AC/DC Converter

Built-in SiC MOSFET Isolation Fly-back Converter

Quasi-Resonant method 48 W 24 V

BM2SCQ123T-LBZ Reference Board

User’s Guide

<High Voltage Safety Precautions>

◇ Read all safety precautions before use

Please note that this document covers only the BM2SCQ123T-LBZ evaluation board (BM2SCQ123T-EVK-001) and its functions. For additional information, please refer to the datasheet.

To ensure safe operation, please carefully read all precautions before handling the evaluation board

Depending on the configuration of the board and voltages used,

Potentially lethal voltages may be generated.

Therefore, please make sure to read and observe all safety precautions described in the red box below.

Before Use

[1] Verify that the parts/components are not damaged or missing (i.e. due to the drops).
[2] Check that there are no conductive foreign objects on the board.
[3] Be careful when performing soldering on the module and/or evaluation board to ensure that solder splash does not occur.
[4] Check that there is no condensation or water droplets on the circuit board.

During Use

[5] Be careful to not allow conductive objects to come into contact with the board.
[6] **Brief accidental contact or even bringing your hand close to the board may result in discharge and lead to severe injury or death.**

Therefore, DO NOT touch the board with your bare hands or bring them too close to the board.
In addition, as mentioned above please exercise extreme caution when using conductive tools such as tweezers and screwdrivers.

[7] If used under conditions beyond its rated voltage, it may cause defects such as short-circuit or, depending on the circumstances, explosion or other permanent damages.
[8] Be sure to wear insulated gloves when handling is required during operation.

After Use

[9] The ROHM Evaluation Board contains the circuits which store the high voltage. Since it stores the charges even after the connected power circuits are cut, please discharge the electricity after using it, and please deal with it after confirming such electric discharge.
[10] Protect against electric shocks by wearing insulated gloves when handling.

This evaluation board is intended for use only in research and development facilities and should by handled **only by qualified personnel familiar with all safety and operating procedures.**
We recommend carrying out operation in a safe environment that includes the use of high voltage signage at all entrances, safety interlocks, and protective glasses.

AC/DC Converter

Built-in SiC MOSFET Isolation Fly-back Converter QR method Output 48 W 24 V BM2SCQ123T Reference Board

BM2SCQ123T-EVK-001

The BM2SCQ123T-EVK-001 evaluation board outputs 24 V voltage from the input of 300 to 900 Vdc. The output current supplies up to 2.0 A. The BM2SCQ123T which is quasi-resonant method DC/DC converter IC built-in 1700 V SiC MOSFET (Silicon-Carbide) is used.

The BM2SCQ123T contributes to low EMI by soft switching in quasi-resonant method. The integrated 1700 V 4 A SiC MOSFET contributes to ease of power supply design. Built-in burst mode reduces power loss at light loads.

The BM2SCQ123T is a ranked product that guarantees a long-term supply for the industrial equipment market.

Figure 1. BM2SCQ123T-EVK-001

Electronics Characteristics

Not guarantee the characteristics, is representative value. Unless otherwise noted: V_{IN} = 600 V, I_{OUT} = 1.0 A, Ta = 25 ℃

Parameter	Min	Typ	Max	Units	Conditions
Input Voltage Range	300	600	900	V	
Output Voltage	21.6	24.0	26.4	V	
Maximum Output Power	-	-	48	W	I_{OUT} = 2 A
Output Current Range *(NOTE1)*	0.0	1.0	2.0	A	
Stand-by Power	-	310	-	mW	I_{OUT} = 0 A
Efficiency	-	90	-	%	I_{OUT} = 2 A
Output Ripple Voltage *(NOTE2)*	-	100	-	mVpp	
Operating Temperature Range	-10	+25	+65	℃	

(NOTE1) Please adjust operating time, within any parts surface temperature under 105 ℃

(NOTE2) Not include spike noise

Operation Procedure

1. Operation Equipment
   - (1) 3-Phase AC Power supply 210 ~ 480 Vac, or DC Power supply 300 ~ 900 Vdc, over 50W
   - (2) Electronic Load capacity 2.0 A
   - (3) Multi meter

2. Connect method

3-phase AC power supply or a DC power supply can be used as an input power supply.

*In the case of 3-phase AC Power supply

(1) AC power supply presetting range 210 ~ 480 Vac, Output switch is off.
(2) AC power supply terminals connect to the CN1 of the board.
(3) AC power meter connect between AC power supply and board

*In the case of DC Power supply

(1) DC power supply presetting range 300 ~ 900 Vdc, Output switch is off.
(2) DC power supply + (VIN) terminal connect to the board DC of CN2-1, and – (GND) terminal connect to its CN2-3
(3) DC power meter connect between DC power supply and board

* From below on, common operation

(4) Load + terminal connect to VOUT, GND terminal connect to GND terminal
(5) Output test equipment connects to output terminal
(6) Power supply switch ON.
(7) Check that output voltage is 24 V.
(8) Electronic load switch ON.
(9) Check output voltage drop by load connect wire resistance

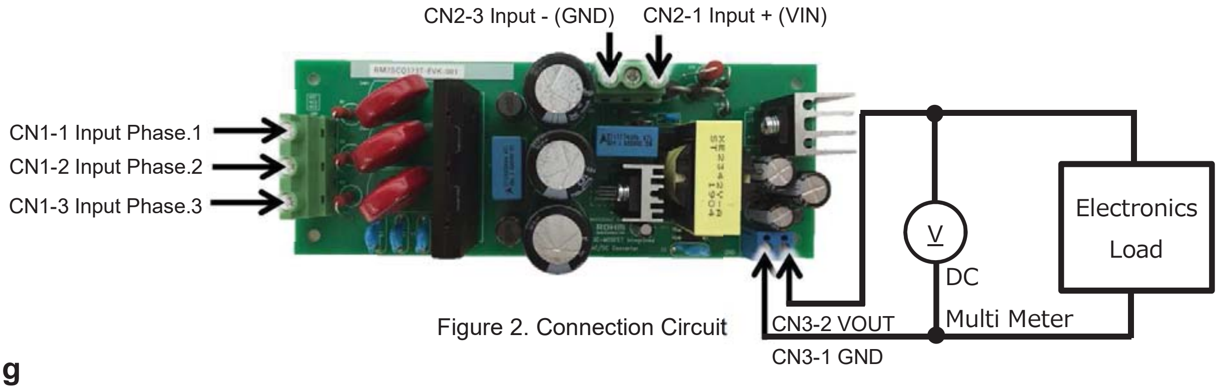


Figure 2. Connection Circuit

Deleting

Maximum Output Power Po of this reference board is 48 W.

The derating curve is shown on the right. If ambient temperature is over 45℃,

Please adjust load continuous time by over 105 ℃ o f any parts surface temperature.

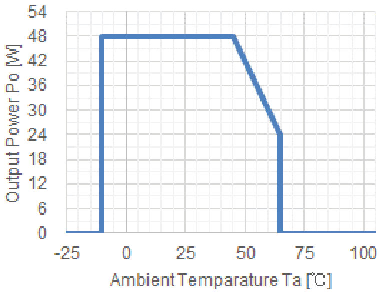


Figure 3. Temperature Deleting curve

Application Circuit

BM2SCQ123T-EVK-001 is a fly-back type circuit method, built in AC/DC IC: BM2SCQ123T-LBZ.
BM2SCQ123T-LBZ contributes to energy saving, because of built-in SiC MOSFET which is high withstand voltage V_{DSS}: 1700 V and a low on resistance $R_{DS(ON)}$:1.12 Ω. Compared with general application circuits using Si-MOSFET, the number of parts is reduced, contributing to miniaturization. The high-breakdown-voltage clamp circuit and the gate clamp circuit and drive circuit required for the SiC MOSFET are built-in, which reduces the number of design steps for adopting the SiC MOSFET, reduces the number of reliability evaluations, reduces the number of component assembly steps, and component failure risk There are various benefits, such as reduction.

The voltage of the output (VOUT) is monitored by a feedback circuit and fed back to the FB terminal of IC1 through a photo coupler. The ZT pin of IC1 realizes a quasi-resonant system by indirectly monitoring the waveform of the drain voltage of the MOSFET from the auxiliary winding of VCC.
At startup, the VCC voltage is raised by supplying VIN to CVCC through the startup resistor: RSTART. IC operation starts when the VCC voltage exceeds the UVLO release voltage 19.5V typ.

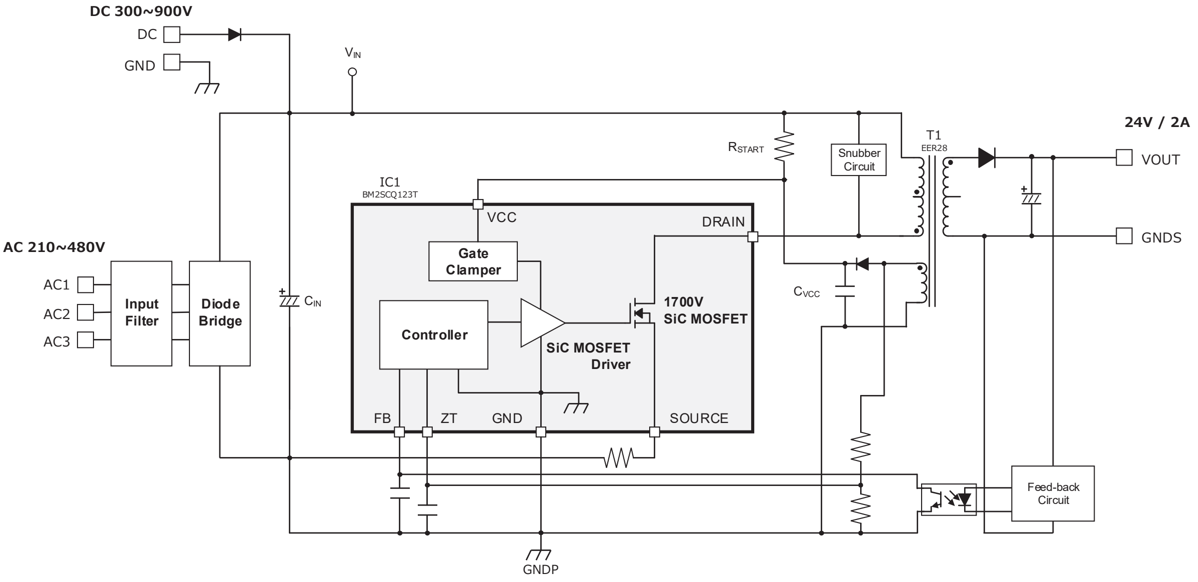


Figure 4. BM2SCQ123T-EVK-001 Application Circuit

Application Circuit – Continued

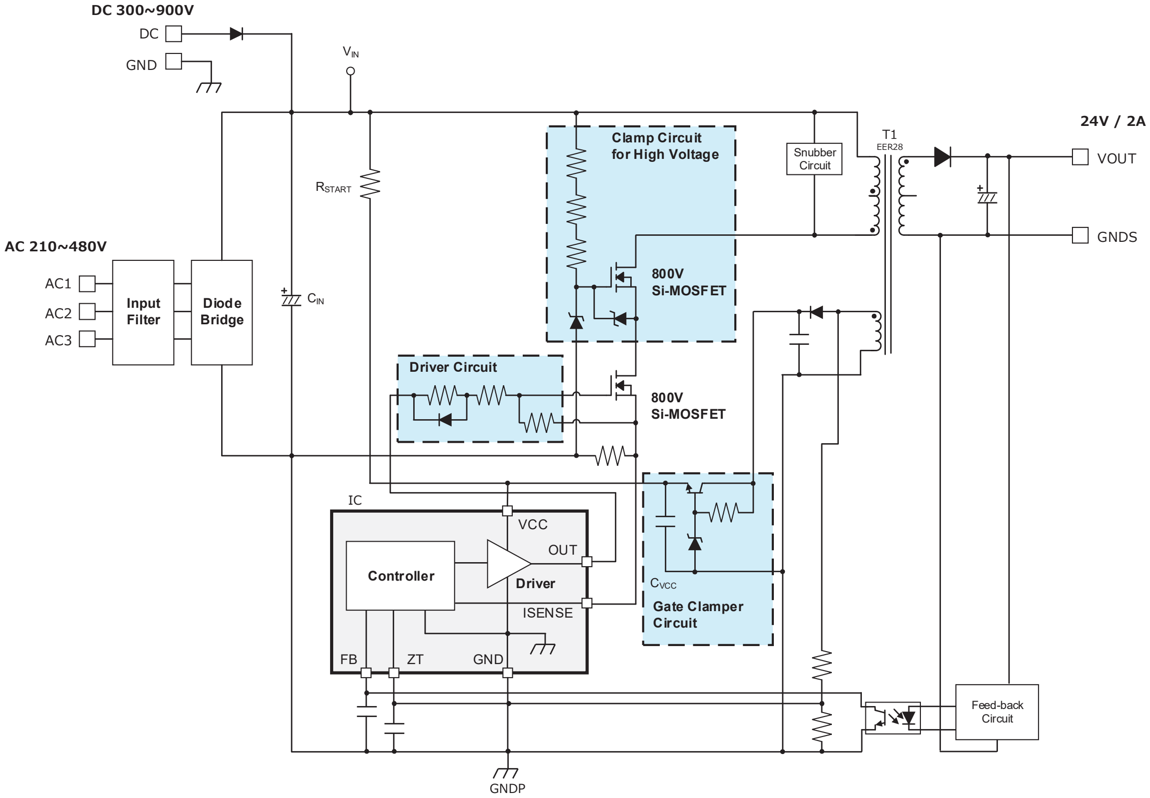


Figure 5. General application circuit compatible with high input voltage

BM2SCQ123T Overview

Feature

- Long Time Support Product for Industrial Application
- 6 Pins: TO-220-6 Package
- Built-in 1700 V/ 4 A/ 1.12 Ω SiC MOSFET
- Quasi-resonant Type (Low EMI)
- Frequency Reduction Function
- Low Current Consumption(19 μA) during Standby
- Burst Operation at Light Load
- SOURCE Pin Leading Edge Blanking
- VCC UVLO (Under Voltage Drop Out protection)
- Soft Start Function
- ZT Pin Trigger Mask Function
- ZT OVP (Over Voltage Protection)

Key specifications

■ Operation Voltage Range:	VCC:	15.0 V ~ 27.5 V
	DRAIN:	1700 V(Max)
■ Normal Operating Current:		2000 μA(Typ)
■ Burst Operating Current:		500 μA(Typ)
■ Maximum Switching Frequency:		120 kHz(Typ)
■ Operating Temperature:		-40 ℃ ~ +105 ℃
■ MOSFET Ron:		1.12 Ω(Typ)

Series Line-up

Product Name	FB OLP	VCC OVP
BM2SCQ121T-LBZ	Auto Restart	Latch
BM2SCQ122T-LBZ	Latch	Latch
BM2SCQ123T-LBZ	Auto Restart	Auto Restart
BM2SCQ124T-LBZ	Latch	Auto Restart

Application

Power supply for Industrial Equipment, AC Adaptor, Household Application

Dimension

	W(Typ) x D(Typ) x H(Max)
TO220-6	10.0 mm x 4.5 mm x 25.6 mm

Figure 6. TO220-6 Package

(*) Product structure: Monolithic integrated circuit mainly made of silicon and silicon carbide. No radiation resistant design

(*) Exceeding the absolute maximum ratings, such as applied voltage and operating temperature range, may lead to deterioration or destruction. Also, the short mode or open mode cannot assume the destruction state. If a special mode that exceeds the absolute maximum rating is assumed, Please consider physical safety measures such as fuses.

Table 1. BM2SCQ123T PIN description

No.	Name	I/O	Function	ESD Diode	
				VCC	GND
1	DRAIN	I/O	MOSFET DRAIN pin	-	✓
2	SOURCE	I	MOSFET SOURCE pin	✓	✓
3	FB	I	Feed-back input pin	✓	✓
4	GND	I/O	GND pin	✓	-
5	ZT	I	Zero current detection pin	-	✓
6	VCC	I	Power supply input pin	-	✓

Design Overview

1 Important parameter

- V_{IN} : Input Voltage Range AC 210 V ~ 480 Vac (DC 300 V ~ 900 V)
- V_{OUT} : Output Voltage DC 24 V
- I_{OUT}(typ) : Constant Output Current 1.0 A
- I_{OUT}(max) : Maximum Output Current 2.0 A
- f_{SW} : Max Switching Frequency min:106 kHz, typ:120 kHz, max:134 kHz
- V_{LIM1A} : Over Current Detection Voltage min:0.95 V, typ:1.00 V, max:1.05 V

Quasi-resonant converter is a self-excited fly-back converter power supply system that utilizes voltage resonance of transformer primary winding inductor and resonance capacitor. In general, quasi-resonant converters can reduce losses and noise more than PWM fly-back converters. In a quasi-resonant converter, the operation mode is discontinuous at light loads, and the switching frequency rises with the load. After that, it becomes boundary operation at a certain load, and in this state the switching frequency decreases as the load rises. The relationship between output load and switching frequency is shown in Figure 7-1. In addition, Figure 7-2 shows the switching waveforms during boundary operation and discontinuous operation.

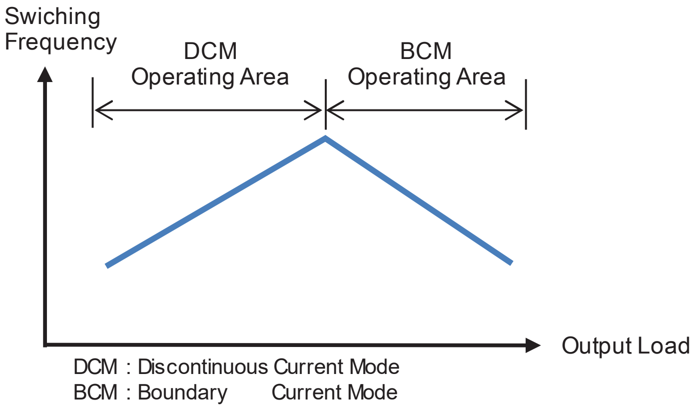


Figure 7-1. Output Load vs. Switching Frequency

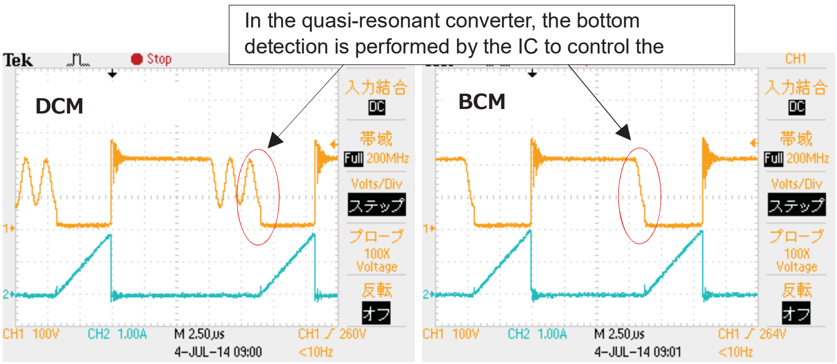

In the quasi-resonant converter, the bottom detection is performed by the IC to control the

Figure 7-2. Switching waveform (MOSFET V_{DS}, I_{DS})

Design Overview – Continued

2 Transformer design

2.1 Determination of fly-back voltage VOR

Determine the fly-back voltage VOR and calculate the turns ratio Np: Ns, Duty ratio. With VIN (min) = 300 V and Vf = 1.5 V, aim VOR to about 100 V.

In this case, the turns ratio Np: Ns = 4.4 determined later.

$$\mathrm{VOR} = (V_{OUT} + V_F) \times \frac{N_p}{N_s} = \frac{t_{on}}{t_{off}} \times V_{IN} = 112.2$$

$$\frac{N_p}{N_s} = \frac{VOR}{V_{OUT} + V_F} = \frac{112.2V}{24V + 1.5V} = 4.4$$

$$\mathrm{Duty}(max) = \frac{VOR}{V_{IN}(min) + VOR} = \frac{112.2\ V}{300\ V + 112.2\ V} = 0.272$$

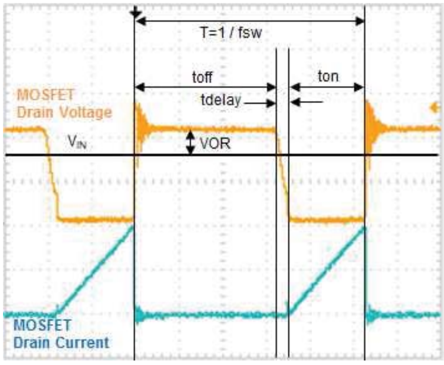


Figure 8. MOSFET Drain waveform

Set VOR so that Duty is 0.5 or less in consideration of MOSFET loss etc.

2.2 Determination of Minimum switching frequency f_{SW} and primary inductance

At minimum input (V_{IN} = 300 V), determine the minimum oscillation frequency f_{SW} at maximum load, and find the primary winding inductance Lp and the maximum primary current I_{PPK}. The minimum oscillation frequency f_{SW} = 30 kHz at the minimum input (V_{IN} = 300 V).Other parameters are as follows.

- Po(max)=52.8 W (derating 0.9) from Po=24 V x 2 A=48 W in consideration of overload protection etc.
- Transfer Efficiency η=90 %
- Capacity for resonance Cv=100 pF

The MOSFET on time t_{ON} is expressed by the following equation

$$I_{PPK} = \frac{V_{IN}(min)}{L_P} \times t_{ON} \rightarrow t_{ON} = I_{PPK} \times \frac{L_P}{V_{IN}(min)}$$

The MOSFET off time t_{OFF} is expressed by the following equation

$$I_{SPK} = \frac{V_{OUT} + V_F}{L_S} \times t_{OFF} \rightarrow t_{OFF} = I_{SPK} \times \frac{L_S}{V_{OUT} + V_F}$$

The half cycle time t_{delay} of the automatic oscillation until the MOSFET turns on is expressed by the following equation.

$$t_{delay} = \pi \times \sqrt{L_P \times C_V}$$

2.2 Determination of Minimum switching frequency f_{SW} and primary inductance - Continued

The peak current on the primary side I_{PPK} is expressed by the following equation

$$I_{PPK} = \sqrt{\frac{2 \times P_O}{\eta \times L_P \times f_{SW}}}$$

Calculate the primary side inductance value L_P such that the lowest oscillation frequency f_{SW} = 30 kHz.

$$f_{SW} = \frac{1}{T} = \frac{1}{t_{ON} + t_{OFF} + t_{delay}} > 30\ [kHz]$$

From the formulas up to the previous page, the primary inductance value is expressed by the following equation.

$$L_P = \left\{ \frac{V_{IN}(min) \times Duty(max)}{\sqrt{\frac{2 \times P_O(max) \times f_{SW}}{\eta}} + V_{IN}(min) \times Duty(max) \times f_{SW} \times \pi \times \sqrt{C_V}} \right\}^2 < 1748\ [\mu H]$$

In this case, L_P = 1700 µH. In this case, the switching frequency f_{SW} is 30.8 kHz, and the primary side peak current I_{PPK} is expressed by the following equation.

$$I_{PPK} = \sqrt{\frac{2 \times P_O(max)}{\eta \times L_P \times f_{SW}}} = 1.50\ [A]$$

2.3 Determination of transfer size

The core size of the transformer selects EER28 from Po(max)=48 W

Table 2. Output Power and Transfer Core

Output Power Po(W)	Core size	Core cross section Ae (mm^2)
~30	EI25/EE25	41
~50	EFD30	68
~60	EI28/EE28/EER28	86
~80	EI33/EER35	107

(*) The above values are guidelines. Please check with the transformer manufacturer etc. for details.

2.4 Calculation of primary turns N_P

The maximum value of the magnetic flux density B (T) of a general ferrite core is 0.4 T @ 100 ℃, so B sat = 0.35 T.

$$N_P > \frac{L_P \times I_{PPK}}{A_e \times B_{sat}} = \frac{1700\ \mu H \times 1.50\ A}{86.3\ mm^2 \times 0.35\ T} = 84.3\ [T]$$

The primary winding number NP should be 85 turns or more. In this case, N_P = 88 turns so that it is tightly wound from the size of the bobbin of the transformer. 2. Transformer design - Continued

2.5 Calculation of primary turns N_S

The secondary winding number N_S is expressed by the following equation.

$$\frac{N_P}{N_S} = 4.08 \rightarrow N_S = \frac{88\ [T]}{4.08} = 21.6 \rightarrow 20\ [\mathrm{T}]$$

In this EVK, we have N_S = 20 turns. Also, to reduce leakage inductance, we have selected 20 turns to be tangled from the size of the transformer bobbin.

2.6 Calculation of VCC turns N_D

When VCC=22 V, V_F_VCC=1 V, N_D is expressed by the following equation.

$$N_D = N_S \times \frac{VCC + V_F\_VCC}{V_{OUT} + V_F} = \frac{22\ V + 1.0\ V}{24\ V + 1.5\ V} = 18.04\ [\mathrm{T}]$$

Selected N_D = 18

When driving a SiC MOSFET, set the VCC to 20 V or more because it is necessary to control the Gate voltage.

The transformer specification is as follows.

Table 3. Transformer Specification（Reference）

Core	EER28 compatible
L_P	1700 µH
N_P	88 turns
N_S	20 turns
N_D	18 turns

2 Transformer Design – Continued

2.7 Transformer design example

Manufacturer: ALPHA TRANS CO,. LTD
〒541-0059 Senbanishi KID Bldg 7F, 4-4-11, Bakurou-machi, Chuo-ku, Osaka
http://www.alphatrans.jp/

Product:	XE2342Y AlphaTrans Corp.
Bobin:	FX-2805 10PIN
Core:	EER28/28

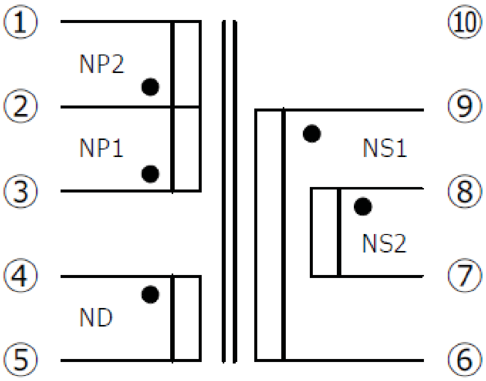


Figure 9. Connection Diagram

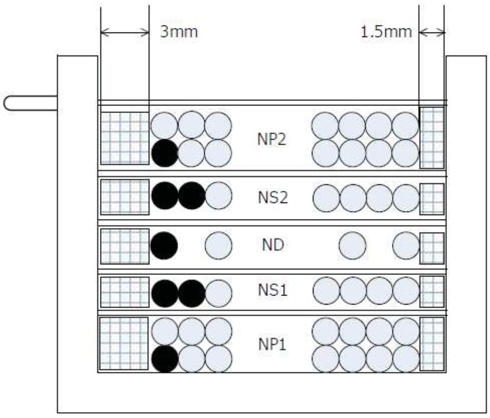


Figure 10. Winding structure diagram

Table 4. Alpha Trans XE2342Y Winding Specification

NO.	WINDING	TERMINAL		WIRE SIZE	TURNS	TAPE LAYERS	WINDING METHOD	NOTE
		START	FINISH					
1	NP1	3	2	2UEW / Φ0.45 * 1	44	1	COMPACT	
2	NS1	9	6	2UEW / Φ0.50 * 1	20	1	COMPACT	
3	ND	4	5	2UEW / Φ0.20 * 1	18	1	SPACE	
4	NS2	8	7	2UEW / Φ0.50 * 1	20	1	COMPACT	
5	NP2	2	1	2UEW / Φ0.45 * 1	44	3	COMPACT	

Inductance (Lp) 1700 μH±15 % (100 kHz, 1 V)

Leakage Inductance	70 μH MAX	
Withstand Voltage	Pri – Sec AC3000 V	
	Pri - Core	AC1500 V
	Sec – Core	AC1500 V
Insulation resistance	100 MΩ over (DC500 V)	

Design Overview - Continued

3 Selection of main parts

3.1 Input Capacitor : C8,C9,C10 Balance Resister : R4,R5,R6,R7,R8,R9

Input capacitor value is selected according to Table 3-3

Table 5. Selection for Intput Capacitor

Input Voltage（Vdc）	C_{IN} (μF)
< 250	2 x P_{OUT} (W)
250 <	1 x P_{OUT} (W)

(*) select according to specifications such as holding time.

From POUT = 48 [W], a capacity equivalent to 48 W x 1 = 48 μF is required.

In this case, three series of 100 μF are considered to be approximately 33 μF in consideration of the withstand voltage and ripple current of the capacitor. The withstand voltage of the capacitor needs more than the maximum input voltage. Assuming a derating of 0.8,It will be VIN (max) / Derating = 900 [V] / 0.8 = 1125 [V].

By using three 450V capacitors in series, the capacitor has a breakdown voltage of 450 V × 3 = 1350 V.

It is important to note that when capacitors are connected in series, a balancing resistor is needed to keep the voltage across all capacitors constant.As resistors are losses, we recommend a resistor of 470 kΩ or more.

Losses of R1, R2, R3, R4, R5 and R6: $P_{R1\text{-}R6}$ are as follows.

$$P_{R1-R6} = \frac{V_{IN}(max)^2}{R4+R5+R6+R7+R8+R9} = \frac{900\ [V]^2}{2820\ [k\Omega]} = 0.287\ [\mathrm{W}]$$

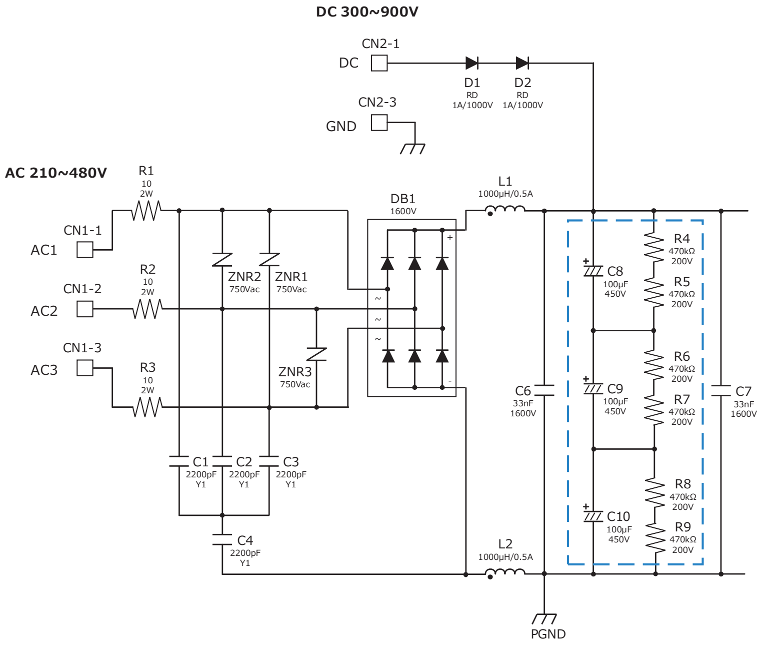


Figure 11. Balance Resistor for Input capacitor

3. Selection of main parts – Continued

3.2 Current detection resistor : R14

Set the overload protection point of the output by limiting the current flowing to the primary side. The higher the input voltage, the shorter the ON time and the higher the switching frequency. As a result, the maximum allowable power increases for certain over-current limiters. The countermeasure is taken by switching the over current protection function inside the IC. For high voltage, determine the ON time or set the current comparator to 0.7 times the normal. The input voltage is detected and switching is performed by monitoring the inflow current of the ZT pin. When the MOSFET is turned on, the ZT pin clamps near 0 V inside the IC. Inflow current: I_{ZT} is expressed by the following equation.

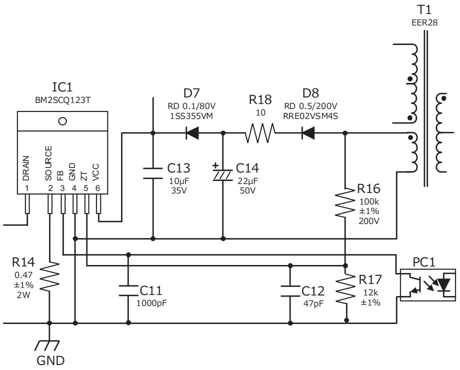


Figure 12. Current detection resistor and ZT circuit

$$I_{ZT} = V_{IN} \times \frac{N_S}{N_P} \div R14$$

Switching of the over current limiter is switched at I_{ZT}: 1 mA. The switching input voltage is V_{IN} = 537 V. Since the overload protection point is at the minimum at the switching voltage, the current detection resistance is calculated at this input voltage.

The overload protection point is the maximum load current I_{OUT} (max): 2.4 A at 2.0 A + 20%. The switching frequency at this time is 35.2 kHz, and the peak current on the primary side: I_{PPK} is 1.46 A. Overcurrent detection voltage: V_{LIM1} is 1.0 V.

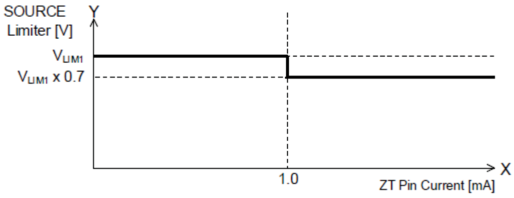


Figure 13. ZT Input current and Over current limit voltage

$$\mathrm{R14} = \frac{V_{LIM1A} \times 0.7}{I_{PPK}} = \frac{0.7\ [V]}{1.46\ [A]} = 0.479\ [\Omega]$$

Current detection resistance: R14 is 0.47 Ω.

In addition, the loss P_{R14} of the current detection resistor is expressed by the following equation.

$$P_{R14}(peak) = {I_{PPK}}^2 \times R14 = 1.46^2 \times 0.47 = 1.00\ [W]$$

$$P_{R14}(rms) = {I_{PRMS}}^2 \times R14 = \left[I_{PPK} \times \sqrt{\frac{Duty(max)}{3}} \right]^2 \times R14 = \left[1.46 \times \sqrt{\frac{0.183}{3}} \right]^2 \times 0.47 = 0.061\ [W]$$

Allowable power should be 1 W or more in consideration of pulse resistance. With regard to pulse resistance, the same power rating may change depending on the structure of the resistor.

Check with the resistor manufacturer to be used.

3. Selection of main parts – Continued

3.3 Resistor for overload protection switching point : R20

It has an overload protection compensation function for the input voltage. There is a delay time before the switching operation is stopped after the IC detects an overload. This delay increases the overload protection point as the input voltage rises. The correction function reduces the current detection level when the input voltage exceeds a certain value. This function compensates for the overload. Set the input voltage as three-phase 380Vac input and proceed with the design. The maximum input voltage of three-phase 380Vac is set from 380 V×$\sqrt{2}$=537 V, and the switching voltage is set to DC 537 V. Note that I_{ZT} in the formula is the current flowing from the IC to the N_D winding of the transformer when switching is ON. By lowering the current detection level when I_{ZT} is above 1 mA, this is the point where the overload protection point can be lowered.

$$\mathrm{R16} = \mathrm{VIN}(change) \times \frac{N_D}{N_P} \times \frac{1}{I_{ZT}} = 537\ V \times \frac{18\ turns}{88\ turns} \times \frac{1}{1\ mA} = 109.8\ [\mathrm{k\Omega}]$$

R16 is 100 kΩ. Next, recheck if the rated load can be taken after the overload protection point has been switched. When the overload protection point switches, Vcs changes from 1.0 V to 0.7 V. Calculate each parameter at this time.

$$I'_{PPK} = \frac{Vcs}{R14} = \frac{0.70\ V}{0.47\ \Omega} = 1.49\ \mathrm{A}$$

$$t'_{ON} = \frac{L_P \times I_{PPK}'}{VIN(change)} = \frac{1700\ \mu H \times 1.49\ A}{537\ V} = 4.72\ \mu sec$$

$$I'_{SPK} = \frac{N_P}{N_S} \times I'_{PPK} = \frac{88\ turns}{20\ turns} \times 1.49\ A = 6.56\ A$$

$$L_S = L_P \times \left(\frac{N_S}{N_P}\right)^2 = 1700\ \mu H \times \left(\frac{20\ turns}{88\ turns}\right)^2 = 87.8\ \mu H$$

$$t'_{OFF} = \frac{L_S \times I_{SPK}'}{V_{OUT} + V_F} = \frac{87.8\ \mu H \times 6.56\ A}{24\ V + 1.5\ V} = 22.59\ \mathrm{\mu sec}$$

$$t_{DELAY} = \pi \times \sqrt{L_P \times C_V} = 3.14 \times \sqrt{1700\ \mu H \times 100\ pF} = 1.29\ \mu sec$$

$$f'_{SW} = \frac{1}{t'_{ON} + t'_{OFF} + t_{DELAY}'} = \frac{1}{4.72\ \mu s + 22.59\ \mu s + 1.29\ \mu s} = 34.97\ [\mathrm{kHz}]$$

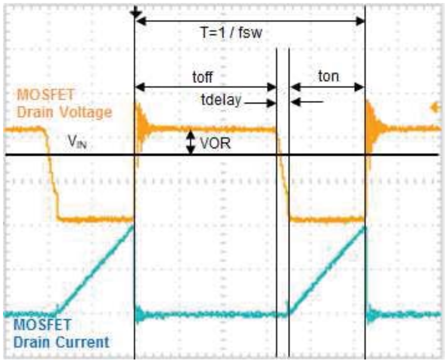


Figure 14. MOSFET Drain Waveform

3.3. Resistor for overload protection switching point: R20 - Continued

The output power after overload switching is the following equation. The conversion efficiency of the transformer is η = 0.9.

$$P_{OUT} = \frac{1}{2} \times L_P \times {I_{PPK}}'^2 \times f_{SW} \times \eta = \frac{1}{2} \times 1700\ \mu\mathrm{H} \times 1.49\ A^2 \times 34.97\ kHz \times 0.9 = 59.39\ [W]$$

It has been confirmed that the maximum output power P_{OUT} (MAX) = 48W can be secured.

As described above, the overload point changes when the input voltage is about 520 V. The measured value of this board is shown in Fig.15. The overload protection point is checked in the product.

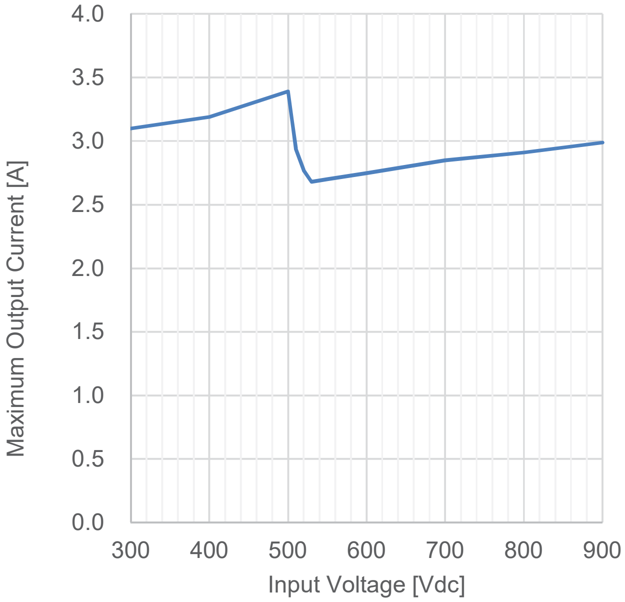


Figure 15. Over Current Detection Result (reference data)

3.4 Resistor for ZT terminal voltage setting : R17

Sets the bottom detection voltage at the ZT terminal.

The bottom detection voltage at the ZT pin is Vzt1 = 100 mV (typ) (when the ZT pin voltage drops), Vzt2 = 200 mV (typ) (when the ZT pin voltage rises), and from ZT OVP (min) = 3.30 V As a guide, set V_{ZT} = 1 to 3 V or so. This time, set V_{ZT} = 2.5 V.

$$V_{ZT} = (V_{OUT} + V_F) \times \frac{N_D}{N_S} \times \frac{R17}{R16 + R17} = 2.5\ V \rightarrow \mathrm{R17} = 12.22\ \mathrm{k\Omega}$$

R17 is 12 kΩ.

3.5 Capacitor for ZT terminal: C12

C12 is a capacitor for stabilization of the ZT pin and timing adjustment for bottom detection. Check and set the ZT terminal waveform and bottom detection timing.

3. Selection of main parts – Continued

3.6 Diode for VCC terminal : D7, D8

For the VCC diode, a high speed diode is recommended. When V_F = 1 V, the reverse voltage V_D applied to the VCC diode is expressed by the following equation.

$$V_D = VCC(max) + V_F + V_{IN}(max) \times \frac{N_D}{N_P}$$

This IC has a VCC OVP function, and VCC OVP (max) = 31.5 V.
Make sure that the reverse voltage of the diode does not exceed the V_D of the diode used even if the VCC voltage rises to VCC OVP.

$$V_D = 31.5\,V + 1.0\,V + 900V \times \frac{18\ turns}{88\ turns} = 216.6\,V$$

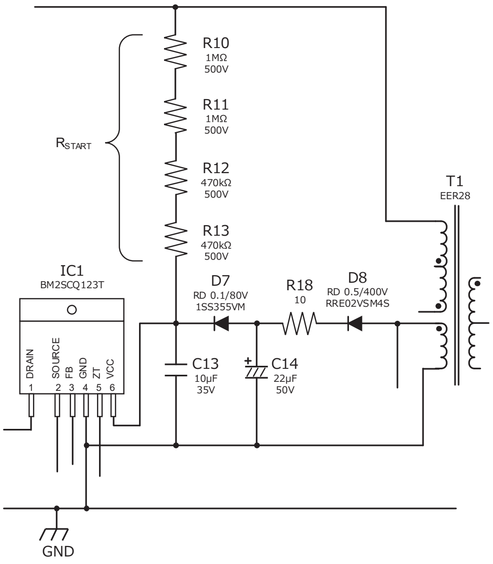


Figure 16. Start-up resistor and VCC capacitor

Select the 216.6 V / 0.7 = 309 V → 400 V product considering the margin.
(Example ROHM RRE02VSM4S 400 V 0.2 A)
D7 uses switching diodes such as 1SS355VM.

3.7 Surge voltage limiting resistor for VCC winding : R18

The transformer's leakage inductance (Lleak) generates a large surge voltage (spike noise) the moment the MOSFET is turned off. This surge voltage may be induced in the VCC winding, and the VCC voltage may rise to affect the VCC over voltage protection of the IC. Insert a limiting resistor R18 (about 5 to 22 Ω) to reduce the surge voltage induced in the VCC winding. Regarding the rise of the VCC voltage, check it in the state of being incorporated in the product.

3.8 Resister for VCC Starter (R_{START}) ; R10,R11,R12,R13 Capacitor ; C13,C14

The startup resistor is a resistor required for the IC to operate. Setting a smaller value for start-up resistor R_{START} increases standby power and shortens start-up time. Conversely, if the value of start resistor R_{START} is increased, standby power will be reduced and start time will be extended. Start-up current from the VCC pin (max) = 30 μA, and with a margin, start-up current consumption (max) = 40 μA. Based on the conditions of start-up input voltage VIN_start = 180 V, VCCUVLO (max) = 20 V, and protection circuit operation VCC current (min) = 0.3 mA, it is expressed by the following equation.

$$R_{START} < \frac{V_{IN\_START} - VCCUVLO(min)}{I_{START}} = \frac{(180\ V - 20\ V)}{40\ \mu A} = 4000\ \text{k}\Omega$$

$$R_{START} > \frac{V_{IN}(MAX) - VCCOVP(max)}{I_{CC\_PROTECT}} = \frac{900\ V - 31.5V}{0.3\ mA} = 2895\ \text{k}\Omega$$

$$2895\ \text{k}\Omega < R_{START} < 4000\ k\Omega$$

From the above, R_{START} = 2940 kΩ (1 MΩ × 2 + 470 kΩ × 2 in series).

3.8. Resister for VCC Starter – Continued

The relationship between start-up time and VCC capacitor value is shown in Figure 17.

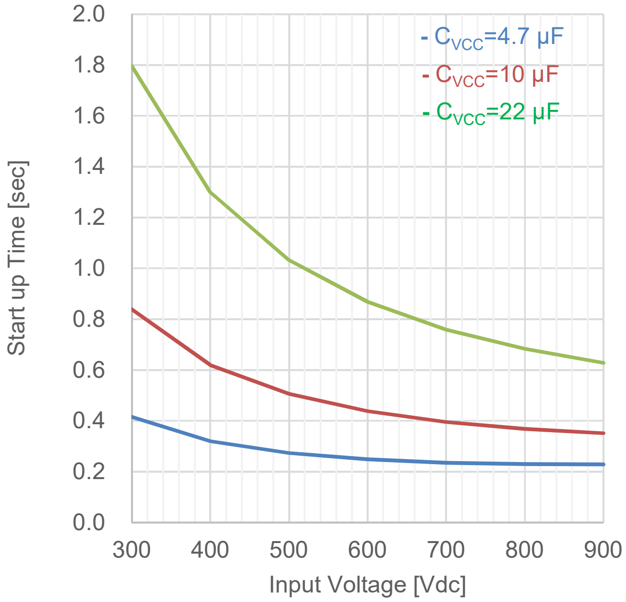


Figure 17. Start-up Time (reference data)

The VCC capacitor C_{VCC} is required to stabilize the VCC voltage of the IC.
The recommended capacity is 4.7 µF to 22 µF. This example recommends the circuit in Figure.16 for start-up time and stability. At startup, only C13 operates because of high-speed startup, and C14 operates when the output voltage becomes equal to or higher than a certain voltage after startup.

3.9 Snubber circuit : C_snubber, R19, D3,D4,D5,D6

The transformer leakage inductance (L_{LEAK}) generates a large surge voltage (spike noise) the moment the MOSFET is turned off. This surge voltage is applied between the drain and source of the MOSFET, and in the worst case, the MOSFET may be destroyed. A RCD snubber circuit is recommended to suppress this surge voltage.

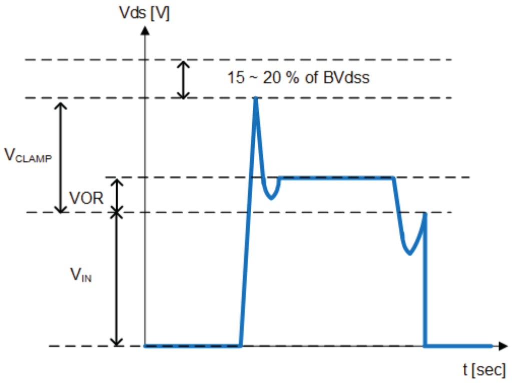


Figure 18. MOSFET Drain voltage waveform

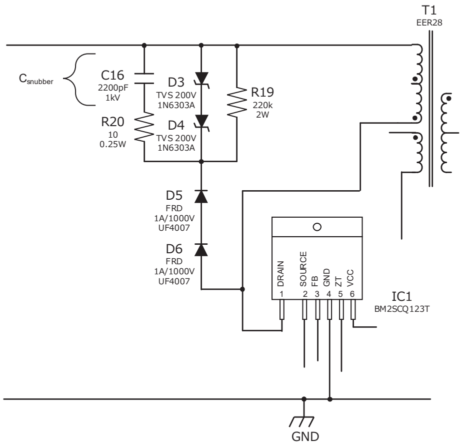


Figure 19 Snubber circuit

3.9. Snubber circuit - Continued

i. Determination of clamp voltage (V_{CLAMP}) and clamp Ripple voltage (V_{RIPPLE})

The clamp voltage is determined by taking into consideration the margin from the breakdown voltage of the MOSFET.

$$V_{CLAMP} = V_{DS} \times 0.8 - V_{IN}(max) = 1700\ V \times 0.8 - 900\ V = 460\ V$$

Set the clamp ripple voltage (V_{RIPPLE}) to about 50 V.

ii. Determination of snubber resistance:R19

The snubber resistance is selected to satisfy the following conditions.

$$R_{SNUBBER} < 2 \times V_{CLAMP} \times \frac{V_{CLAMP} - VOR}{L_{LEAK} \times {I_P}^2 \times f_{SW}(max)}$$

L_{LEAK} is 70 µH from the transformer specification. The primary side peak current when P_{OUT} = 48 W, V_{IN} (max) = 900 V: I_{PPK} and switching frequency: f_{SW} are calculated from the following equation.

$$I_{PPK} = \frac{V_{CS}}{R14} = \frac{0.7\ V}{0.47\ \Omega} = 1.49\ [\mathrm{A}]$$

$$f_{SW} = \frac{1}{t_{ON} + t_{OFF} + t_{DELAY}} = \frac{1}{\left(\frac{L_P}{V_{IN}} \times I_P\right) + \left(\frac{L_S}{V_{OUT} + V_F} \times \frac{N_P}{N_S} \times I_P\right) + \pi \times \sqrt{L_P \times C_V}} = 37.49\ [\mathrm{kHz}]$$

Thus, Snubber resistance: $R_{SNUBBER}$ is expressed by the following equation.

$$R_{SNUBBER} < 2 \times V_{CLAMP} \times \frac{V_{CLAMP} - VOR}{L_{LEAK} \times {I_P}^2 \times f_{SW}(max)} = 2 \times 460\ V \times \frac{460\ V - 112\ V}{70\ \mu H \times 1.49^2\ A \times 37.49\ kHz} = 54.95\ [k\Omega]$$

In fact, due to the influence of the MOSFETs, the snubber resistance is selected to be 220 kΩ from the actual device evaluation, not according to this equation. Snubber resistance loss: $P\_R_{SNUBBER}$ is expressed by the following equation.

$$P\_R_{SNUBBER} = \frac{{V_{CLAMP}}^2}{R_{SNUBBER}} = \frac{460\ V^2}{220\ k\Omega} = 0.96\ [W]$$

Select 2W or more considering the margin.

iii. Determination of Snubber capacitor: $C_{SNUBBER}$: C16 and C17

The snubber capacitor is selected to meet the following conditions.

$$C_{SNUBBER} > \frac{V_{CLAMP}}{V_{RIPPLE} \times f_{SW}(min) \times R_{SNUBBER}} = \frac{1360\ V}{50\ V \times 37.49\ kHz \times 220\ k\Omega} = 3298\ [\mathrm{pF}]$$

3.9. Snubber circuit - Continued

The snubber capacitor is 2200 pF. The voltage applied to $C_{SNUBBER}$ is 1360 V-900 V = 460 V. Look at the margin and make it 600 V or more. In this EVK, the 1000V withstand voltage is selected.

iv. Determination of D5,D6

Use a fast recovery diode for the diode. Make the breakdown voltage higher than the Vds (max) of the MOSFET.
Surge voltage is affected by the pattern of the board as well as the transformer's leakage inductance. Check the Vds voltage with the product incorporated, and adjust the snubber circuit as required.

v. Determination of TVS:D15,D16

For higher protection performance, TVS can be used to clamp transient spice noise. Determine the breakdown voltage and operating waveform of the MOSFET after confirmation.

3.10 Capacitor for FB terminal : C11

C11 is a stabilization capacitor for the FB pin (about 1000 pF to 0.01 uF is recommended).

3.11 Output rectification diode : D9

Use a high speed diode (Schottky barrier diode, fast recovery diode) as the output rectification diode. Assuming that the reverse voltage applied to the output diode is V_F = 1.5 V and V_{OUT} (max) = 24.0 V + 5% = 25.2 V, the reverse voltage V_D applied to the diode of D9 is expressed by the following equation

$$V_D = V_{OUT}(max) + V_F + V_{IN}(max) \times \frac{N_S}{N_P} = 25.2\ \mathrm{V} + 1.5\ \mathrm{V} + 900\ \mathrm{V} \times \frac{20\ turns}{88\ turns} = 231.2\ [\mathrm{V}]$$

Select a 350 V product considering the margin.
The current I_S (rms) flowing through the output diode is expressed by the following equation.

$$I_S(rms) = I_{SPK} \times \sqrt{\frac{1 - Duty}{3}}$$

$$I_{SPK} = \frac{2 \times I_{OUT}(max)}{1 - Duty(max)} = \frac{2 \times 2\ A}{1 - 0.272} = 5.49\ [A]$$

$$I_S(rms) = I_{SPK} \times \sqrt{\frac{1 - Duty}{3}} = 5.49\ A \times \sqrt{\frac{1 - 0.272}{3}} = 2.70\ [A]$$

Also, the diode loss (approximate value) is Pd = Vf x Iout = 1.5 V x 2.7 A = 4.05 W.
(Example: ROHM RFH25TB3SNZ: 350 V 20 A, TO-220 package)

It is recommended to use a voltage margin of 70 % or less and a current of 50 % or less. Check the temperature rise with the product incorporated in the product, re-examine the parts if necessary, and dissipate the heat from the heat sink.

3. Selection of main parts – Continued

3.12 Output Capacitor : C19,C20

The output capacitor is selected by the Peak to Peak Ripple voltage (ΔVpp) and Ripple current that are acceptable at the output load. The output capacitor is selected by the Peak to Peak Ripple voltage and Ripple current that are acceptable at the output load. When the MOSFET is on, the output diode is off. At this time, current is supplied from the output capacitor to the load. When the MOSFET is off, the output diode is on, charging the output capacitor and also providing the load current. Assuming that ΔV_{PP} = 200 mV under the condition (V_{IN} = 300 V, P_{OUT} = 53.3 W) calculated by the transformer calculation,

$$Z_C < \frac{\Delta V_{PP}}{I_{SPK}} = \frac{\Delta V_{PP}}{\frac{N_P}{N_S} \times I_{PPK}} = \frac{200\ mV}{\frac{88\ turns}{20\ turns} \times 1.50\ A} = 33\ [\mathrm{m\Omega}]$$

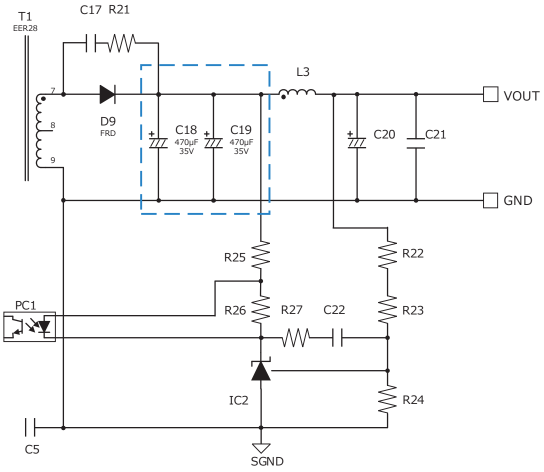


Figure 20 Output Capacitor circuit

A general electrolytic capacitor for switching power supply (low impedance product) has an impedance of 100 kHz, so it is converted to 30.5 kHz.

$$Z_C < 33\ m\Omega \times \frac{30.8\ kHz}{100\ kHz} = 10.2\ [\mathrm{m\Omega}]$$

Also, the ripple current I_C (rms) to the capacitor is expressed by the following equation.

$$I_C(rms) = I_{SPK} \times \sqrt{\frac{1 - Duty}{3}} = \frac{N_P}{N_S} \times I_{PPK} \times \sqrt{\frac{1 - Duty}{3}} = \frac{88\ turns}{20\ turns} \times 1.50\ A \times \sqrt{\frac{1 - 0.272}{3}} = 3.25\ [Arms]$$

$$I_C(rms) = \sqrt{I_S(rms)^2 - {I_{OUT}}^2} = \sqrt{3.25^2 - 2.20^2} = 2.56\ [\mathrm{Arms}]$$

The withstand voltage of the capacitor should be 80 % derating as a guide to the output voltage. 24V / 0.8 = 30 V or more.

Select an electrolytic capacitor that meets these conditions.
In this EVK, low impedance type 35 V 470 µF x 2 parallel for switching power supply: UHD1V471 MPD: made by Rubycon is selected.
Check the actual Ripple voltage and Ripple current on the actual device.

3. Selection of main parts – Continued

3.13 Output Voltage setting resistor: R22,R23,R24

The output voltage is set by the following equation.

$$V_{OUT} = \left(1 + \frac{R22 + R23}{R24}\right) \times Vref$$

Set the feedback current I_{BIAS} flowing to R24 at 0.1 mA to 1.0 mA. Assuming that I_{BIAS} = 0.25 mA, and the reference voltage VREF = 2.485 V of the shunt regulator IC2, the resistance value of R24 is

$$\mathrm{R24} = \frac{V_{REF}}{I_{BIAS}} = \frac{2.485\ V}{0.25\ mA} = 9.9\ [\mathrm{k\Omega}]$$

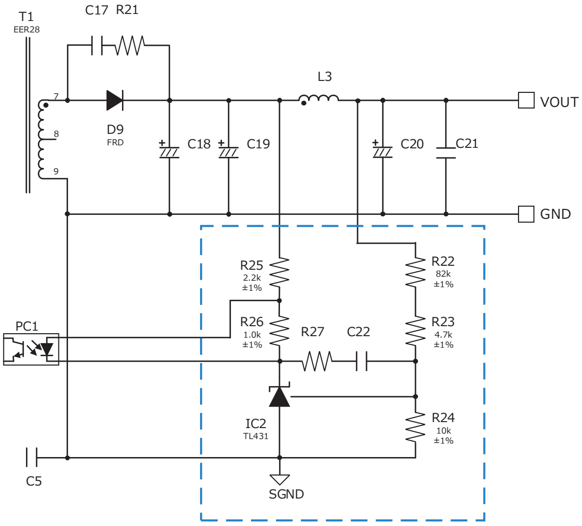


Figure 21. Feed-back Circuit

In this EVK, select R24:10 kΩ.
The combined resistance of the feedback resistors (R22+R23+R24) is

$$\mathrm{R22} + \mathrm{R23} + \mathrm{R24} = \frac{V_{OUT}}{I_{BIAS}} = \frac{24\ V}{0.25\ mA} = 96\ [k\Omega]$$

In this EVK, R22=82 kΩ and R23=4.7 kΩ are selected. The ideal value of the output voltage is as follows.

$$V_{OUT} = \left(1 + \frac{82\ k\Omega + 4.7\ k\Omega}{10\ k\Omega}\right) \times 2.485\ \mathrm{V} = 24.03\ \mathrm{V}$$

3.14 Control circuit adjustment: R25,R26,R27,C22

R24 is the dark current setting resistor for shunt regulator IC2. The current value Imin for stable operation of the shunt regulator is 1.2 mA according to the data sheet of the IC. This current is the combined current of R26 and the photo coupler's IF. Since the voltage applied to R26 is the VF of the photo coupler, assuming that the VF of the photo coupler is 1.1 V,

$$\mathrm{R26} < \frac{V_F}{Imin} = \frac{1.1\ V}{1.2\ mA} = 0.92\ [\Omega]$$

In this EVK, R26=1.0 kΩ is selected. R25 is control circuit current limiting resistor. Adjust with 300~2.2kΩ.
E25=2.2 kΩ is selected.
R27 and C22 are phase compensation circuits. Adjust R27 = 1 to 30 kΩ, C15 = 0.1 µF or so with the actual device.

Design Overview – Continued

4 EMI measures

Check the following as EMI measures.

(*) The constant is reference value. Adjust by the influence of noise

- Additional filter to input parts
- Additional capacitor between primary side and secondary side (CY5 : Y-Cap about 2200 pF)
- Additional RC snubber to secondary rectification diode

5 Output noise measures

Output LC filter as a measure against output noise

Additional capacitor（L: 10 µH C: about 10 µF~330 µF）

(*) The constant is reference value. Adjust by the influence of noise

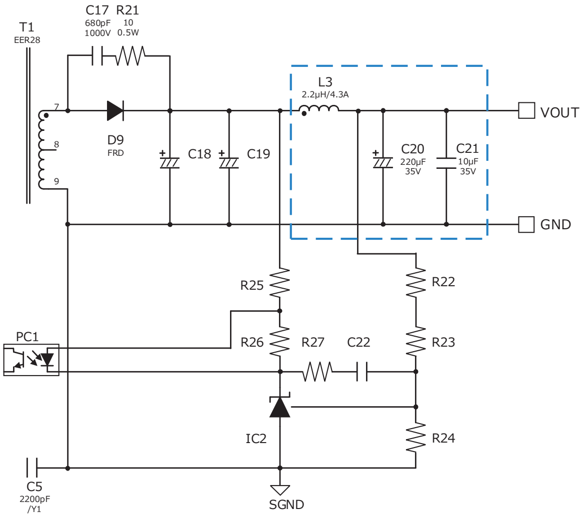
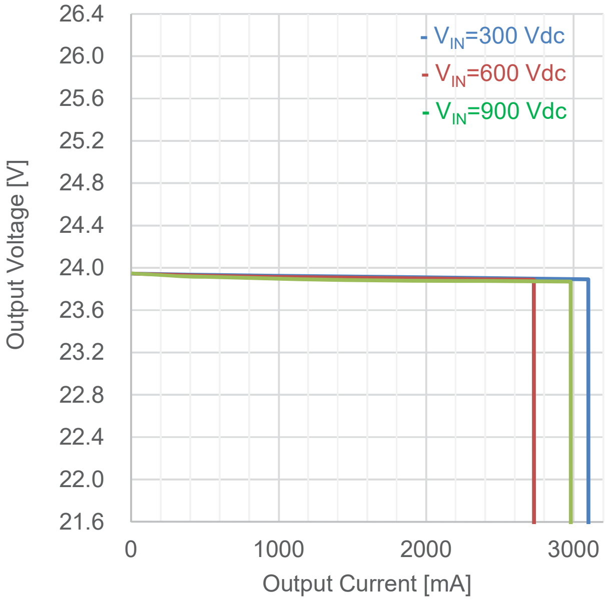


Figure 22. LC filter additional circuit

Performance Data

Load Regulation



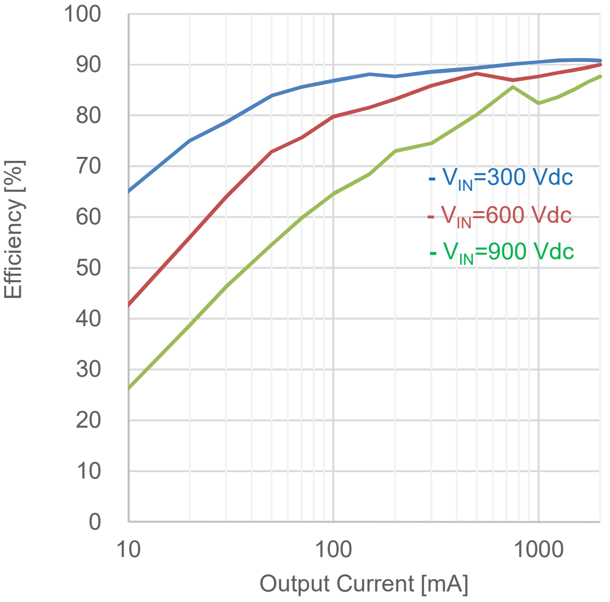


Figure 23. Load Regulation (I_{OUT} vs V_{OUT})

Figure 24. Load Regulation (I_{OUT} vs Efficiency)

Table 6-1. Load Regulation (V_{IN}=300 V)

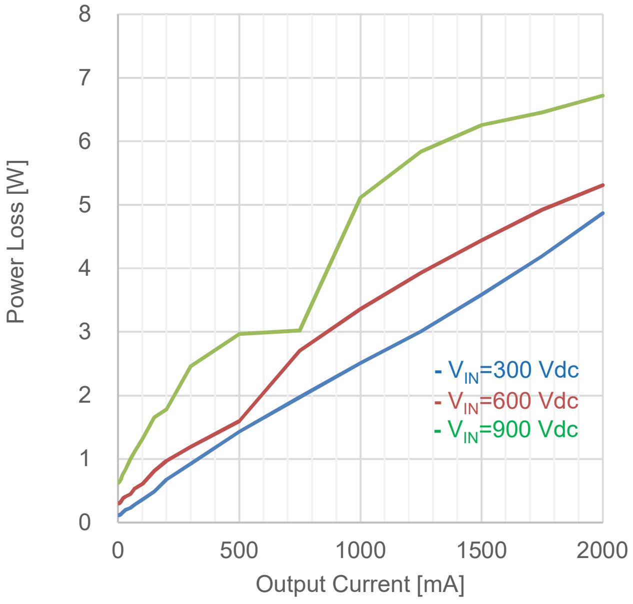
I_{OUT}	V_{OUT}	Efficiency
0.5 A	23.935 V	89.34 %
1.0 A	23.926 V	90.51 %
1.5 A	23.917 V	90.91 %
2.0A	23.908 V	90.76 %

Table 6-2. Load Regulation (V_{IN}=600 V)

I_{OUT}	V_{OUT}	Efficiency
0.5 A	23.927 V	88.22 %
1.0 A	23.915 V	87.68 %
1.5 A	23.905 V	88.98 %
2.0A	23.899 V	90.00 %

Table 6-3. Load Regulation (V_{IN}=900 V)

I_{OUT}	V_{OUT}	Efficiency
0.5 A	23.916 V	80.11 %
1.0 A	23.898 V	82.38 %
1.5 A	23.883 V	85.13 %
2.0A	23.880 V	87.66 %



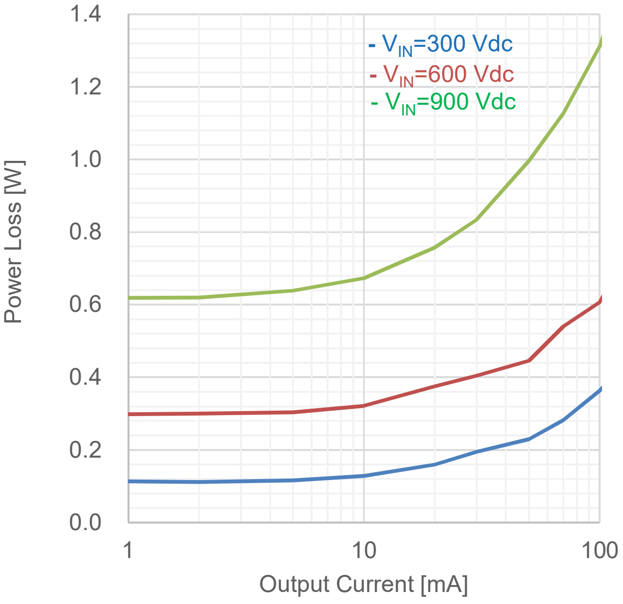


Figure 25. Load Regulation (I_{OUT} vs P_{LOSS})

Figure 26. Load Regulation (I_{OUT} vs P_{LOSS})

Performance Data – Continued

Table 7-1. Load Regulation : V_{IN}=300 Vdc

V_{IN} [Vac]	P_{IN} [W]	V_{OUT} [V]	I_{OUT} [mA]	P_{OUT} [W]	P_{LOSS} [W]	Efficiency [%]
300	0.12	23.945	0	0.000	0.118	0.00
300	0.14	23.945	1	0.024	0.113	17.48
300	0.16	23.945	2	0.048	0.111	30.12
300	0.24	23.945	5	0.120	0.115	50.95
300	0.37	23.945	10	0.239	0.129	65.07
300	0.64	23.945	20	0.479	0.159	75.06
300	0.91	23.945	30	0.718	0.195	78.68
300	1.43	23.944	50	1.197	0.230	83.90
300	1.96	23.944	70	1.676	0.282	85.60
300	2.76	23.943	100	2.394	0.364	86.81
300	4.08	23.942	150	3.591	0.485	88.11
300	5.46	23.941	200	4.788	0.675	87.65
300	8.11	23.939	300	7.182	0.926	88.58
300	13.40	23.935	500	11.968	1.428	89.34
300	19.92	23.931	750	17.948	1.975	90.09
300	26.44	23.926	1000	23.926	2.509	90.51
300	32.91	23.921	1250	29.901	3.008	90.86
300	39.46	23.917	1500	35.876	3.587	90.91
300	46.04	23.913	1750	41.848	4.195	90.89
300	52.69	23.908	2000	47.816	4.869	90.76
300	58.02	23.905	2200	52.591	5.432	90.64
300	63.39	23.902	2400	57.365	6.026	90.49
300	82.21	23.890	3100	74.059	8.154	90.08
300	0.60	0.000	3110	0.000	0.600	0.00

Table 7-2. Load Regulation: V_{IN}=600 Vdc

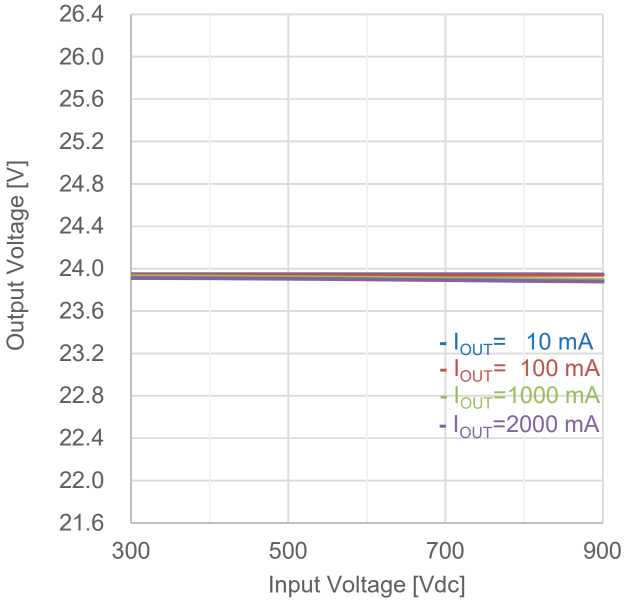
V_{IN} [Vac]	P_{IN} [W]	V_{OUT} [V]	I_{OUT} [mA]	P_{OUT} [W]	P_{LOSS} [W]	Efficiency [%]
600	0.31	23.947	0	0.000	0.308	0.00
600	0.32	23.946	1	0.024	0.298	7.44
600	0.35	23.947	2	0.048	0.300	13.76
600	0.42	23.946	5	0.120	0.303	28.30
600	0.56	23.946	10	0.239	0.322	42.68
600	0.85	23.945	20	0.479	0.375	56.08
600	1.12	23.945	30	0.718	0.405	63.97
600	1.64	23.944	50	1.197	0.446	72.87
600	2.22	23.942	70	1.676	0.540	75.63
600	3.00	23.941	100	2.394	0.607	79.78
600	4.40	23.938	150	3.591	0.811	81.57
600	5.75	23.935	200	4.787	0.967	83.19
600	8.37	23.932	300	7.180	1.187	85.81
600	13.56	23.927	500	11.964	1.598	88.22
600	20.65	23.921	750	17.941	2.704	86.90
600	27.28	23.915	1000	23.915	3.361	87.68
600	33.81	23.909	1250	29.886	3.927	88.39
600	40.30	23.905	1500	35.858	4.441	88.98
600	46.75	23.902	1750	41.829	4.924	89.47
600	53.11	23.899	2000	47.798	5.312	90.00
600	58.41	23.895	2200	52.569	5.841	90.00
600	63.71	23.892	2400	57.341	6.364	90.01
600	72.35	23.887	2730	65.212	7.133	90.14
600	0.30	0.000	2740	0.000	0.300	0.00

Table 7-3. Load Regulation: V_{IN}=900 Vdc

V_{IN} [Vac]	P_{IN} [W]	V_{OUT} [V]	I_{OUT} [mA]	P_{OUT} [W]	P_{LOSS} [W]	Efficiency [%]
900	0.62	23.948	0	0.000	0.623	0.00
900	0.64	23.948	1	0.024	0.619	3.72
900	0.67	23.948	2	0.048	0.620	7.17
900	0.76	23.947	5	0.120	0.638	15.80
900	0.91	23.947	10	0.239	0.673	26.26
900	1.24	23.946	20	0.479	0.758	38.72
900	1.55	23.945	30	0.718	0.834	46.29
900	2.19	23.943	50	1.197	0.997	54.56
900	2.80	23.942	70	1.676	1.126	59.81
900	3.71	23.940	100	2.394	1.312	64.60
900	5.25	23.936	150	3.590	1.657	68.43
900	6.56	23.933	200	4.787	1.775	72.94
900	9.64	23.925	300	7.178	2.460	74.48
900	14.93	23.916	500	11.958	2.969	80.11
900	20.95	23.906	750	17.930	3.021	85.58
900	29.01	23.898	1000	23.898	5.112	82.38
900	35.70	23.890	1250	29.863	5.840	83.64
900	42.08	23.883	1500	35.825	6.256	85.13
900	48.25	23.881	1750	41.792	6.458	86.62
900	54.48	23.880	2000	47.760	6.722	87.66
900	59.84	23.878	2200	52.532	7.308	87.79
900	65.04	23.877	2400	57.305	7.735	88.11
900	80.08	23.871	2980	71.136	8.944	88.83
900	0.68	0.000	2990	0.000	0.680	0.00

Performance Data – Continued

Line Regulation



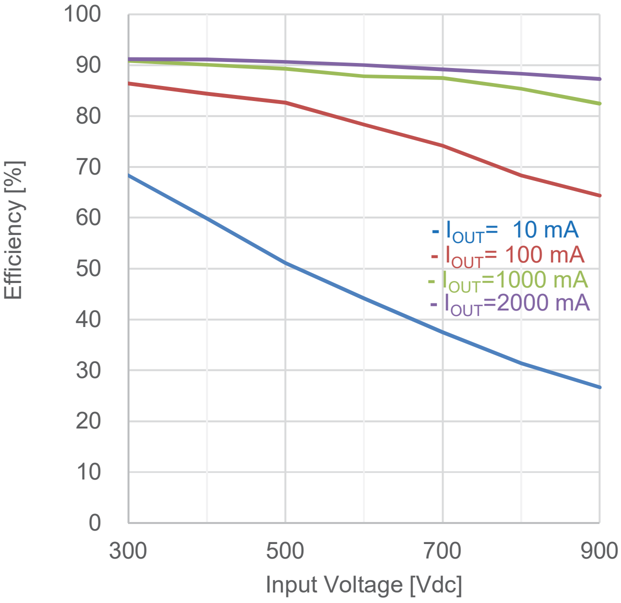


Figure 27. Line Regulation (V_{IN} vs V_{OUT})

Figure 28. Line Regulation (V_{IN} vs Efficiency)

Switching Frequency

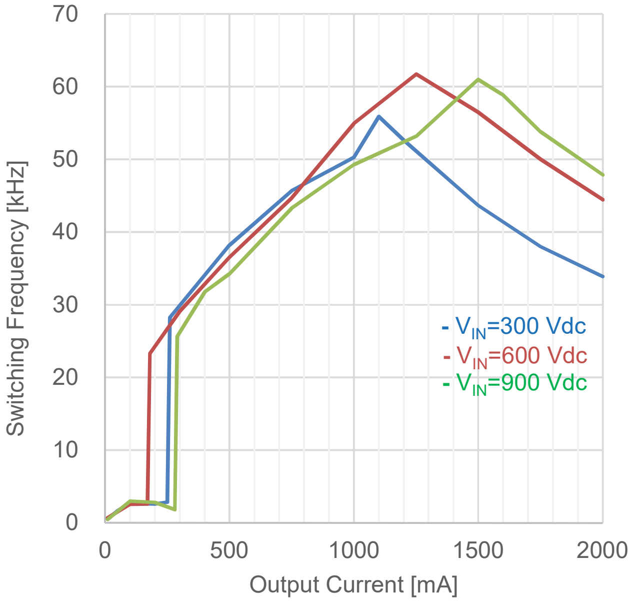
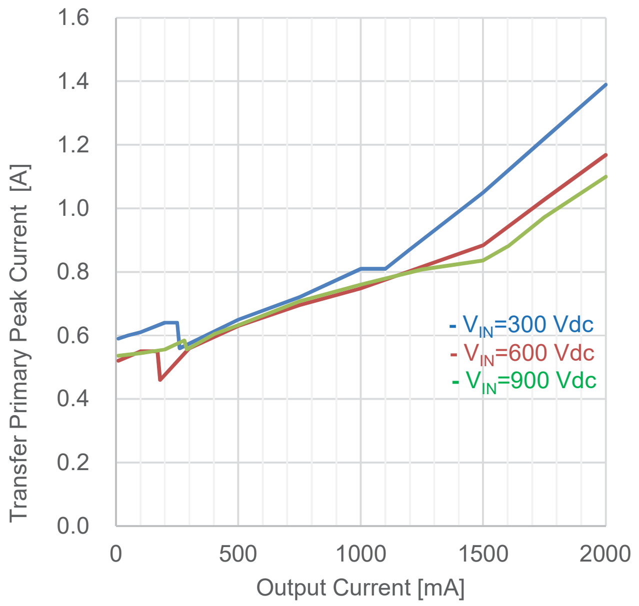


Figure 29. Switching Frequency (I_{OUT} vs f_{SW})

Performance Data – Continued

Transfer Peak Current



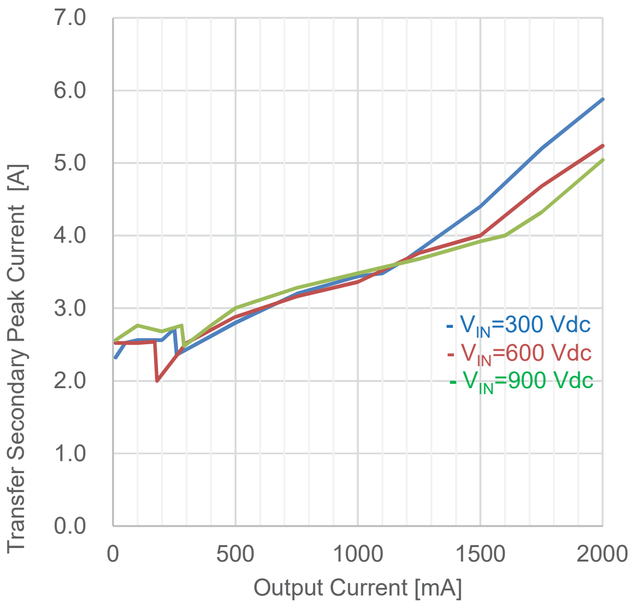


Figure 30. Transfer Primary Peak Current (I_{OUT} vs I_{PPK})

Figure 31. Transfer Secondary Peak Current (I_{OUT} vs I_{SPK})

Performance Data – Continued

Operation Waveform

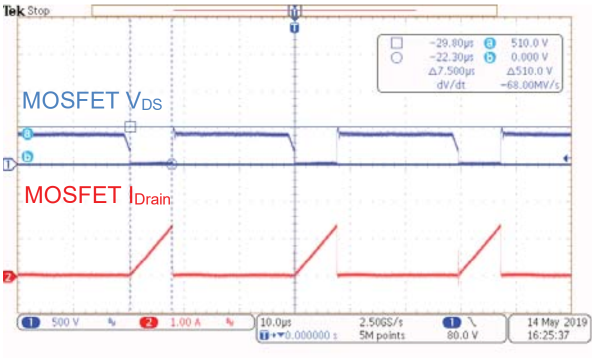


Figure 32. MOSFET V_{IN} = 300 Vdc, I_{OUT} = 2.0 A

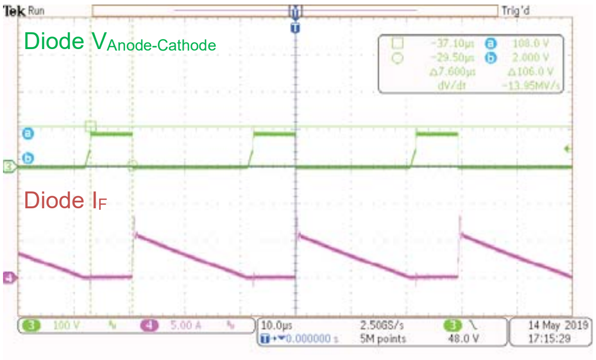


Figure 33. Diode V_{IN} = 300 Vdc, I_{OUT}=2.0 A

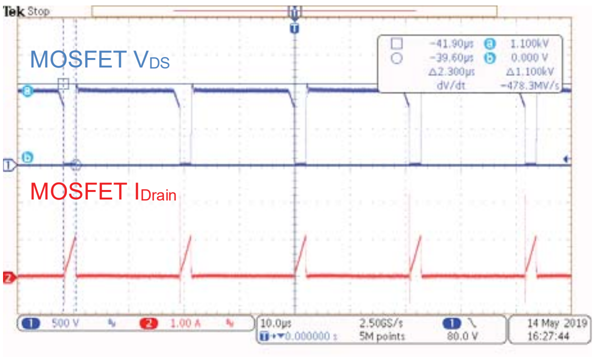


Figure 34. MOSFET V_{IN} = 900 Vdc, I_{OUT} = 2.0 A

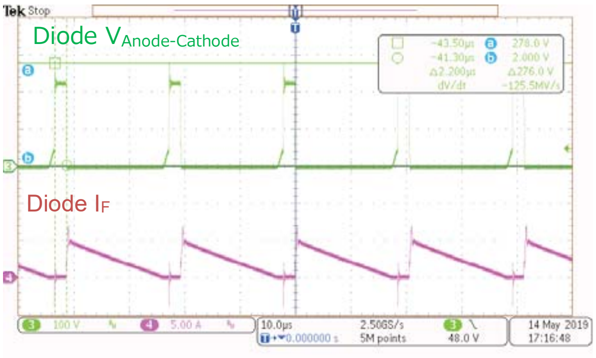


Figure 35. Diode V_{IN} = 900 Vdc, I_{OUT} = 2.0 A

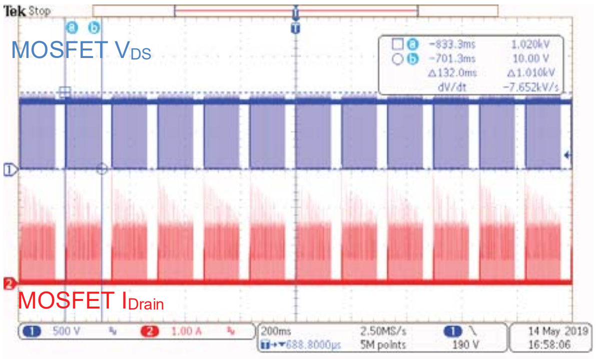


Figure 36. MOSFET V_{IN} = 900 Vdc, Output Short

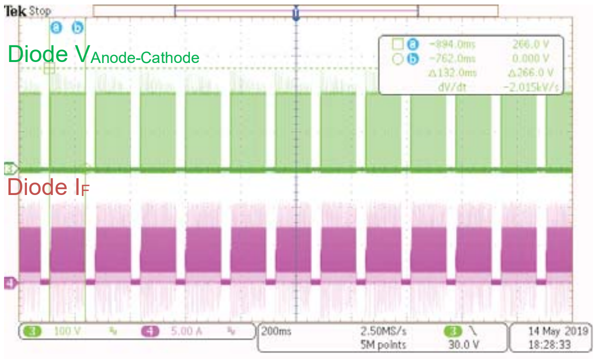


Figure 37. Diode V_{IN} = 900 Vdc, Output Short

Performance Data – Continued

Power On

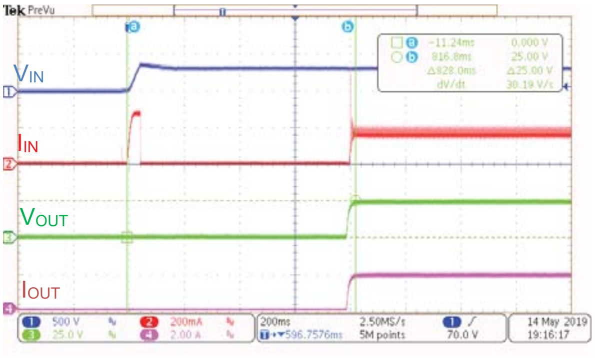


Figure 38. V_{IN} = 300 Vdc, I_{OUT} = 2.0 A

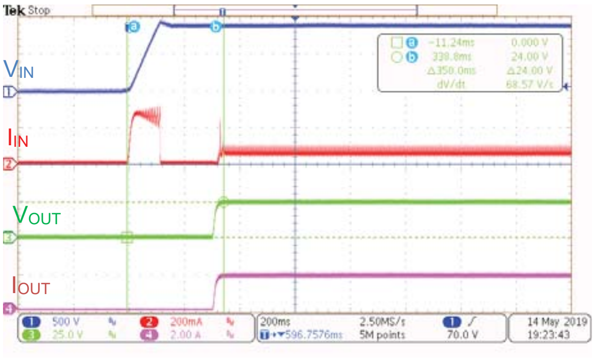


Figure 39. V_{IN} = 900 Vdc, I_{OUT} = 2.0 A

Dynamic Response

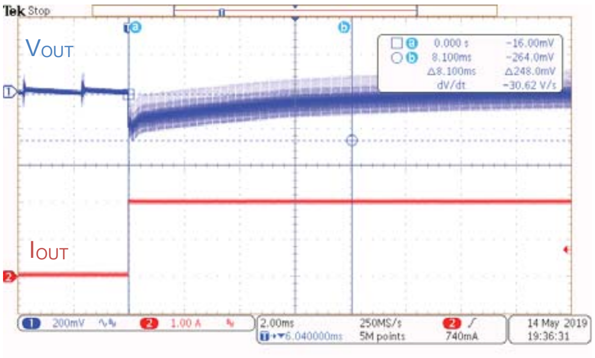


Figure 40. V_{IN} = 300 Vdc, I_{OUT} = 10 mA → 2.0 A

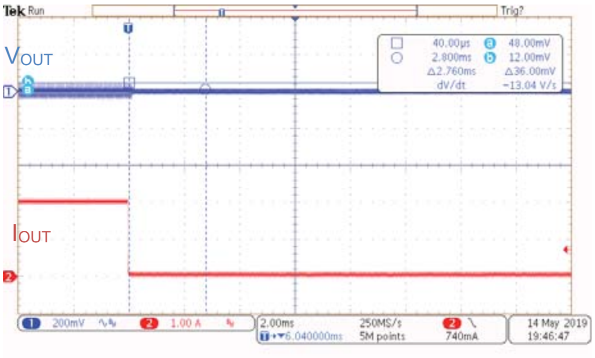


Figure 41. V_{IN} = 300 Vdc, I_{OUT} = 2.0 A → 10 mA

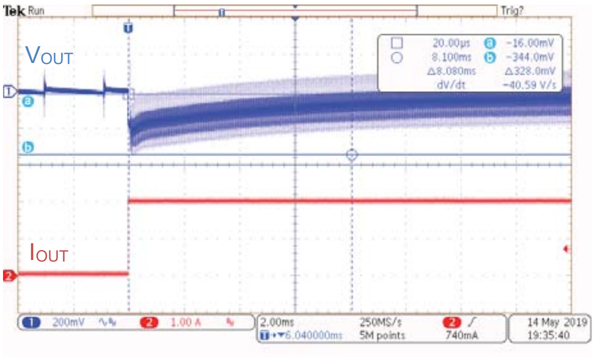


Figure 42. V_{IN} = 900 Vdc, I_{OUT} = 10 mA → 2.0 A

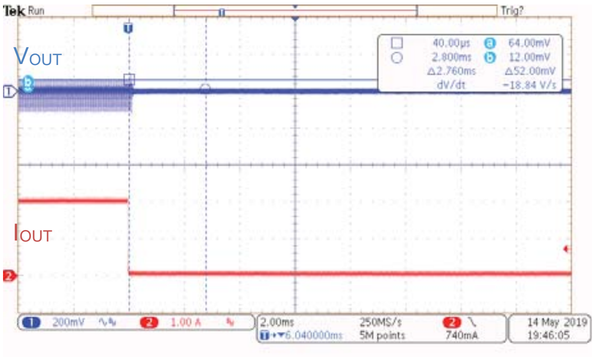


Figure 43. V_{IN} = 900 Vdc, I_{OUT} = 2.0 A → 10 mA

Performance Data – Continued

Output Ripple Voltage

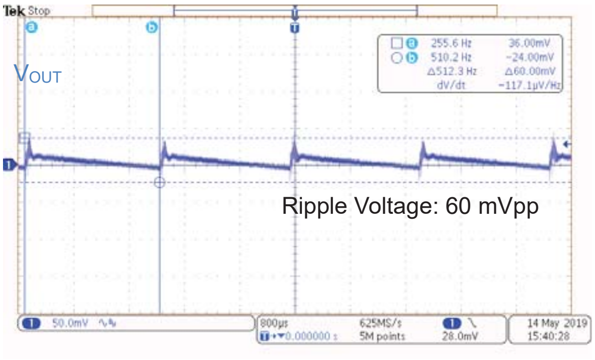


Figure 44. V_{IN} = 300 Vdc, I_{OUT} = 10 mA

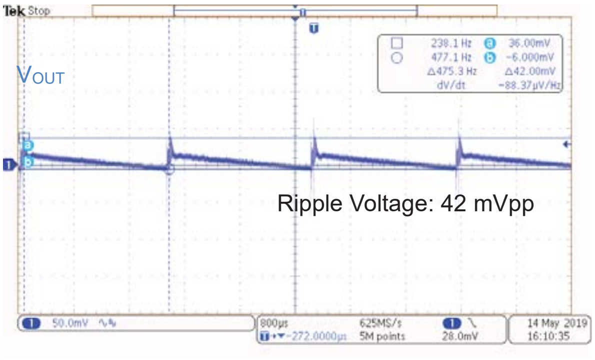
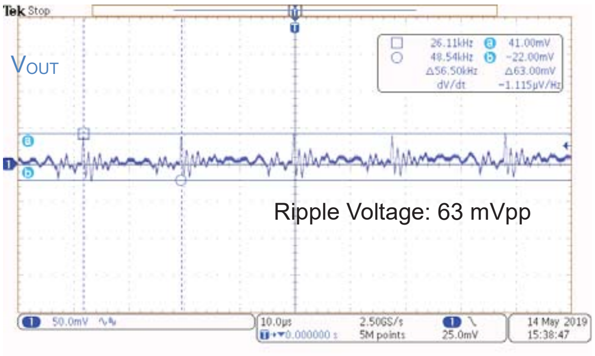


Figure 45. V_{IN} = 900 Vac, I_{OUT} = 10 mA



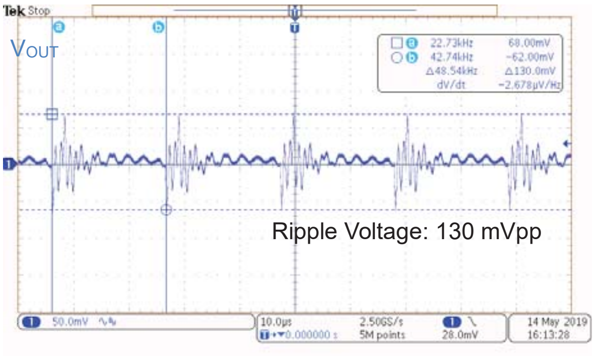
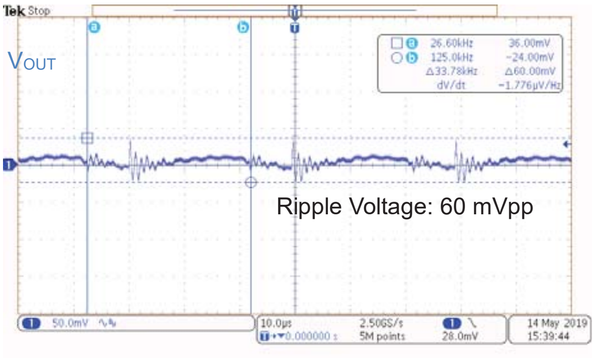


Figure 46. V_{IN} = 300 Vdc, I_{OUT} = 1.0 A

Figure 47. V_{IN} = 900 Vac, I_{OUT} = 1.0 A



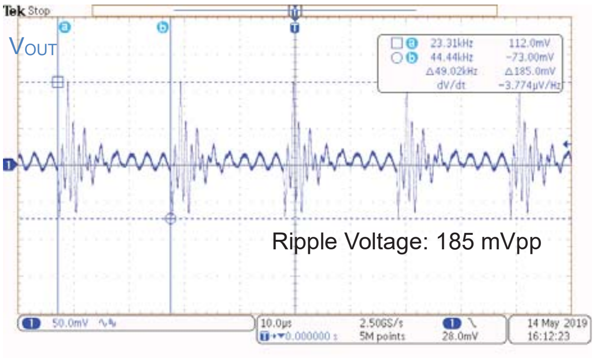


Figure 48. V_{IN} = 300 Vdc, I_{OUT} = 2.0 A

Figure 49. V_{IN} = 900 Vac, I_{OUT} = 2.0 A

Performance Data – Continued

Parts surface temperature

Table 8. Parts surface temperature Ta = 25 ℃, m easured 30minites after startup

Part	Condition			
	V_{IN}=300 Vdc, I_{OUT}=1 A	V_{IN}=300 Vdc, I_{OUT}=2 A	V_{IN}=900 Vdc, I_{OUT}=1 A	V_{IN}=900 Vdc, I_{OUT}=2 A
IC1	36.5 ℃	42.1 ℃	70.4 ℃	73.8 ℃
R19	40.9 ℃	46.0 ℃	47.5 ℃	52.3 ℃
T1	45.4 ℃	58.5 ℃	69.4 ℃	82.7 ℃
D9	50.1 ℃	66.4 ℃	56.8 ℃	70.2 ℃

When the input voltage is high (V_{IN} = 900 Vdc), the switching loss of the SiC MOSFET built into IC1 (BM2SC123T-LBZ) increases and IC1 becomes hot. This evaluation board measures the heat by attaching a heat sink. When the input voltage is low, the heat generation of IC1 is small and the heat sink is not necessary.

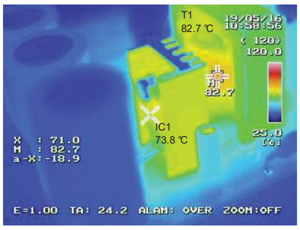


Figure 50-1. Thermal Image

“With” heat sink V_{IN}: 900Vdc, I_{OUT}: 2A

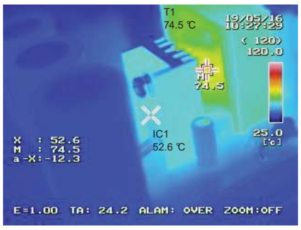


Figure 50-2. Thermal Image

“With” Heat sink V_{IN}: 600Vdc, I_{OUT}: 2A

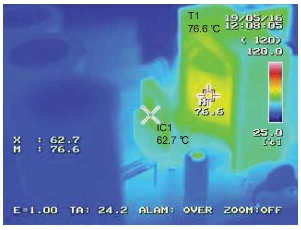


Figure 50-3. Thermal Image

“No” heat sink V_{IN}: 600Vdc, I_{OUT}: 2A

Schematics

V_{IN} = 300 ~ 900 Vdc, V_{OUT} = 24 V

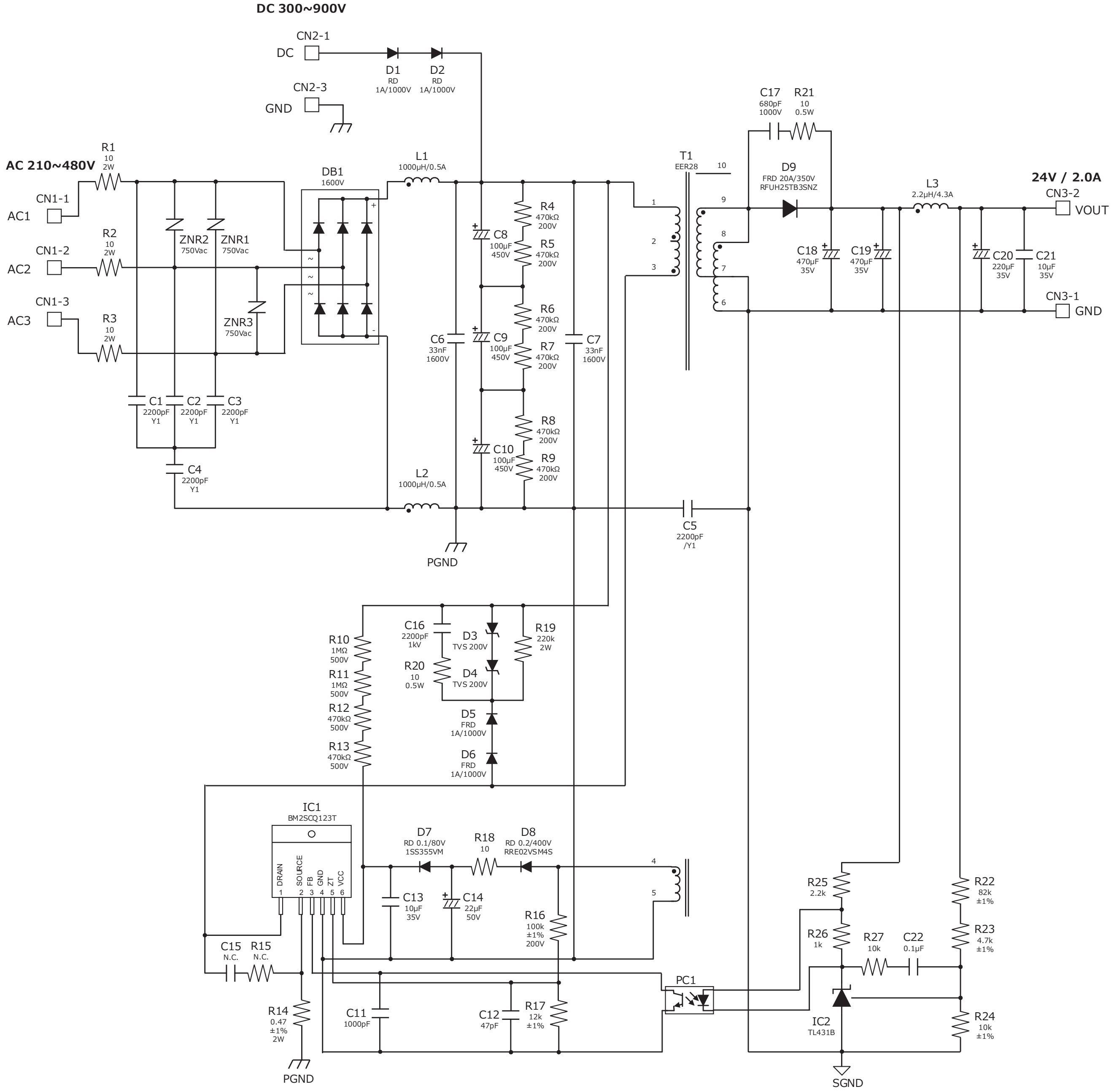


Figure 51. BM2SCQ123T-EVK-001 Schematics

Bill of Materials

Table 9. BoM of BM2SCQ123T-EVK-001

Part Reference	Qty.	Type	Value	Description	Part Number	Manufacture	Configuration mm (inch)
C1,C2,C3, C4,C5	5	Ceramic	2200pF	300Vac, ±20%, Y1	DE1E3RA222MJ4BP01F	Murata	-
C6,C7	2	Film	33nF	1600V, X7R, ±5%	B32672L1333J	TDK Epcos	-
C8,C9,C10	3	Electrolytic	100µF	450V, ±20%	450BXW100MEFR18X30	Rubycon	18mmΦX30mm
C11	1	Ceramic	1000pF	100V, X7R, ±20%	HMK107B7102MA-T	Taiyo Yuden	1608 (0603)
C12	1	Ceramic	47pF	250V, C0G, ±10%	GRM1885C2E470JW07	Murata	1608 (0603)
C13,C21	2	Ceramic	10µF	35V, X7R, ±20%	GMK316AB7106ML-TR	Taiyo Yuden	3216 (1206)
C14	1	Electrolytic	22µF	50V, Low-Z	UHD1H220MDD	Nichicon	5mmΦ x 11mm
C15	0	Ceramic	-	-	N.C.	-	3216 (1206)
C16	1	Ceramic	2200pF	1000V, X7R, ±10%	RDER73A222K2K1H03B	Murata	-
C17	1	Ceramic	680pF	1000V, X7R, ±10%	GRM31B5C2J681FW01L	Murata	3216 (1206)
C18,C19	2	Electrolytic	470µF	35V, Low-Z	UHD1V471MPD	Nichicon	10mmΦ x 20mm
C20	1	Electrolytic	220µF	35V, Low-Z	UHD1V221MPD	Nichicon	8mmΦ x 15mm
C22	1	Ceramic	0.1µF	100V, X7R, ±20%	HMK107B7104MA-T	Taiyo Yuden	1608 (0603)
CN1	1	Connector	3pin	9.52mm pitch	691 250 910 003	Wurth	-
CN2	1	Connector	3pin	6.35mm pitch	691 250 610 003	Wurth	-
CN3	1	Connector	2pin	5.0mm pitch	691 101 710 002	Wurth	-
D1,D2	2	RD	1A	1000V	1N4007GP	Vishay	DO-41
D3,D4	2	TVS	200V	-	1N6303A	Vishay	1.5KE
D5,D6	2	FRD	1A	1000V	UF4007	Vishay	DO-41
D7	1	RD	0.1A	80V	1SS355VM	ROHM	UMD2
D8	1	RD	0.2A	400V	RRE02VSM4S	ROHM	TUMD2SM
D9	1	FRD	20A	350V	RFUH25TB3SNZ	ROHM	TO-220
DB1	1	Bridge	45A	1600V	D45XT160-7000	Shindengen	-
HS1	1	Heat Sink	-	32.7℃/W	OSH-1525-SFL	Sankyo Thermotec	-
HS2	1	Heat Sink	-	22.9℃/W	IC-1625-STL	Sankyo Thermotec	-
-	2	Skrew	-	M3L=8mm	SEMS-SCREW-P4-3X8	TOMOHO	-
IC1	1	AC/DC Converter	-	1700V	BM2SCQ123T-LBZ	ROHM	DIP7
IC2	1	Shunt Regulator	-	±0.5%	TL431BIDBZT	TI	SOT-23-3
L1,L2	2	Coil	1000µH	0.5A	768 772 102	Wurth	-
L3	1	Coil	2.2µH	4.3A	744 746 202 2	Wurth	-
PC1	1	Optocoupler	-	5kV	LTV-817M-B	LiteOn	DIP4
R1,R2,R3	3	Fuible Resistor	10Ω	2W, ±10%	PR02FS0201009KR500	Vishay	-
R4,R5,R6, R7,R8,R9	6	Resistor	470kΩ	0.25W, ±5%	MCR18EZPJ474	ROHM	3216(1206)
R10,R11	2	Resistor	1MΩ	0.5W, ±5%	KTR18EZPJ105	ROHM	3216 (1206)
R12,R13	2	Resistor	470kΩ	0.5W, ±5%	KTR18EZPJ474	ROHM	3216 (1206)
R14	1	Resistor	0.47Ω	2W, ±1%	LTR100JZPFLR470	ROHM	6432 (2512)
R15	0	Resistor	-	-	N.C.	-	3216 (1206)
R16	1	Resistor	100kΩ	0.25W, ±1%	MCR18EZPF1003	ROHM	3216 (1206)
R17	1	Resistor	12kΩ	0.1W, ±1%	MCR03EZPFX1202	ROHM	1608 (0603)
R18	1	Resistor	10Ω	0.25W, ±5%	MCR18EZPJ100	ROHM	3216 (1206)
R19	1	Resistor	220kΩ	2W, ±5%	PR03000202203JAC00	Vishay	-
R20,R21	2	Resistor	10Ω	0.5W, ±5%	MCR25JZHJ100	ROHM	3225 (1210)
R22	1	Resistor	82kΩ	0.1W, ±1%	MCR03EZPFX8202	ROHM	1608 (0603)
R23	1	Resistor	4.7kΩ	0.1W, ±1%	MCR03EZPFX4701	ROHM	1608 (0603)
R24	1	Resistor	10kΩ	0.1W, ±1%	MCR03EZPFX1002	ROHM	1608 (0603)
R25	1	Resistor	2.2kΩ	0.1W, ±1%	MCR03EZPFX2201	ROHM	1608 (0603)
R26	1	Resistor	1kΩ	0.1W, ±1%	MCR03EZPFX1001	ROHM	1608 (0603)
R27	1	Resistor	10kΩ	0.1W, ±1%	MCR03EZPFX1002	ROHM	1608 (0603)
T1	1	Transformer	-	Bobin:FX2805_10 Core:EER28/28	XE2342Y	Alpha Trans	-
ZNR1, ZNR2, ZNR3	3	Varistor	-	750Vac, 1080Vmin, 100A	TMOV20RP750E	LitteleFuse	20mmΦ Disc

PCB

Size : 60 mm x 160 mm

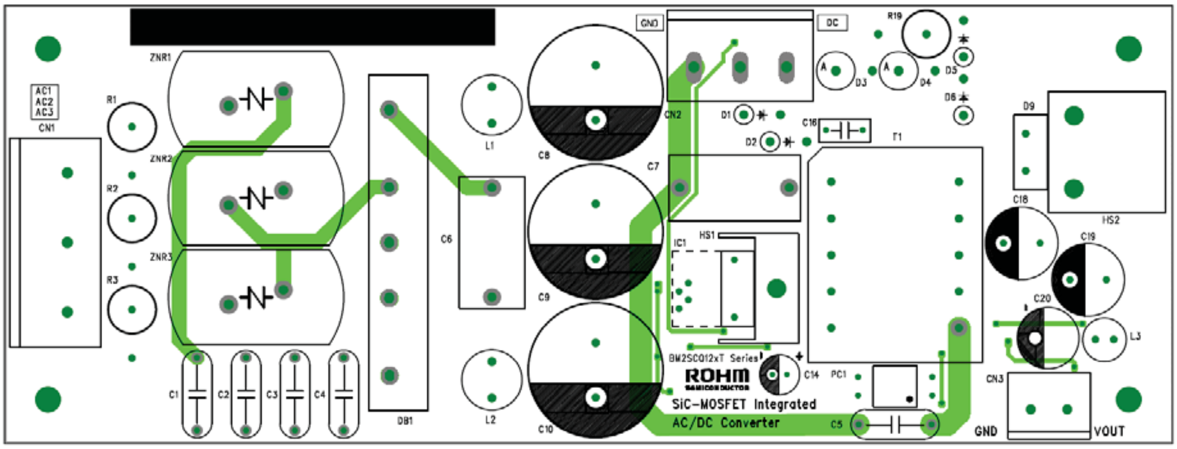


Figure 52. Top Layout (Top view)

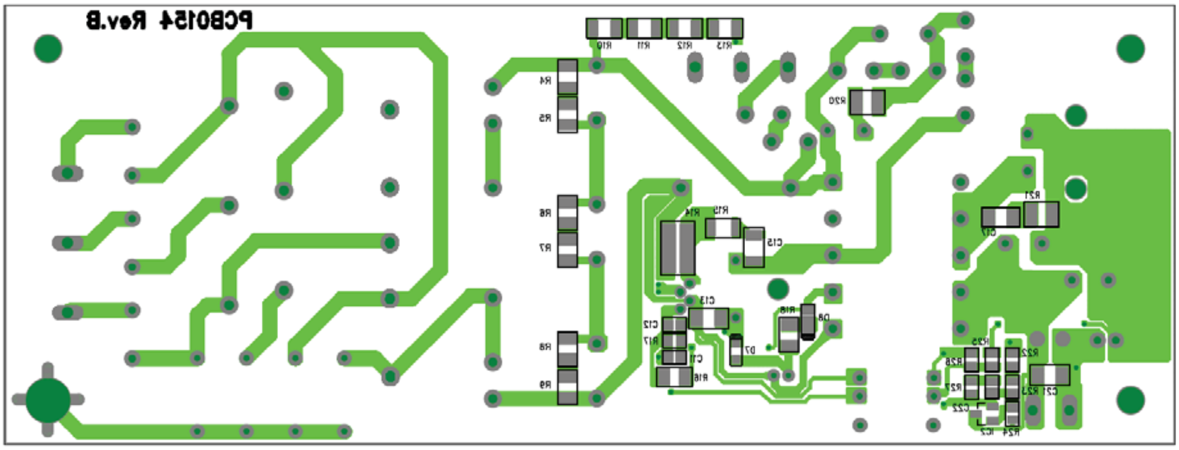


Figure 53. Bottom Layout (Top view)

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