anode side is connected with the positive output (the connector P2); the cathode side is connected with the shunt regulator U2 via the current-sensing resistor R52. The resistor R51, connected across the anode and cathode of the light-emitting element of the optocoupler PC1, supplies the idling current flowing through PC1 to the shunt regulator U2. In order to enhance the constant voltage control, a high-precision resistor with an allowable tolerance of ±1% or less should be used for the resistors R54 to R56, which produce a voltage to be applied to the reference pin for the shunt regulator U2.

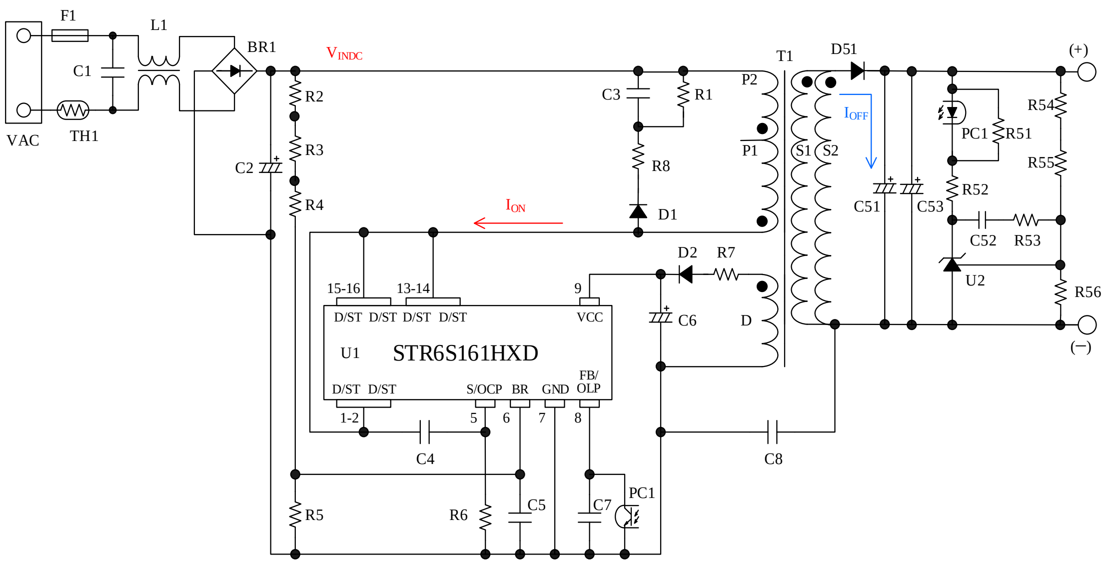


Figure 6-1. Circuit Diagram

7. Designing the Power Supply

7.1 Setting an Output Voltage

The equation below defines the relation between: the output voltage, V_{OUT}; the reference voltage, $V_{FB(REF)}$, of the shunt regulator U2; and the resistors R54 to R56.

$$V_{OUT} = \frac{(R54 + R55 + R56) \times V_{FB(REF)}}{R56}. \qquad (1)$$

Here are example setting values for $V_{FB(REF)}$ and the resistors R54 to R56 when V_{OUT} = 12 V:
$V_{FB(REF)}$ = 2.495 V
R54 = 3.9 kΩ
R55 = 47 kΩ
R56 = 10 kΩ

7.2 Selecting the Bridge Rectifier Diode BR1

For the bridge rectifier diode BR1, 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 288 VAC, the voltage to be applied to BR1 is as follows: $V_P = 288\ (VAC) \times \sqrt{2} \approx 407\ (VDC)$. When a derating of ≥80% is applied to the BR1 breakdown voltage, BR1 requires a breakdown voltage of ≥509 V.
The equation below defines the input current, I_{IN}:

$$I_{IN} = \frac{P_{OUT}}{V_{INAC(MIN)} \times \eta \times PF}. \qquad (2)$$

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 (2), when P_{OUT} = 21.8 W, $V_{INAC(MIN)}$ = 90 VAC, η = 0.84, PF = 0.6, hence I_{IN} ≈ 481 mA. When a derating of ≥80% is applied to the BR1 rated current, BR1 requires a rated current of ≥601 mA.
For the design example, we selected the bridge rectifier diode with a breakdown voltage of 1000 V and a rated current of 1.5 A, from the ones available in the market.

7.3 Selecting the Clamp Snubber Circuit (D1, C3, R1, R8)

For reducing surge voltages between the D/ST and S/OCP pins of the power supply circuit (U1: STR6S161HXD), a clamp snubber circuit should be connected. As the maximum rated voltage of the internal power MOSFET is 700 V, the capacitor C3 and the discharging resistor R1 should be adjusted so that the power supply IC will have a surge voltage with a peak value of approximately 600 V. The reference capacitance of C3 is 1000 pF to 3300 pF, whereas the reference resistance of R1 is 390 kΩ to 1 MΩ.
For D1 used in the design example, we selected the SARS05, our 800 V/1.0 A diode dedicated for snubber circuits. R8 is the current-limiting resistor for energy discharging and is recommended to use a resistor of about 68 Ω as we selected the SARS05 for the snubber diode.

7.4 Selecting the VCC Pin Rectifier Diode D2

For D2, select a fast recovery diode with a short recovery time because switching currents flow through it. Its rated voltage should have a sufficient margin to the voltage acorss the auxiliary winding D.

The design example employs the SJPX-F2, a 200 V/1.5 A fast recovery diode.

7.5 Selecting the Current-sensing Resistor R6

When determining a constant of the current-sensing resistor R6, the OCP threshold voltage, $V_{OCP(H)}$, of the power supply IC (U1: STR6S161HXD) and resistance loss should be taken into accout. Be sure to use a high-precision resistor with an allowable tolerance of ±2% or less for enhancing the constant voltage control.

When R6 = 1 Ω, the upper limit of $V_{OCP(H)}$ for the STR6S161HXD is 0.933 V. Hence, the peak current that will flow through R6, I_{R6_P}, is obtained by:

$$I_{R6\_P} = \frac{0.933\ (V)}{1\ (\Omega)} = 0.933\ (A)\,.$$

When the power supply IC operates at switching duty cycle = 0.5, the effective current that will flow through R6, I_{R6_RMS}, is as follows:

$$I_{R6\_RMS} = \frac{0.933\ (A)}{\sqrt{3}} \times 0.5 \approx 0.269\ (A)\,.$$

Thus, the resistance loss in R6, P_{R6}, is determined by:

$$P_{R6} = {I_{R6\_RMS}}^2 \times R6 = 0.269^2 \times 1 \approx 0.072\ (W)\,.$$

Based on the above calculation results, we selected the resistor with a resistance of 1 Ω and a rated power of 1/2 W.

7.6 Selecting the Secondary Rectifier Diode D51

For D51, use a Schottky diode for minimizing the effect of the forward voltage, V_F, to output voltages. Moreover, select a Schottky diode having low leakage current characteristics with safety and power supply efficiency taken into account.

The rated current of D51 should have a sufficient margin to the rated load and rated peak current.

The rated voltage of D51, V_{RM}, should have sufficient margins as follows: to the winding turns ratio (N_S/N_P) of the transformer T1 defined by Equation (3); to the input voltage, V_{INDC}; to a voltage determined by the output voltage, V_{OUT}.

$$V_{RM} \gg \left(\frac{N_S}{N_P} \times V_{INDC}\right) + V_{OUT}\,. \qquad (3)$$

From Equation (3), when $V_{INDC} = 288\ V \times \sqrt{2}$, $V_{OUT} = 15\ V$, $N_S/N_P = 0.1375$, hence $V_{RM} >> 71\ V$. Based on this calcuation result, the design example employs the FMEN-220B, a 150 V/20 A Schottky diode.

7.7 Transformer Specifications

Table 7-1 and Table 7-2 provide the design conditions for the transformer.

Table 7-1. Specifications: Input/Output

Winding	Symbol	Specifications	Remarks
Primary Winding	P	90 VAC to 288 VAC	
Secondary Winding	S	15 V, 1.45 A	Insulated from the winding P
Primary Auxiliary Winding	D	19 V	Non-insulated from the winding P; as a power supply for the VCC pin

Table 7-2. Specifications: Power Supply

Parameter	Specifications	Remarks
Maximum Load	21.8 W	
Input Voltage	288 VAC (max.)	
Circuit Efficiency	89%	
Average Input Current	0.29 A	90 VAC (min.)
Peak Switching Current	0.87 A	90 VAC (min.) at startup
Switching Frequency	100 kHz	
Maximum Duty Cycle	49%	

Table 7-3 lists the specifications of the transformer T1, which is designed from the conditions given in Table 7-1 and Table 7-2.

Table 7-3. Specifications: Transformer

Parameter	Specifications
Primary Inductance, L_P	1.3 mH
Core Size	EE25/25B (see Table 7-4)
Bobbin	Vertical type, 10 pins (see Table 7-5)
AL-value	203 nH/N^2 (center gap: 0.3 mm)
Winding Specifications	See Table 7-6.
Winding Structure	See Figure 7-1.

Table 7-4. Specifications: Core

Parameter	Specifications
Core Shape	EE25/25B
Core Materials	Mn-Zn, 6H20 materials
Effective Core Cross-sectional Area, Ae	51.7 mm^2

Table 7-5. Specifications: Bobbin

Parameter	Specifications
Bobbin Shape	Vertical type EE-2551
Number of Pins	10 pins
Creepage	Primary side: 4.0 mm (min.) Secondary side: 4.0 mm (min.)

Table 7-6. Specifications: Transformer Windings

Winding Name	Symbol	Turn (T)	Pin Numbers		Wire Diameter (mm)	Type
			Winding Start	Winding End		
Primary Winding 1	P1	40	3	4	φ 0.26	Single-layer solenoidal winding
Secondary Winding 1	S1	11	7	10	φ 0.32 × 2, TEX-E	Single-layer solenoidal winding
VCC Auxiliary Winding	D	11	2	1	φ 0.18	Single-layer solenoidal winding (center-wound)
Secondary Winding 2	S2	11	6	9	φ 0.32 × 2, TEX-E	Single-layer solenoidal winding
Primary Winding 2	P2	40	4	5	φ 0.26	Single-layer solenoidal winding

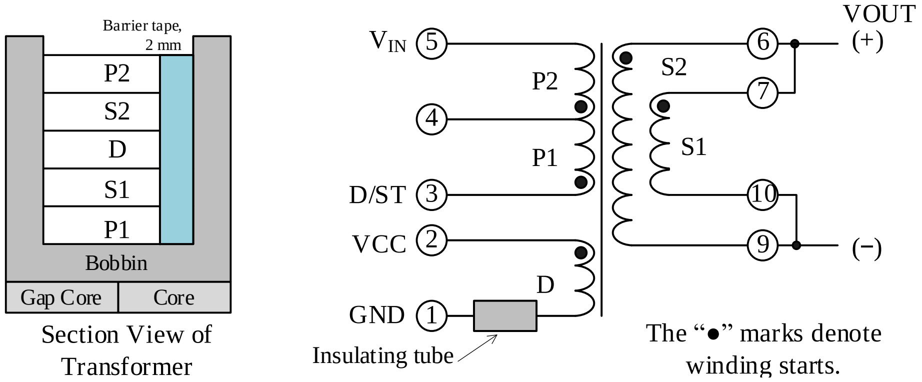


Figure 7-1. Structure of Windings

Core tape

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 21.8 W (15 V, 1.45 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.

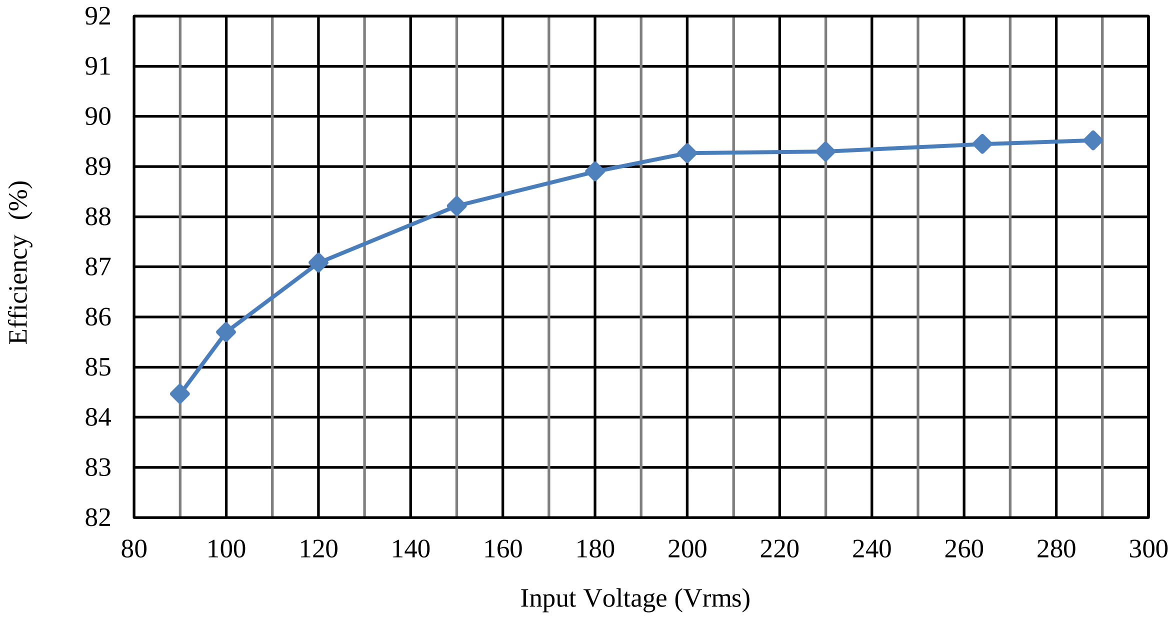


Figure 8-1. Efficiency vs. Input Voltage

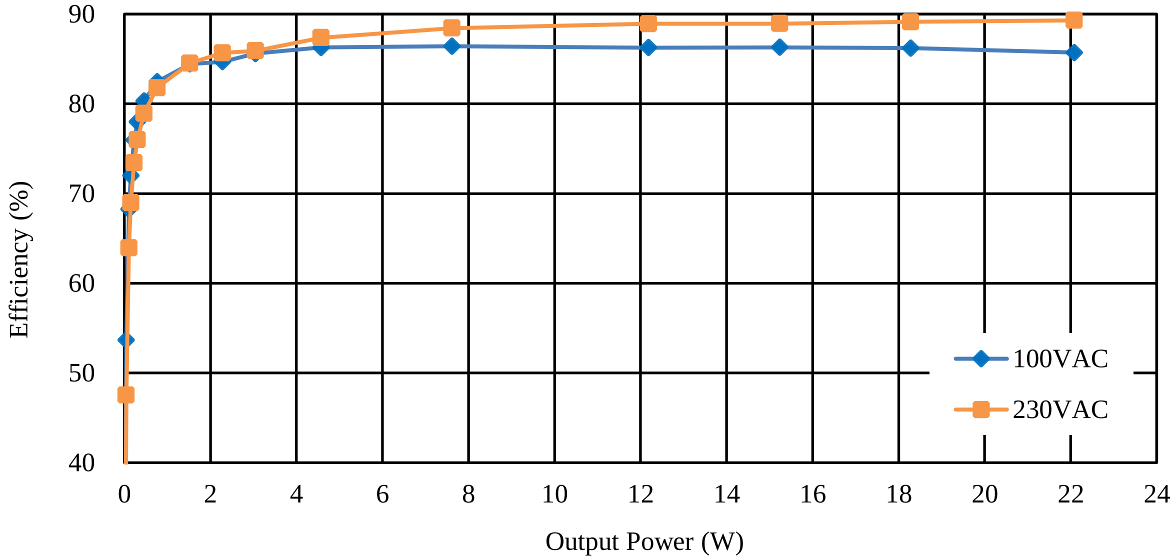


Figure 8-2. Efficiency vs. Output Power

8.2 Standby Power

Table 8-1. Input Power at No Load

Input Voltage	Input Power
100 VAC	54 mW
230 VAC	59 mW

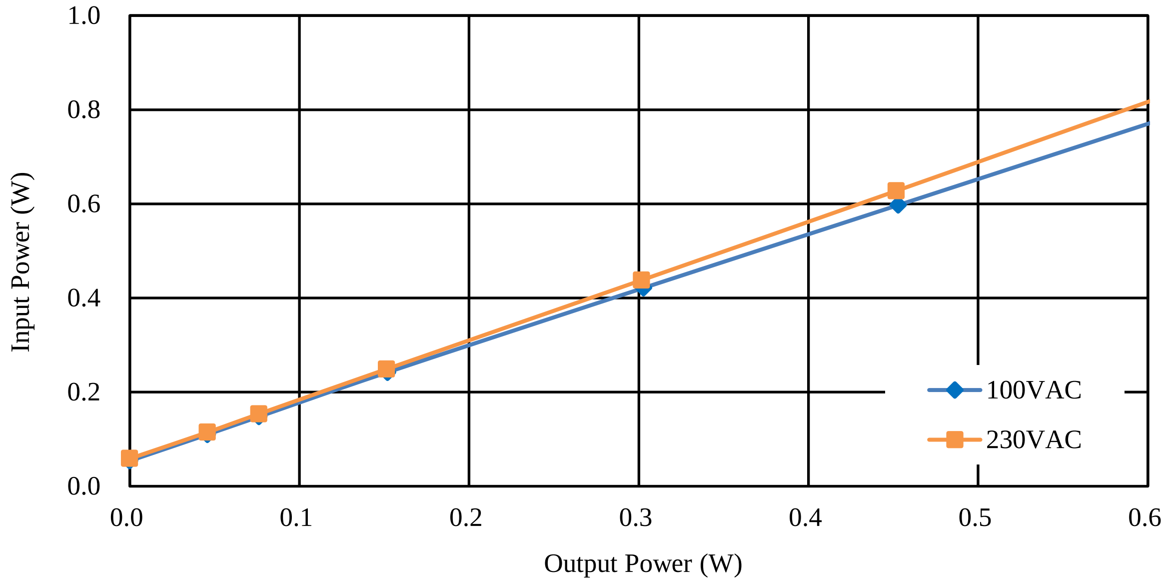


Figure 8-3. Input Power vs. Output Power

8.3 Line Regulation

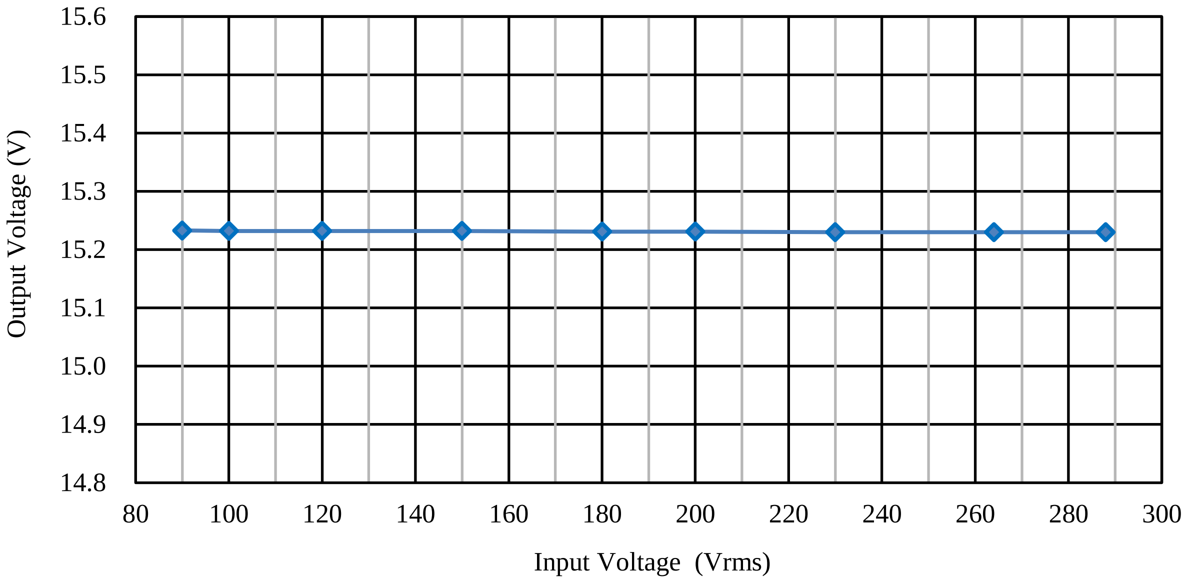


Figure 8-4. Output Voltage vs. Input Voltage

8.4 Load Regulation

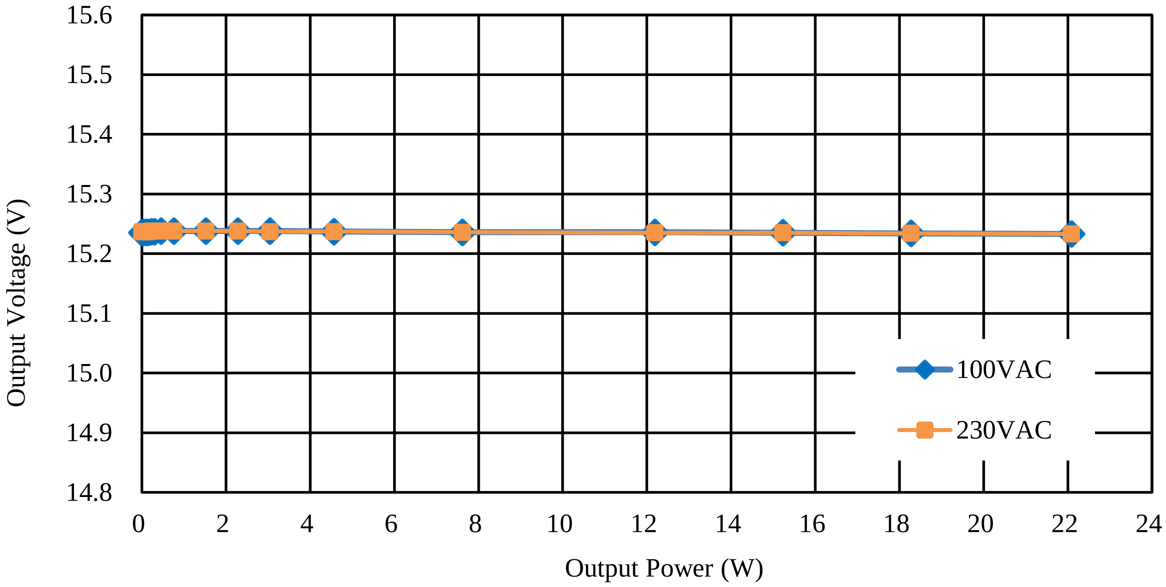


Figure 8-5. Output Voltage vs. Output Power

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 21.8 W (15 V, 1.45 A).

For more details on the power supply IC (STR6S161HXD) 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 the voltage across the current-sensing resistor R6 reaches the OCP threshold voltage of the power supply IC, 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 VD/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.

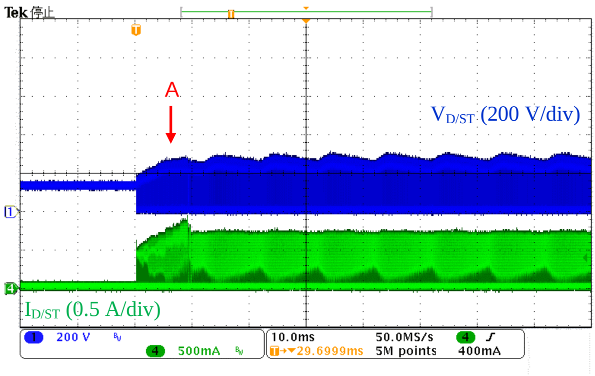


Figure 9-1. Operational Waveforms at Startup (V_{IN} = 90 VAC, I_O = 1.45 A)

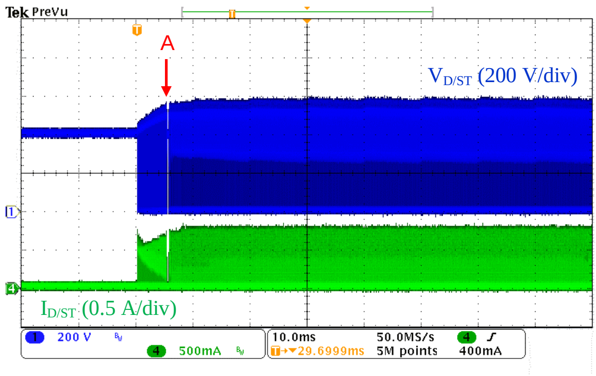


Figure 9-2. Operational Waveforms at Startup (V_{IN} = 288 VAC, I_O = 1.45 A)

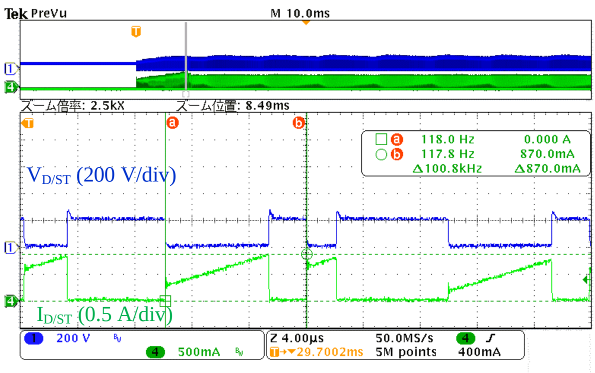


Figure 9-3. Operational Waveforms at Startup (Expanded Scale of A in Figure 9-1)

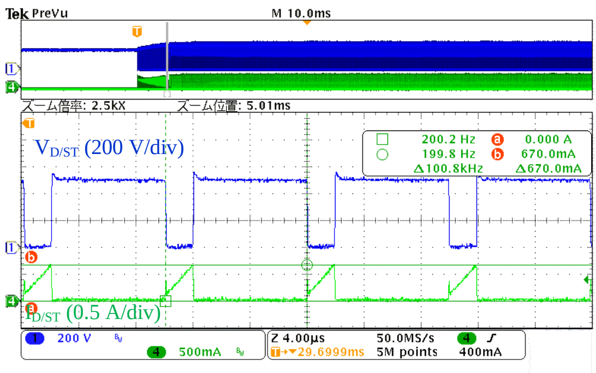


Figure 9-4. Operational Waveforms at Startup (Expanded Scale of A in Figure 9-2)

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.

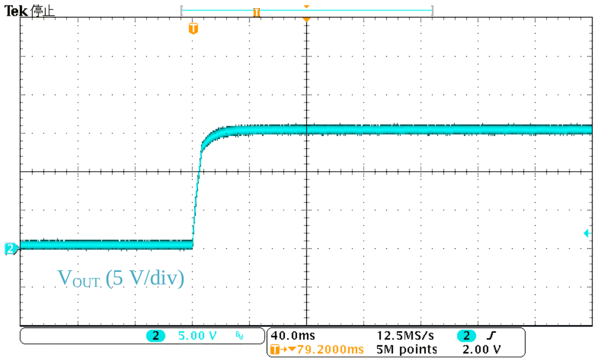


Figure 9-5. Output Voltage Waveform at Startup (V_{IN} = 90 VAC, I_O = 0 A)

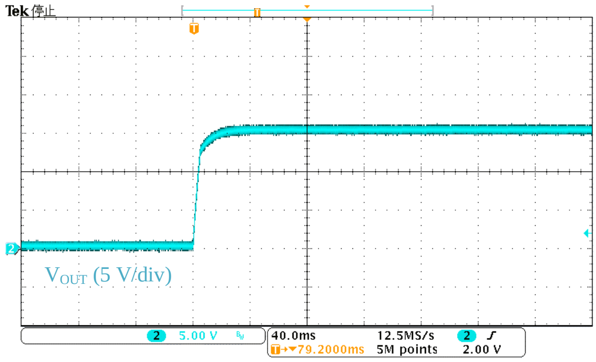


Figure 9-6. Output Voltage Waveform at Startup (V_{IN} = 288 VAC, I_O = 0 A)

9.1.3 VCC Pin Voltage

The auxiliary winding D of the transformer T1 is a voltage supply source for the VCC pin. Set the auxiliary winding D so that the VCC pin voltage, V_{CC}, will fall within the range of $V_{CC(BIAS)} < V_{CC} < V_{CC(OVP)}$. The reference voltage across the auxiliary winding D, V_D, is about 15 V to 20 V. In no-load operation, the power supply IC enters the burst oscillation operation as soon as its normal operation starts after startup. Thus, the VCC pin voltage decreases shortly after it increases once (see Figure 9-7, Figure 9-8). Note that the R7 value should be adjusted so that the VCC pin voltage will not become $V_{CC(BIAS)}$ = 10.5 V (max.) or less, under all load ranges including the no-load operation.

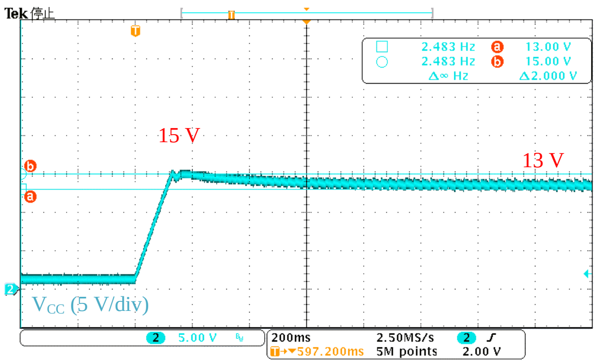


Figure 9-7. VCC Pin Voltage Waveform at Startup (V_{IN} = 90 VAC, I_O = 0 A)

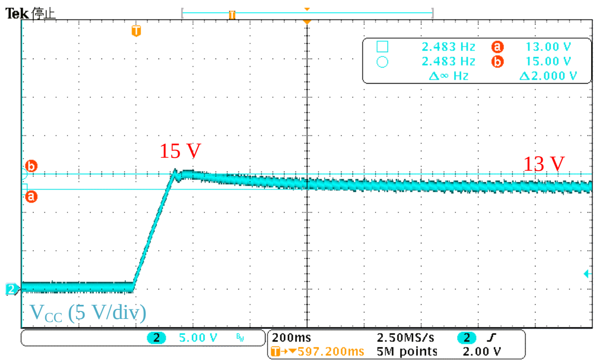


Figure 9-8. VCC Pin Voltage Waveform at Startup (V_{IN} = 288 VAC, I_O = 0 A)

9.1.4 D51 and D2 Applied Voltages

The STR6S161HXD integrates the step drive control circuit that internally controls the gate drive of the power MOSFET in an optimal way, according to load conditions. This helps applications reduce surge voltages, including the one that occurs at a turn-on of the secondary rectifier diode D51, and the one applied to the VCC pin rectifier diode D2. Accordingly, the design example uses diodes with a breakdown voltage lower than conventional diodes. Moreover, the step drive control circuit allows applications to employ lower cost diodes, and to achieve higher circuit efficiency with lower VF characteristics.

Figure 9-9 and Figure 9-10 provide the waveforms of the voltages across D51 and D2 at startup, respectively.

In Figure 9-9, D51 yields the repetitive peak reverse voltage, V_{RM}, of about 115 V at maximum. This means that D51 (FMEN-220B) ensures a sufficient derating (≤77%) to the maximum rated V_{RM} = 150 V.

In Figure 9-10, D2 yields the repetitive peak reverse voltage, V_{RM}, of about 99 V at maximum. This means that D2 (SJPX-F2) ensures a sufficient derating (≤50%) to the maximum rated V_{RM} = 200 V.

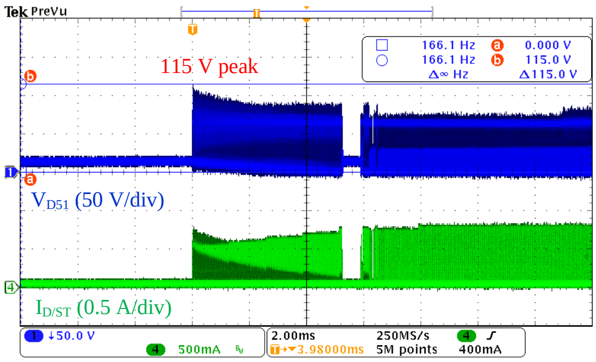


Figure 9-9. D51 Operational Waveforms at Startup (V_{IN} = 288 VAC, I_O = 1.45 A)

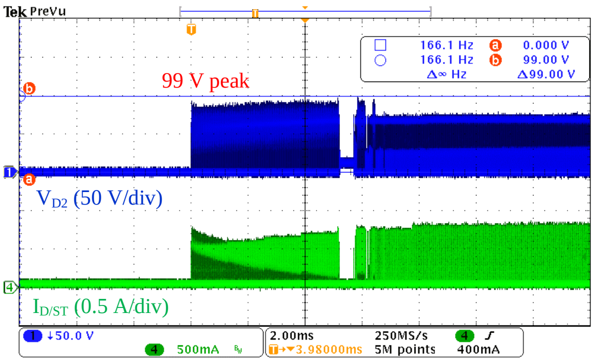


Figure 9-10. D2 Operational Waveforms at Startup (V_{IN} = 288 VAC, I_O = 1.45 A)

9.2 Power Supply IC Switching Operation

The STR6S161HXD automatically shifts its operation modes according to loads and enhances efficiency in all load ranges. Therefore, the power supply IC monitors not only the operation at the rated load but also the operations in all load ranges.

9.2.1 Rated Load Operation

Figure 9-11 to Figure 9-12 provide the waveforms at the rated load. These waveforms show that the frequency is about 99 kHz when V_{IN} = 90 VAC and is about 57 kHz (which is within the frequencies in the green mode) when V_{IN} = 288 VAC. Each drain peak current setting has a margin to its overcurrent operating point.

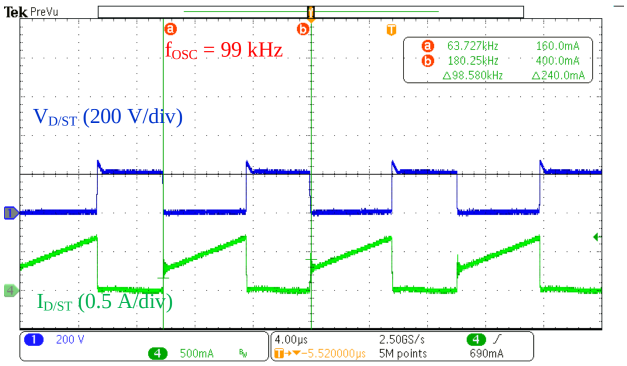


Figure 9-11. Operational Waveforms at Rated Load (V_{IN} = 90 VAC, I_O = 1.45 A)

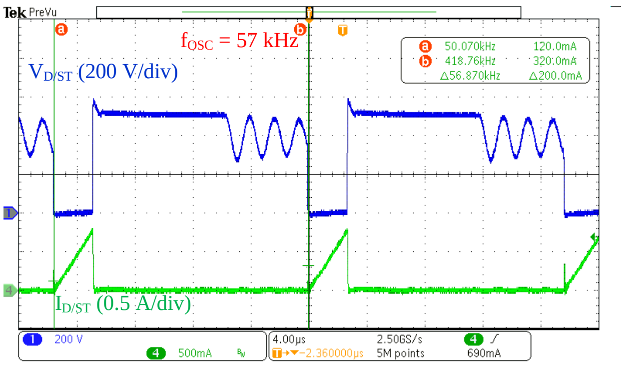


Figure 9-12. Operational Waveforms at Rated Load (V_{IN} = 288 VAC, I_O = 1.45 A)

9.2.2 Light-load Operation (Green Mode, Burst Oscillation)

The lighter the load becomes, the lower the FB/OLP pin voltage decreases. When the FB/OLP pin voltage decreases to $V_{FB(FDS)}$ = 3.60 V (typ.) or less, the power supply IC shifts to the green mode and continues to reduce the frequency until the FB/OLP pin voltage reaches $V_{FB(FDE)}$ = 3.10 V (typ.).

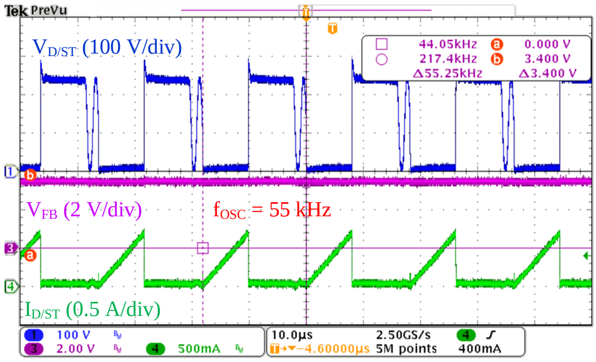


Figure 9-13. Operational Waveforms at Light Load (V_{IN} = 90 VAC, I_O = 1.0 A)

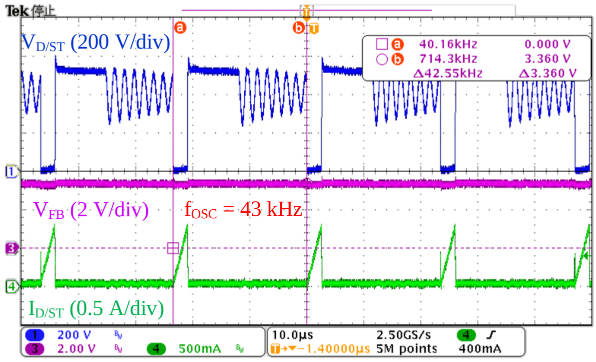


Figure 9-14. Operational Waveforms at Light Load (V_{IN} = 288 VAC, I_O = 1.0 A)

After the operational transition to the green mode, the FB/OLP pin voltage decreases. When the FB/OLP pin voltage reaches a preset standby operating point, the power supply IC shift into the burst oscillation operation.

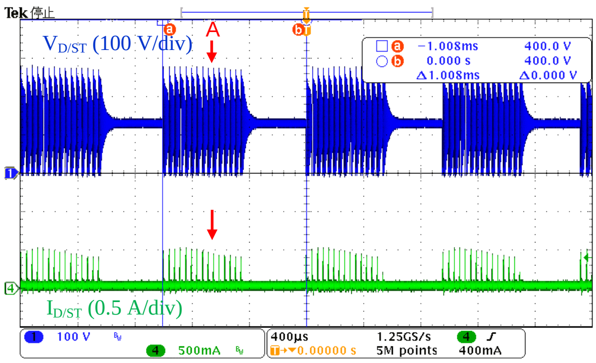


Figure 9-15. Operational Waveforms at Light Load (V_{IN} = 90 VAC, I_O = 0.1 A)

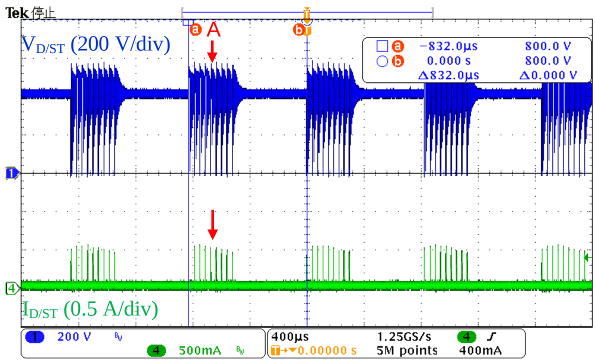


Figure 9-16. Operational Waveforms at Light Load (V_{IN} = 288 VAC, I_O = 0.1 A)

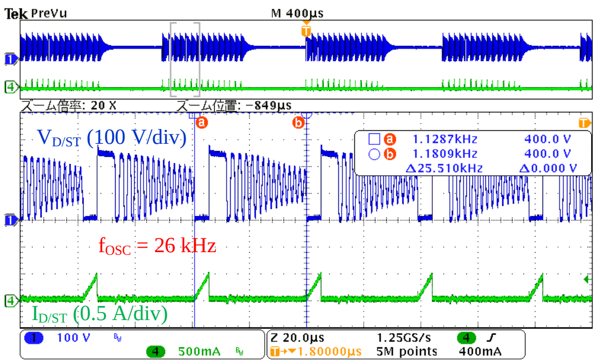


Figure 9-17. Operational Waveforms at Light Load (Expanded Scale of A in Figure 9-15)

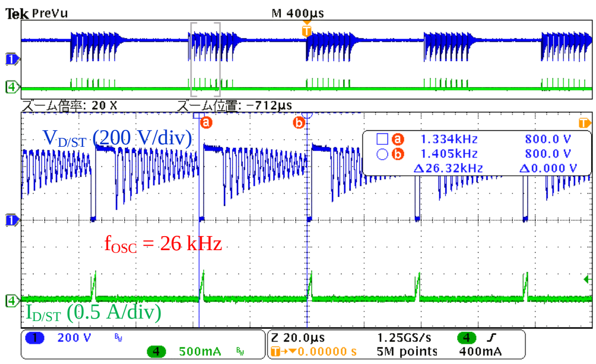


Figure 9-18. Operational Waveforms at Light Load (Expanded Scale of A in Figure 9-16)

9.2.3 No-load Operation (Burst Oscillation)

The burst oscillation period changes according to loads. The burst oscillation period at no load, T_{STBOP}, of the design example is defined as follows: 32 ms when V_{IN} = 90 VAC, and 34 ms when V_{IN} = 288 VAC.

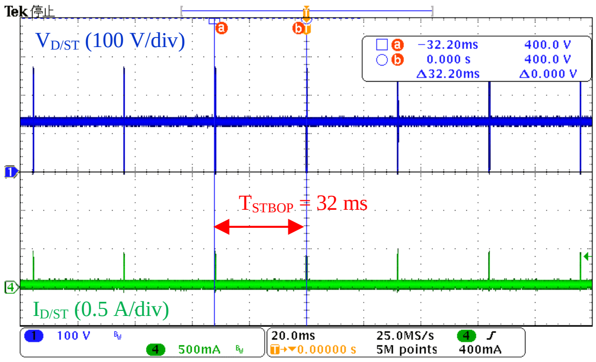


Figure 9-19. Operational Waveforms at No Load (V_{IN} = 90 VAC, I_O = 0 A)

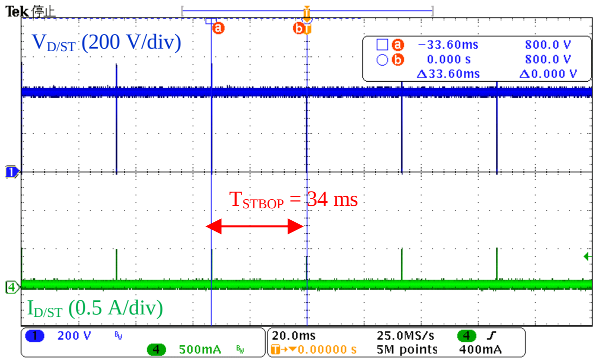


Figure 9-20. Operational Waveforms at No Load (V_{IN} = 288 VAC, I_O = 0 A)

9.3 Output Ripple Voltage

The design example has output ripple voltages as follows: about 370 mV when V_{IN} = 90 VAC, and about 260 mV when V_{IN} = 288 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

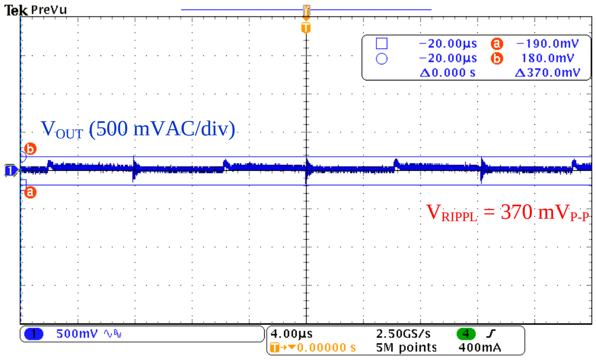


Figure 9-21. Output Ripple Voltage Waveform (V_{IN} = 90 VAC, I_O = 1.45 A)

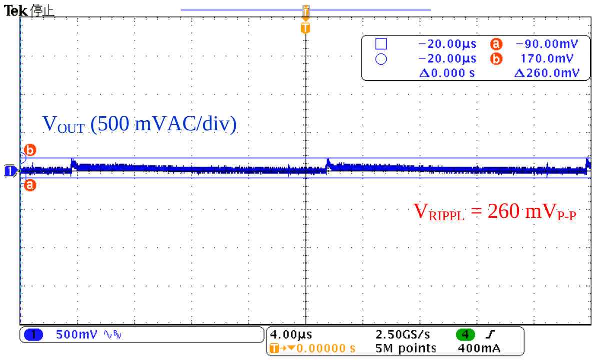


Figure 9-22. Output Ripple Voltage Waveform (V_{IN} = 288 VAC, I_O = 1.45 A)

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}. The equation below defines the relationship between I_{DLIM} and the current-sensing resistor R6:

$$I_{DLIM} = \frac{V_{OCP(H)}}{R6}. \qquad (4)$$

Where:

$V_{OCP(H)}$ is the OCP threshold voltage when STR6S161HXD = 36% duty cycle, and
R6 is the resistance of the current-sensing resistor R6.

When the FB/OLP pin voltage exceeds the OLP threshold voltage, $V_{FB(OLP)}$ = 7.3 V (typ.), and remains exceeded for the OLP delay time, t_{OLP} = 75 ms (typ.) or longer, the overload protection (OLP) is activated to stop switching operation. During the OLP operation, the intermittent oscillation operation repeated by the VCC pin voltage will reduce stresses on components such as the power MOSFET and the secondary rectifier diode. When the causes of the overload condition are eliminated, the power supply IC automatically returns to its normal operation.

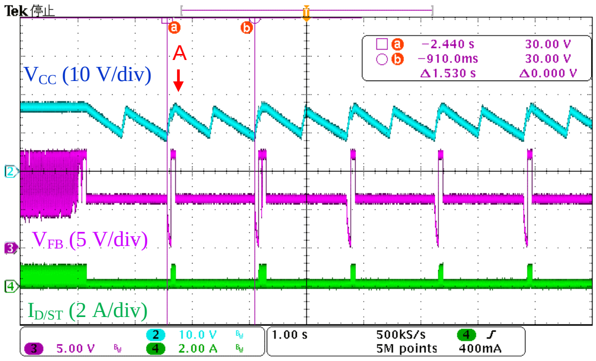


Figure 9-23. OCP and OLP Operational Waveforms (V_{IN} = 90 VAC, I_O > 1.45 A)

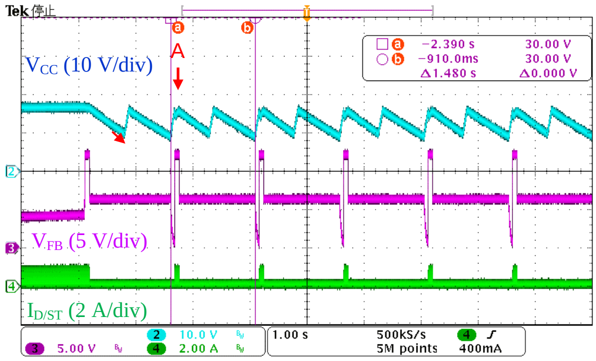


Figure 9-24. OCP and OLP Operational Waveforms (V_{IN} = 288 VAC, I_O > 1.45 A)

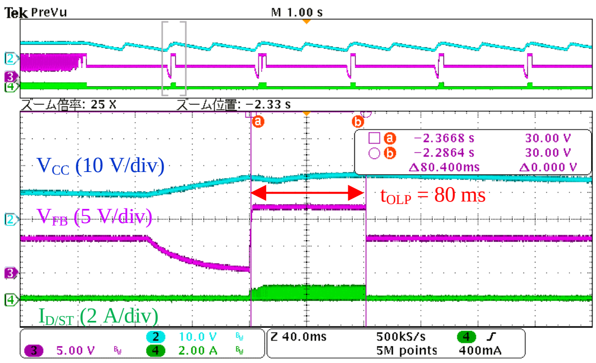


Figure 9-25. OCP and OLP Operational Waveforms (Expanded Scale of A in Figure 9-23)

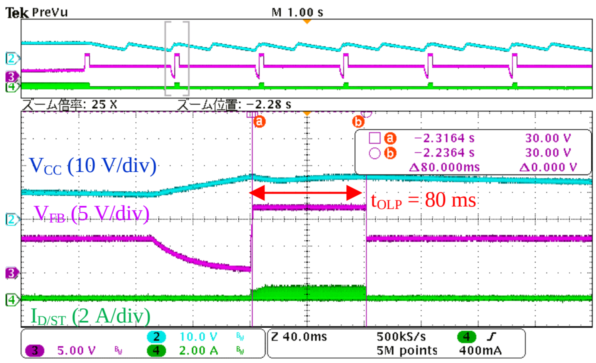


Figure 9-26. OCP and OLP Operational Waveforms (Expanded Scale of A in Figure 9-24)

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, $V_{CC(OVP)}$ = 29.1 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.

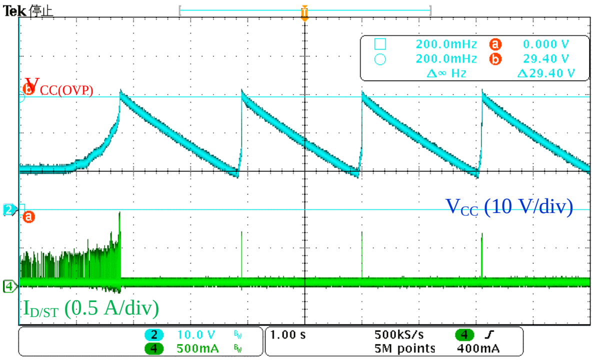


Figure 9-27. OVP Operational Waveforms (V_{IN} = 90 VAC, I_O = 0 A)

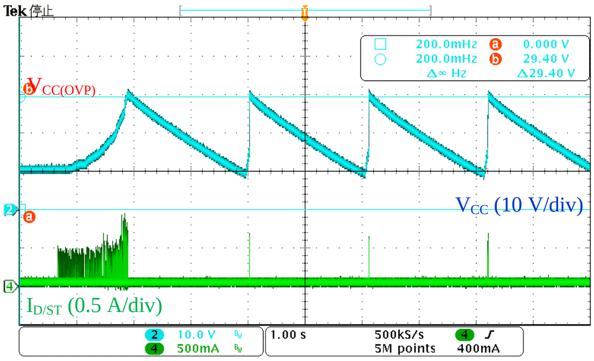


Figure 9-28. OVP Operational Waveforms (V_{IN} = 288 VAC, I_O = 0 A)

9.6 HVP Operation

When the BR pin voltage increases to $V_{BR(HVP)}$ = 5.51 V (typ.) or more, the switching operation stops. When the BR pin voltage decreases to $V_{BR(HVPR)}$ = 5.39 V (typ.) or less along with a lowering in the AC input voltage, the IC resumes switching operation.

Figure 9-29 shows operational waveforms during the HVP operation. When the smoothed voltage reaches 468 V (input voltage is 330 VAC) along with an increase in the input voltage, the IC stops oscillating. Note that the peak drain voltage is about 632 V. The peak drain voltage is less than the breakdown voltage of 700 V of the IC. Figure 9-30 shows the waveforms at HVP release. When the smoothed voltage decreases to 452 V (input voltage is 320 VAC) along with a lowering in the input voltage, the IC resumes oscillating. Note that the peak drain voltage is about 616 V.

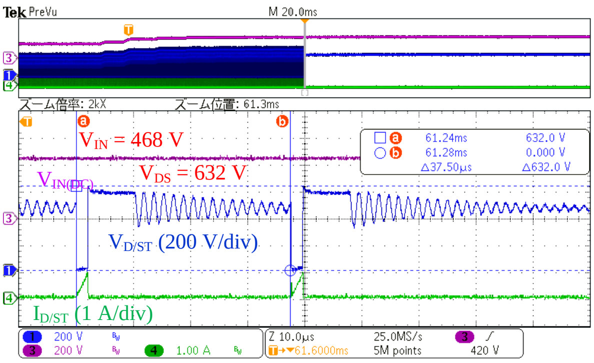


Figure 9-29. HVP Operational Waveforms

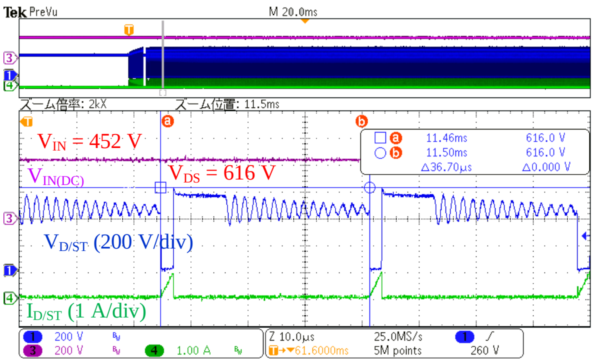


Figure 9-30. Operational Waveforms at HVP Release

9.7 Brown-in and Brown-out Function

When the BR pin voltage decreases to the brown-out threshold voltage, $V_{BR(OUT)}$ = 0.85 V (typ.) or less and this condition persists for the OLP Delay Time, t_{OLP} = 75 ms (typ.) or longer, the switching operation stops even with the IC being in an operation state (i.e., $V_{CC(OFF)} \leq V_{CC}$). When the BR pin voltage increases to the brown-in threshold voltage, $V_{BR(IN)}$ = 1.11 V (typ.) or more along with an increase in the AC input voltage, the IC starts switching operation.

Figure 9-31 shows waveforms during the brown-out operation. When the smoothed voltage decreases to 72 V (input voltage is 51 VAC) along with a lowering in the input voltage, the IC stops oscillating. Figure 9-32 shows waveforms during the brown-in operation. When the smoothed voltage reaches 96 V (input voltage is 68 VAC) along with an increase in the input voltage, the IC resumes oscillating.

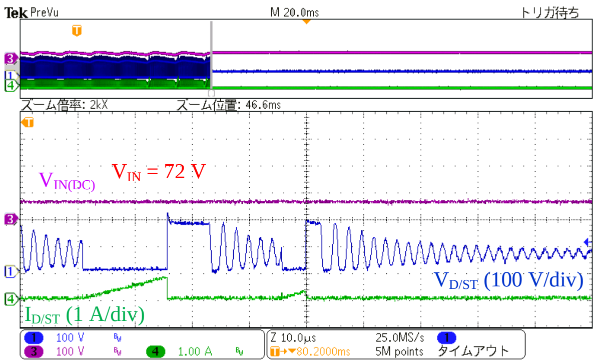


Figure 9-31. Brown-out Operational Waveforms

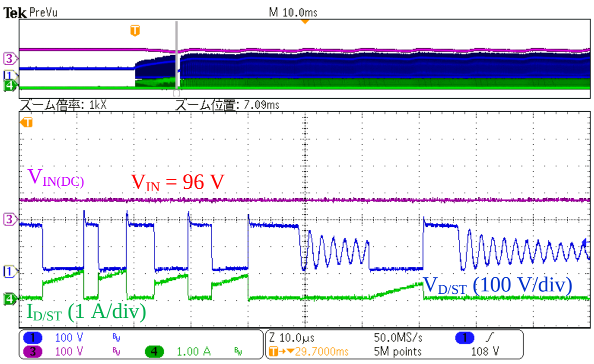


Figure 9-32. Brown-in Operational Waveforms

9.8 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 = 1.45 A)

Ambient Temperature (°C)	Input Voltage (VAC)	Care Temperatures in Normal Operation (°C)		
		Power Supply IC (U1)	Secondary Rectifier Diode (D51)	Transformer (T1)
25	90	73.5	73.1	48.3
	288	54.8	74.6	47.6
50*	90	98.5	98.1	73.3
	288	79.8	99.6	72.6

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

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 = 1.45 A, FG = open
Test mode: Average

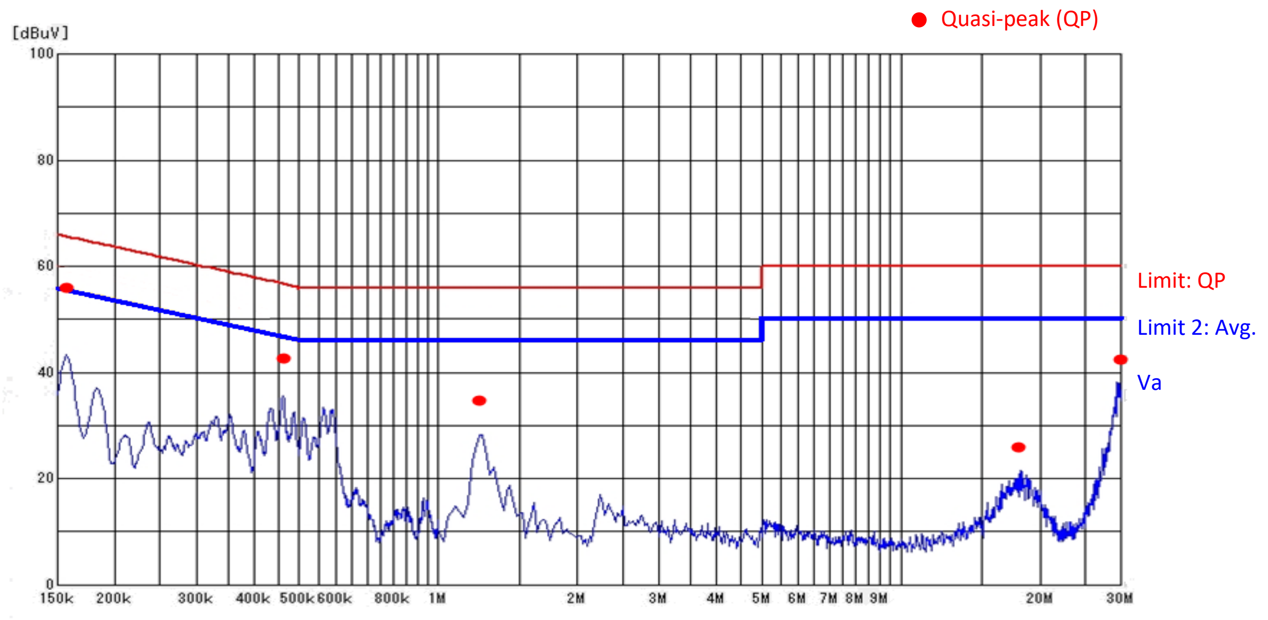


Figure 10-1. EMI Measurement Result (Live, V_{IN} = 100 VAC)

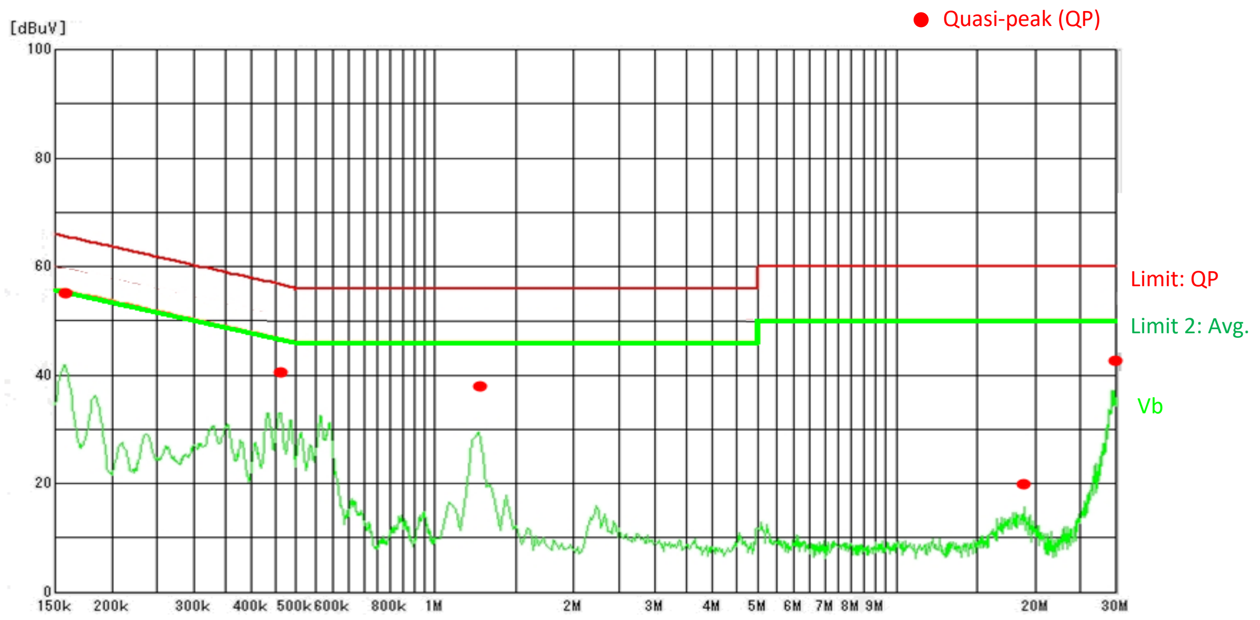


Figure 10-2. EMI Measurement Result (Neutral, V_{IN} = 100 VAC)

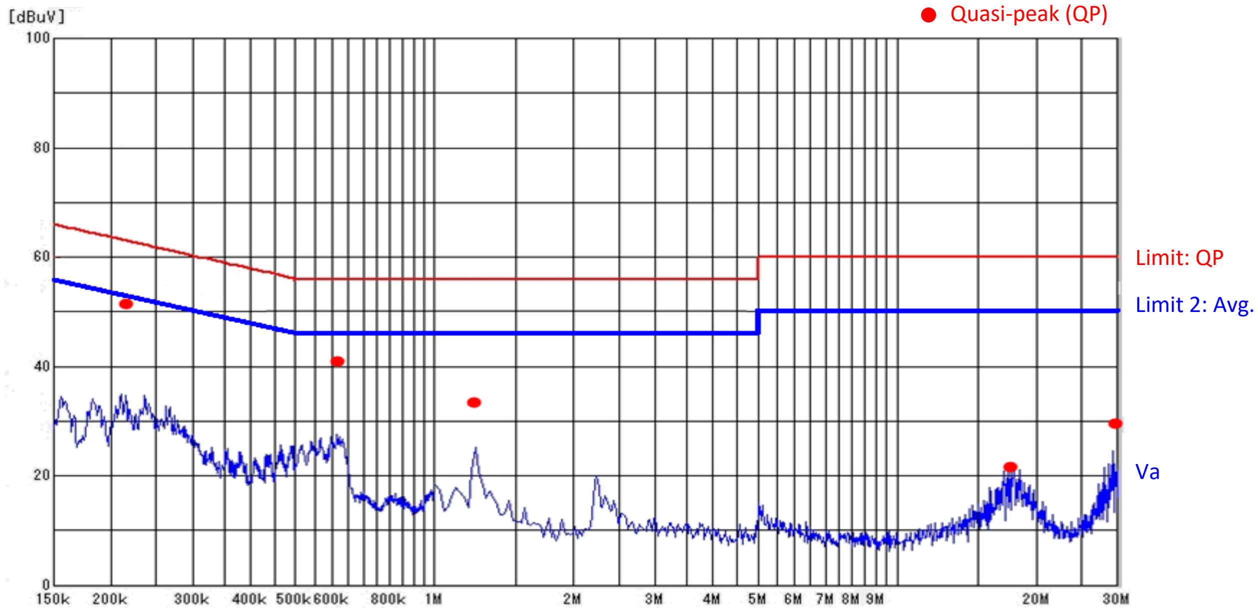


Figure 10-3. EMI Measurement Result (Live, V_{IN} = 230 VAC)

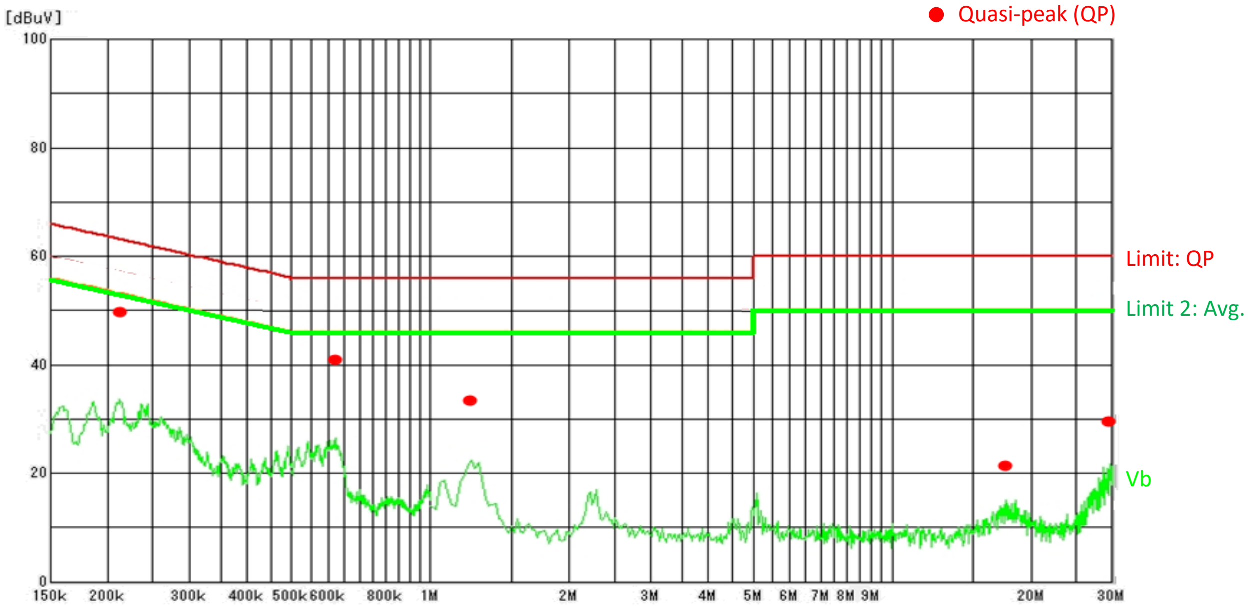


Figure 10-4. EMI Measurement Result (Neutral, V_{IN} = 230 VAC)

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