AC/DC Converter
Isolation Fly-back Converter
Quasi-Resonant method 24W 24V
BD7682FJ-LB Reference Board

User’s Guide

＜High Voltage Safety Precautions＞

◇ Read all safety precautions before use

Please note that this document covers only the BD7682FJ-LB evaluation board (BD7682FJ-LB-EVK-402) 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

Isolation Fly-back Converter Quasi-Resonant method Output 24 W 24 V BD7682FJ-LB Reference Board

BD7682FJ-LB-EVK-402

Overview

BD7682FJ-LB-EVK-402 evaluation board outputs 24 V voltage from the input of 300 Vdc to 900 Vdc. The output current supplies up to 1 A. The BD768xFJ-LB series are Quasi-Resonant switching AC/DC converter for driving SiC (Silicon Carbide) MOSFET. Using external switching MOSFET and current detection resistors provides a lot of flexibility in the design. Power efficiency is improved by the burst function and the reduction of switching frequency under light load conditions.

This is the product that guarantees long time support in the Industrial market.

Electronics Characteristics

Not guarantee the characteristics, is representative value. Unless otherwise noted : VIN = 600 Vdc, IOUT = 1 A, Ta: 25 °C

Parameter	Min	Typ	Max	Units	Conditions
Input Voltage Range	300	-	900	Vdc	
Output Voltage	22.8	24.0	25.2	V	
Maximum Output Power	-	-	24.0	W	IOUT = 1 A
Output Current Range (NOTE1)	0.0	-	1.0	A	
Efficiency	-	85	-	%	
Operating Temperature Range	-10	+25	+65	°C	

(NOTE1) Adjust operating time, within any parts surface temperature under 105 °C

Operation Procedure

1. Operation Equipment
   - (1) 3 phase AC power supply 210 to 480 Vac, over 50W, or DC power supply 300 to 900 Vdc, over 50W
   - (2) Electronic Load capacity 1.0 A
   - (3) Multi meter
2. Connect method

   As an input power supply, 3-phase AC power supply or DC power supply can be used.

*In the case of using 3-phase AC power supply

AC power supply presetting range 210 to 480 Vac, Output switch is off.

AC power supply terminal connect to the CN1.

AC power meter connect between AC power supply and board

*In the case of DC power supply

DC power supply presetting range 300 to 900 Vdc, Output switch is off.

DC power supply +(VIN) terminal connect to the board CN2-1, and - (GND) terminal connect to CN2-3.

DC power meter connect between DC power supply and board

Since then,

Load + terminal connect to CN3-2 (VOUT), GND terminal connect to CN3-1 (GND) terminal

Output test equipment connects to output terminal.

Power supply switch ON.

Check output voltage is 24 V.

Electronic load switch ON

Check output voltage drop by load connect wire resistance

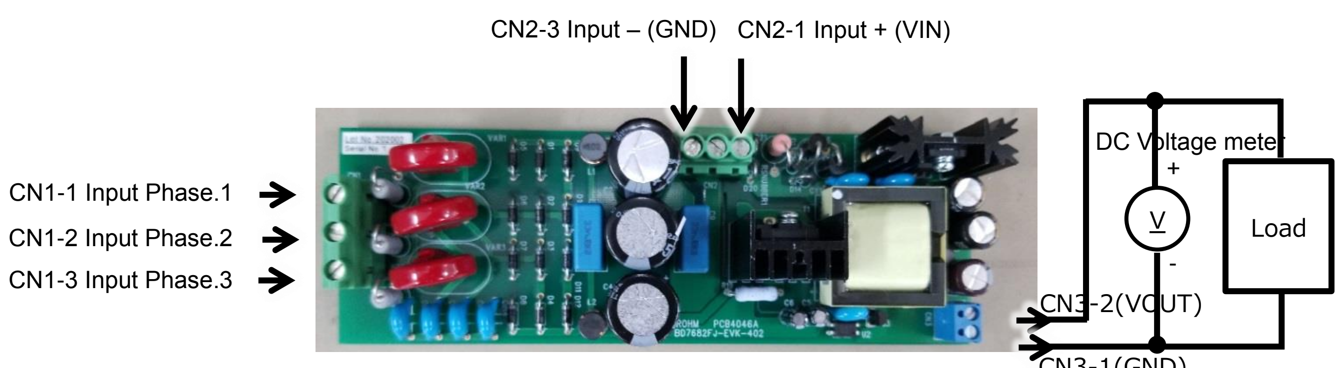


Figure 1. Connection

Derating

Maximum Output Power Po of this reference board is 24.0 W.

The derating curve is shown on the right.

Please adjust load continuous time by over 105 °C

of any parts surface temperature.

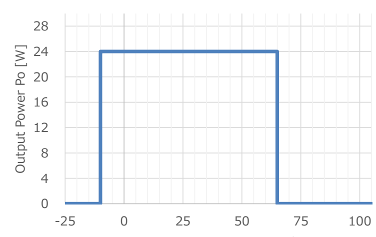


Figure 2. Temperature Derating curve

Block Diagram

VIN = 300 to 900 Vdc, VOUT = 24 V

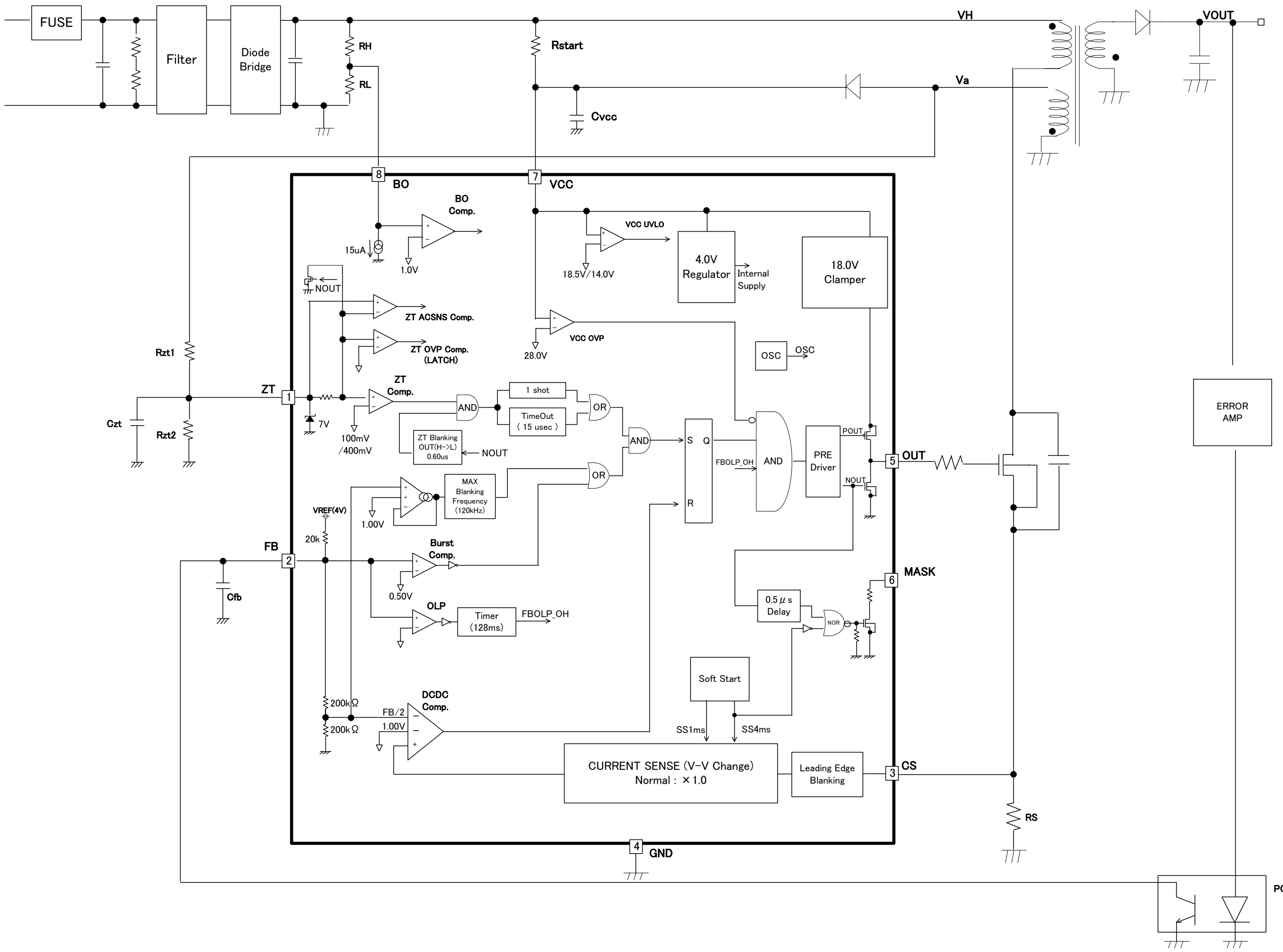


Figure 3. BD7682FJ-LB Block Diagram

BD768xFJ-LB Overview

Feature

- Quasi-resonant method
  (Maximum frequency control 120 kHz)/Current mode
- Low power when load is light (Burst operation)
  / Frequency reduction function
- VCC pin : under voltage protection
  / over voltage protection
- Leading-Edge-Blanking function
- Over-current protection (cycle-by-cycle)
- ZT trigger mask function
- ZT Over voltage protection
- AC voltage correction function
- Soft start
- Brown IN/OUT function
- Gate Clamp circuit
- MASK Function

Key specifications

- Operation Voltage Range: VCC: 15.0 V to 27.5 V
- Circuit Current (ON): 0.8 mA (Typ)
- Circuit Current (Burst mode): 0.5 mA (Typ)
- Switching Frequency: 120 kHz (Typ)
- Operating Temperature: -40 °C to +105 °C

BD768xFJ-LB Series line-up

	FBOLP	VCCOVP
BD7682FJ	AutoRestart	Latch
BD7683FJ	Latch	Latch
BD7684FJ	AutoRestart	AutoRestart
BD7685FJ	Latch	AutoRestart

Application

Industrial equipment, AC Adaptor, Home appliances

Package	W (Typ) x D (Typ) x H (Max)
SOP-J8	4.90 mm x 6.00 mm x 1.65 mm Pitch 1.27 mm

Figure 4. SOP-J8 Package

(*) Product structure : Silicon monolithic integrated circuit This product has no designed protection against radioactive rays

(*) Operating the IC over the absolute maximum ratings may damage the IC. The damage can either be a short circuit between pins or an open circuit between pins and the internal circuitry. Therefore, it is important to consider circuit protection measures, such as adding a fuse, in case the IC is operated over the absolute maximum ratings.

Table 1. BD768xFJ-LB PIN description

No.	Name	I/O	Function	ESD Diode VCC	ESD Diode GND
1	ZT	I	Zero Current Detect pin	-	*
2	FB	I	Feedback signal input pin	*	*
3	CS	I	Current Sense pin	*	*
4	GND	I/O	GND pin	*	-
5	OUT	O	MOSFET drive pin	*	*
6	MASK	I	External TR drive	-	*
7	VCC	O	Power Supply pin	-	*
8	BO	O	Brown IN/OUT monitor pin		*

Design Overview

Contents

Design Overview - Continued

Important Parameter

VIN : Input Voltage Range DC 300 V to 900 Vdc

VOUT : Output Voltage DC 24 V

IOUT : Output Current 1.0 A

f_{SW} : Switching Frequency Min : 106 kHz, Typ : 120 kHz, Max : 134 kHz

Quasi-resonant converter is self-excited fly-back converter power supply system using the voltage resonance of the transformer primary winding inductor and resonant capacitor.

Generally, Quasi-resonant converter is possible to reduce the loss and noise than the PWM fly-back converter.

Quasi-Resonant Converter becomes DCM (Discontinuous Conduction Mode) under light load, and switching frequency increases with the load increasing. When the load increased further, Quasi-Resonant Converter becomes BCM (Boundary Conduction Mode), and switching frequency decreases with the load increasing.

The relation of switching Frequency and output load characteristics is shown in Figure 5. The Switching waveform at DCM and CCM is shown in Figure 6.

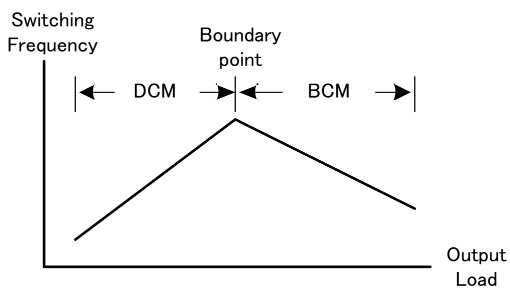


Figure 5. Switching Frequency - Output Load Characteristics

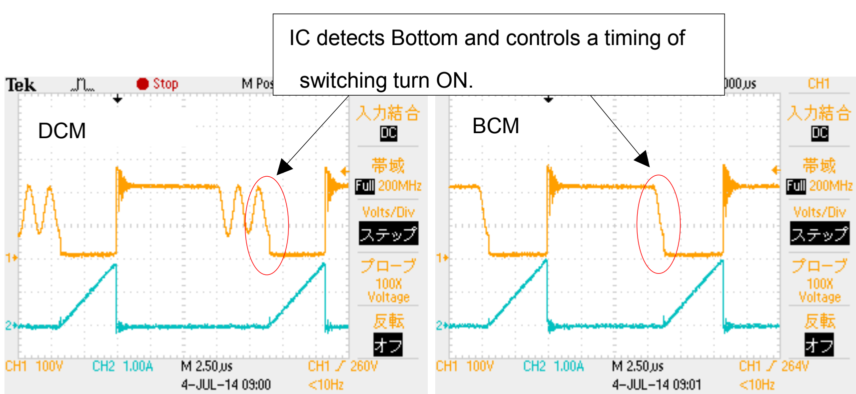


Figure 6. Switching waveform (MOSFET Vds, Ids)

Design Overview – Continued

1. Transformer T1 design

(24 V 1 A, Vin (DC) = 300 V to 900 V)

1-1. Determination of fly-back voltage VOR

Turns-ratio Np : Ns and duty-ratio is determined along with Fly-back voltage VOR

$$VOR = VO \times \frac{Np}{Ns} = \frac{ton}{toff} \times VIN \ \ [V]$$

$$\rightarrow \frac{Np}{Ns} = \frac{VOR}{VO}$$

$$\rightarrow Duty = \frac{VOR}{VIN+VOR}$$

When VIN (MIN) = 300 V, VOR = 200 V, Vf = 1.5 V,

$$\frac{Np}{Ns} = \frac{VOR}{VO} = \frac{VOR}{Vout+Vf} = \frac{200V}{24V+1.5V} = 7.8$$

$$Duty = \frac{VOR}{VIN(min)+VOR} = \frac{200V}{300V+200V} = 0.4$$

(*) VOR is adjusted to set it below 0.5 in consideration of MOSFET's loss.

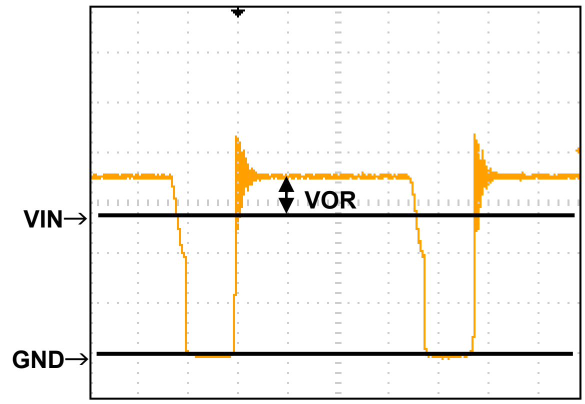


Figure 7. MOSFET Vds

1-2. Determination of Minimum frequency fsw and calculation of primary side winding inductance Lp

The primary side maximum current Ippk and the primary side winding inductance Lp is determined from the minimum input voltage(VIN = 300 V) and the minimum frequency (Fsw = 92 kHz).

Other's parameter is following:

Po = 24 V x 1 A = 24 W, Po (max) = 30 W (derating 0.8) in consideration of over current protection.

Transformer efficiency:η = 85 %

Resonance capacitor: Cv = 100 pF

$$Lp = \left\{ \frac{VIN(min) \times Duty(min)}{\sqrt{\frac{2 \times Po(max) \times fsw}{\eta}} + VIN(min) \times Duty(max) \times fsw \times \pi \times \sqrt{Cv}} \right\}^2 = 1718 \ [\mu H]$$

$$Ippk = \sqrt{\frac{2 \times Po(max)}{\eta \times Lp \times fsw}} = 0.668 \ [A]$$

1-3. Determination of transformer size

Core size of the transformer is determined to EFD30 by the condition of Po (max) = 30 W.

Table 2. Output Voltage and Transformer Core

Output power Po (W)	Core size	Core sectional area Ae (mm^2)
To 30	EI25/EE25	41
To 50	EFD30	68
To 60	EI28/EE28/EER28	84
to 80	EI33/EER35	107

(*) The above is guideline values. For details, check with the transformer manufacturer, etc.

Transformer T1 Design - Continued

1-4. Calculation of primary-side turn count Np

Generally, the maximum magnetic flux density B (T) for an ordinary ferrite core is 0.4 T @100 °C, so Bsat = 0.28 T (30% margin).

$$NP > \frac{Lp \times Ippk}{Ae \times Bsat} = \frac{1718\mu H \times 0.668A}{68mm^2 \times 0.28T} = 60.3 \text{ [turns]}$$

→Np set to at least 61 turns.

In order not to cause a magnetic saturation, the IC must be used in areas that do not saturate from AL_Value-NI characteristics.

In the case of Np = 64 turns:

$$AL\_Value = \frac{Lp}{Np^2} = \frac{1718\mu H}{64turns^2} = 419.5 \text{ [nH/turns}^2\text{]}$$

$$NI = Np \times Ippk = 64turns \times 0.668A = 42.8 \text{ [A*turns]}$$

In this case, this point is within the tolerance range

Np = 64 turns is determined

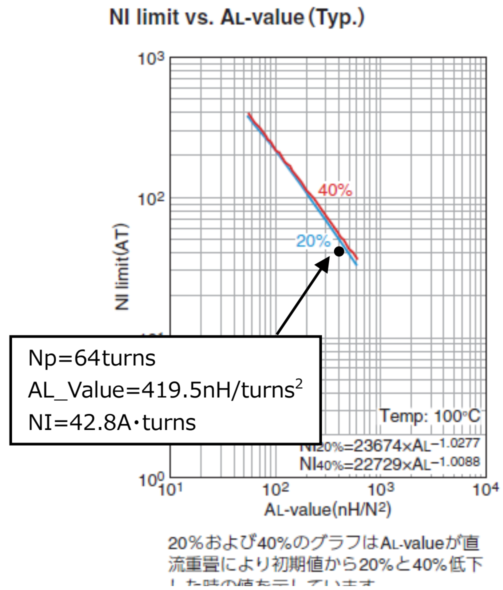


Figure 8. AL_Value – NI Limit Reference Characteristics

1-5. Calculation of secondary-side turn count Ns

$$\frac{Np}{Ns} = 7.8 \quad \rightarrow Ns = \frac{64}{7.8} = 8.2 \text{ [turns]}$$

→Ns = 9 turns is determined.

In the case of driving SiC-MOSFET, since it is necessary to control the Gate voltage, VCC is required more than 19 V.

1-6. Calculation of VCC turn count Nd

When driving a SiC-MOSFET, VCC should be set to 19V or more because the gate voltage must be controlled.

When VCC = 21 V, Vf_vcc = 1 V,

$$Nd = Ns \times \frac{VCC + Vf\_vcc}{Vout + Vf} = 9turns \times \frac{21V + 1.0V}{24V + 1.5V} = 7.8 \text{ [turns]}$$

→Nd = 8 turns is determined.

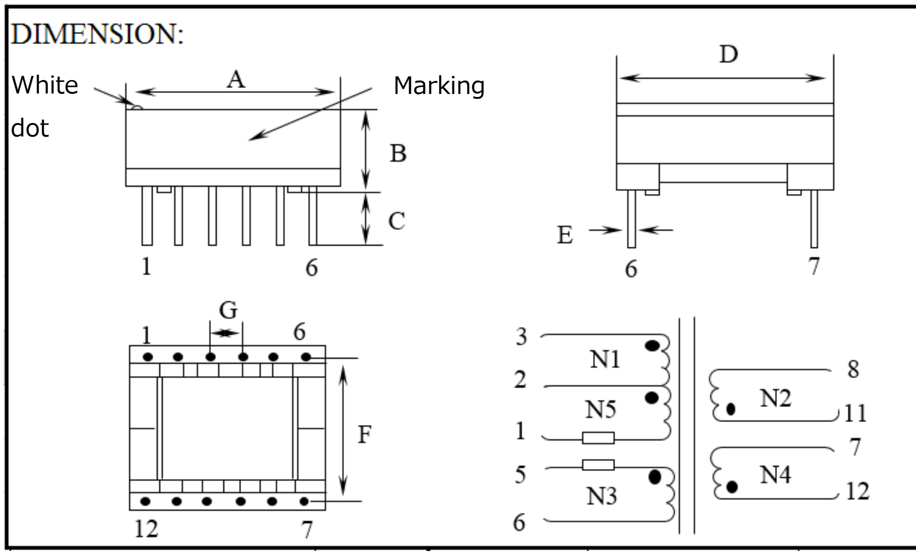
As a result, the transformer specifications are as follows.

Table 3. Transformer Specifications

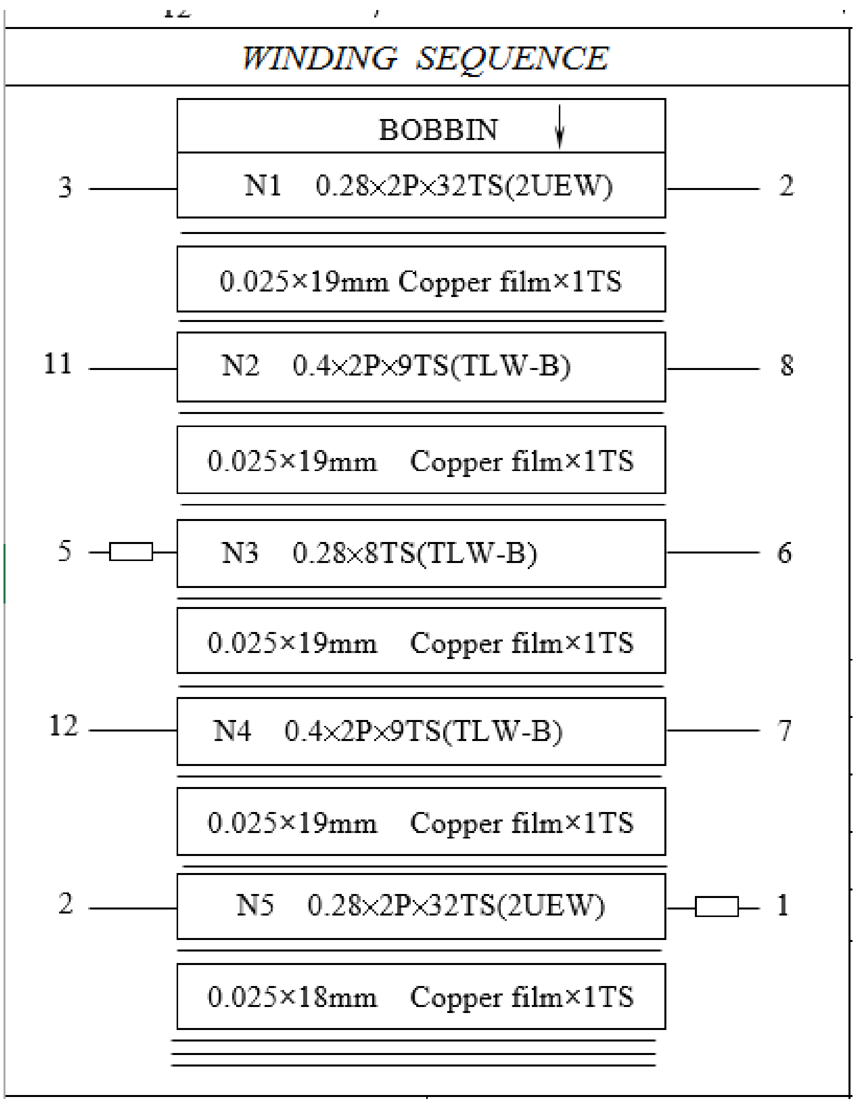
Core	EFD30 compatible
Lp	1718 μH
Np	64 turns
Ns	9 turns
Nd	8 turns

Transformer T1 Design - Continued

1-7. Transformer design



A	33.0Max	m/m
B	18.0Max	m/m
C	4.0±1.0	m/m
D	32.5Max	m/m
E	0.8±0.1	m/m
F	27.5±0.5	m/m
G	5.0±0.3	m/m
H		m/m
I		m/m
J		m/m



Design Overview - Continued

2. Selection of main components

2-1. MOSFET : Q1

For MOSFET selection, it must be considered maximum voltage between the drain and source Vds, peak current Ippk, losses due to

Ron, maximum power dissipation of the package.

At low input voltage, the ON time of the MOSFET becomes long and the heat generated by Ron loss is bigger.

Be sure to confirm the state incorporated in the product and execute the heat dissipation of the heat sink as needed.

Current rating should be selected twice about Ippk.

$$Vds(max) = VIN(max) + VOR + Vspike$$

$$= VIN(max) + (Vout + Vf) \times \frac{Np}{Ns} + Vspike$$

$$= 900Vdc + (24V + 1.5V) \times \frac{64turns}{9turns} + Vspike = 1081V + Vspike \text{ [V]}$$

Calculation of Vspike is difficult. MOSFET breakdown voltage is 1700 V by using a snubber circuit.

In this design example, ROHM's MOSFET SCT2H12NZ (1700 V 1.15 Ω) is selected.

Below show the typical characteristics of SCT2H12NZ. Please refer to the SCT2H12NZ data sheet for formal data.

ABSOLUTE MAXIMUM RATINGS [Tj = 25 °C]		
DRAIN-SOURCE VOLTAGE	V_{DSS}	1700 V
GATE-SOURCE VOLTAGE	V_{GSS}	-6 V to +22 V
TOTAL POWER DISSIPATION	P_D	35 W
JUNCTION TEMPERATURE	T_j	175 °C
RANGE OF STORAGE TEMPERATURE	T_{stg}	-55 to 175 °C

SCT2H12NZ

V_{DSS}	1700V
$R_{DS(on)}$ (Typ.)	1.15Ω
I_D	3.7A
P_D	35W

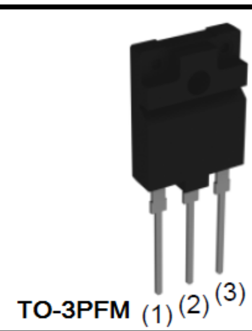


Figure 9. SCT2H12NZ Spec

2. Section of main components - Continued

2-2. Input capacitor: C2,C3,C4 Balance resistance: R1,R2,R3,R4,R5,R6

Use Table 4 to select the capacitance of the input capacitor.

$$Pin = \frac{Pout}{\eta} = \frac{24V \times 1A}{85\%} = 28.2 \text{ [W]}$$

Cin = 28.2 W-> above 28.2 μF → selected 33 μF

Table 4. Input Capacitor

Input voltage [Vdc]	Cin [μF]
< 300	2 x Pin [W]
300 <	1 x Pin [W)

(*) When selecting, also consider other specifications such as the retention-time.

The breakdown voltage of the capacitor is required above the maximum input voltage.

VIN (MAX)/de-rating = 900 V / 0.8 = 1125 V

Using three 450 V breakdown voltage capacitors in series, the breakdown voltage of the capacitor is 450 V x 3 = 1350 V.

As noted, when connecting the capacitors in series, the balanced resistance is required for a constant voltage applied to all capacitors. Since the resistance is in loss, it is recommended to use more resistance 470 kΩ.

R1,R2,R3,R4,R5,R6's loss is below.

$$P_{R1-R6} = \frac{VIN(max)^2}{R} = \frac{900V^2}{470k\Omega \times 6} = 0.287 \text{ [W]}$$

It is shown in Figure 10.

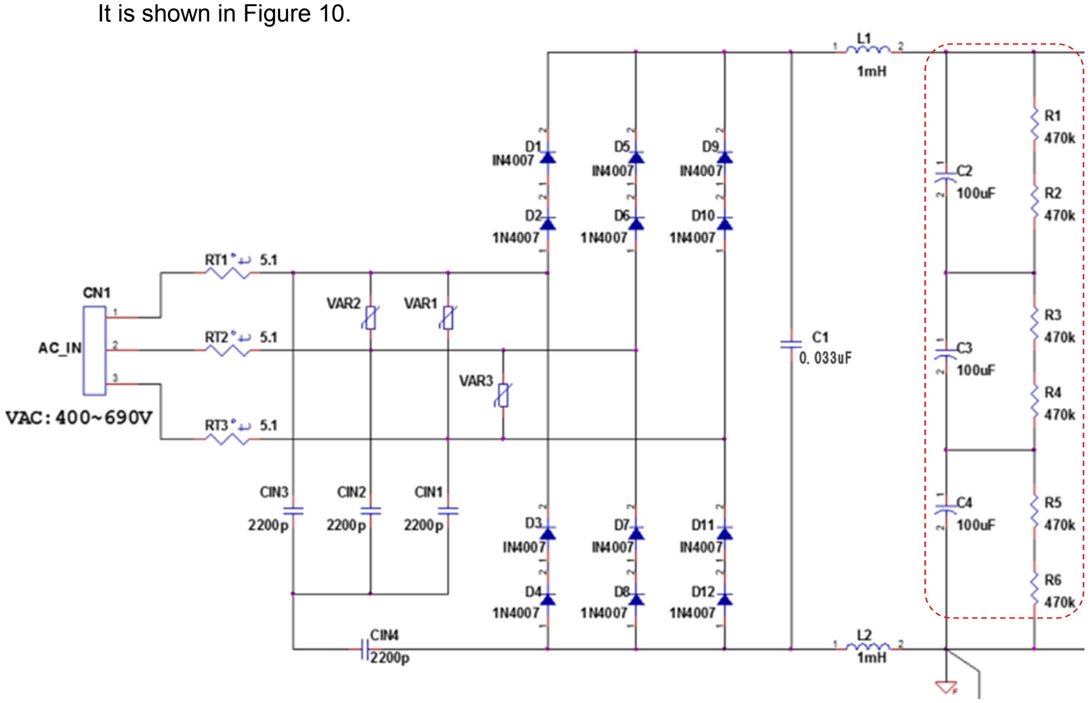


Figure 10． Input capacitor and Balance resistance

2. Section of main components - Continued

2-3. Current-sensing resistor: R19 Resistance for noise protection of CS terminal : R22

The current-sensing resistor limits the current that flows on the primary side to provide protection against output overload.

$$R19 = \frac{V_{CS}}{I_{ppk}} = \frac{1.0\ V}{0.668\ A} = 1.5\ [\Omega]$$

Sensing resistor loss P_R19:

$$P\_R19\ (Peak) = Ippk^2 \times R19 = 0.668\ A^2 \times 1.5\Omega = 0.67\ [W]$$

$$P\_R19(rms) = Iprms^2 \times R19 = \left(Ippk \times \sqrt{\frac{Duty(max)}{3}} \right)^2 \times R19$$

$$= \left(0.66\ A \times \sqrt{\frac{0.4}{3}} \right)^2 \times 1.5\Omega = 0.089\ [W]$$

Set the value 1 W or above in consideration of pulse resistance.

The structure of the resistance may vary the pulse resistance even with the same power rating.

Check with the resistor manufacturers for details.

R22 is protection resistor for CS terminal by noise or surge current. Usually we use 1 kΩ.

2-4. Overload protection correction setting resistor: R20

BD768xFJ-LB series has overload protection correction function in the input voltage. After the IC detects overload, there is a delay time to stop the switching operation. This delay is to increase the overload protection point with an increase input voltage. Correction function reduces the current detection level when it equals or exceeds an input voltage value. However, since this EVK assumes a power supply specification for industrial equipment, it does not assume that the input voltage will fluctuate depending on the set. Therefore, the OCP switching function is set not to operate.

Izt is the current flowing from the IC to the transformer Nd winding in time of the switching ON.

Izt lower the current detection level at the top than 1 mA, overload protection point is lowered.

VIN_OCP is the changing input voltage of over current protection, VIN_OCP = 1200V to not detect.

$$R20 = VIN\_OCP \times \frac{Nd}{Ns} \times \frac{1}{Izt} = 1200\ V \times \frac{8}{64} \times \frac{1}{1mA} = 150\ [k\Omega]$$

R20 = 150 kΩ is selected.

2-5. Setting resistor for ZT terminal voltage: R21

The ZT bottom detected voltage is Vzt1 = 100 mV (typ) (ZT fall), Vzt2 = 200 mV (typ) (ZT rise), and ZT OVP (min) is 3.30 V, so as a guide, set Vzt to 1 V to 3 V. ZT lower resistance R21 at R20 = 150 kΩ is

$$Vzt = (Vout + Vf) \times \frac{Nd}{Ns} \times \frac{R21}{R20 + R21} = 2.7\ [V]$$

R21 = 20.28 kΩ→20 kΩ is selected.

2. Section of main components - Continued

2-6. ZT terminal capacitor: C11

C11 is a capacitor for stability of ZT voltage and timing adjustment of the bottom detection.

Check the waveform of ZT terminal and the timing of bottom detection, and adjust it as necessary.

2-7. VCC-diode: D18

A high-speed diode is recommended as the VCC-diode.

When D13_Vf = 1 V, reverse voltage Vdr applied to the VCC-diode:

$$Vdr = VCC(max) + VIN(max) \times \frac{Nd}{Np} \text{ [V]}$$

This IC has VCC OVP function, VCC OVP (max) = 31.5 V.

Reverse voltage of the diode is set so as not to exceed the Vr of diode in conditions of VCC OVP (max).

$$Vdr = 31.5V + 900V \times \frac{8turns}{64turns} = 144 \text{ [V]}$$

With a design-margin taken into account, 144 V / 0.8 = 180 V → 200 V component is selected.

(Example: ROHM's RF05VAM2S 200 V 0.5 A)

2-8. VCC winding surge-voltage limiting resistor: Rvcc1

Based on the transformer's leakage inductance (Lleak), a large surge-voltage (spike noise) may occur during the instant when the MOSFET is switched from ON to OFF. This surge-voltage is induced in the VCC winding, and as the VCC voltage increases the IC's VCC overvoltage protection may be triggered. A limiting resistor R16 (approximately 5 Ω to 22 Ω) is inserted to reduce the surge-voltage that is induced in the VCC winding.

Confirm the rise in VCC voltage while the resistor is assembled in the product.

2-9. VCC starter resistance ; R11,R12,R13,R14 capacitance ; C5,C6 and Switching diode ; D18, D19

Start resistance Rstart is the resistance required to start the IC. When the start resistance Rstart value is reduced, the standby power is increased and the startup time is shortened. Conversely, when the start resistance Rstart value is increased, the standby power is reduced and the startup time is lengthened. When BD768xFJ is in standby mode, current Istart becomes 30μA (max) However, this is the minimum current required to start the IC.

In this case current Istart is 40 μA (max) with margin.

Input voltage VIN_start = 180 V : VCC_uvlo (max) = 20 V: I_{ON1} (min) = 0.3 mA:

$$Rstart < \frac{VIN\_start - VCC\_uvlo(max)}{Istart(max)} = \frac{(180V - 20V)}{40\mu A} = 4000 \text{ [k}\Omega\text{]}$$

$$Rstart > \frac{VIN(max) - VCC\_ovp(max)}{I_{ON1}(min)} = \frac{(900V - 31.5V)}{300\mu A} = 2895 \text{ [k}\Omega\text{]}$$

$$2895\ \ k\Omega < Rstart < 4000\ \ k\Omega$$

From the above results, set Rstart = 2940 kΩ (1MΩ x 2 + 470 kΩx 2 series).

Start-up time is shown in Figure 11.

2-9. VCC starter resistance ; R11,R12,R13,R14 capacitance ; C5,C6 and Switching diode ; D19 D18-continued

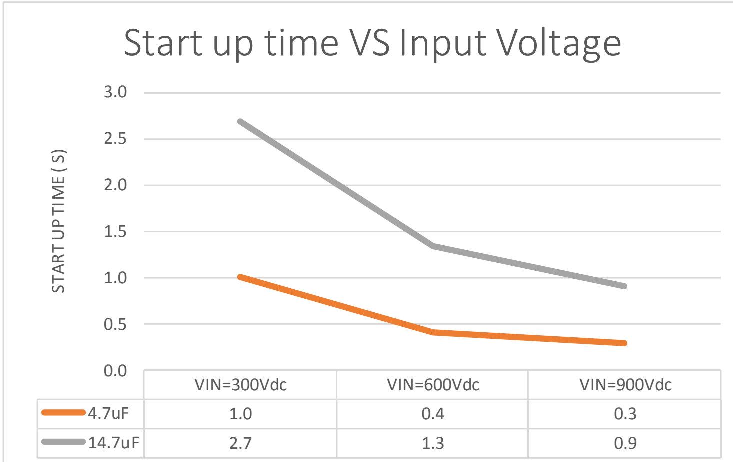


Figure 11. Start up time

A VCC capacitor is needed to stabilize the IC's VCC voltage.

Capacitance of 2.2 μF or above is recommended.

This example is recommended circuit of Figure 12 for the start-up time and stability.

At startup, only the C6 works for fast start. After starting, after the output voltage is above a certain voltage, C5 operates. For D18, use Fast Recovery Diode with a withstand voltage higher than the negative voltage generated in the auxiliary winding of the transformer. It is calculated as Vin*Nd/Np+VCC. Normally, noise is generated in this voltage, so set it with a margin. D19 is recommended Low IR Switching diode. (Example Rohm 1SS355VM)

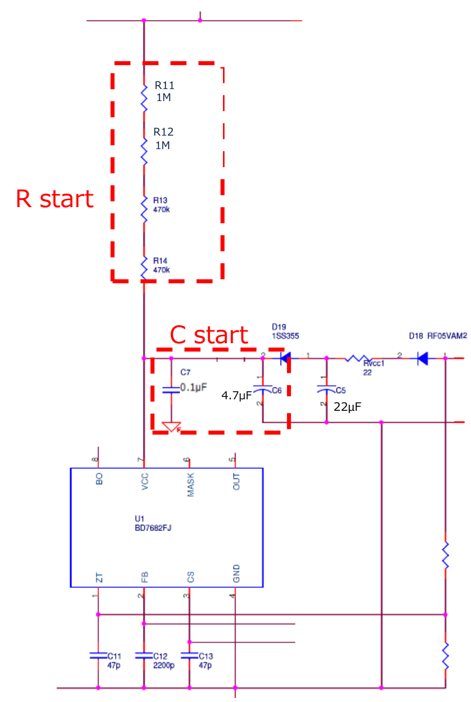


Figure 12. Resistance of Starter and VCC capacitor

2. Section of main components - Continued

2-10. Brown IN/OUT resistance: R7,R8,R9,R10,R15 and BO capacitor: C8

When the input VIN value is low, the brown out function stops the DC/DC operations (The IC itself continues to operate).

In the following example,

V_{HON} is the operation start V_H voltage (L to H), and V_{HOFF} is the operation stop V_H voltage (H to L).

IC start up (OFF => ON)

$$\frac{V_{ON}-1.0V}{R_H} = \frac{1.0V}{R_L} + 15\mu A$$

IC stop (ON => OFF)

$$\frac{V_{OFF}F-1.0V}{R_H} = \frac{1.0V}{R_L} \text{ [A]}$$

Based on the above, R_H and R_L can be calculated as follows.

$$R_H = \frac{(V_{ON}-V_{OFF})}{15\mu A} \text{ [Ω]}$$

$$R_L = \frac{1.0V}{(V_{OFF}-1.0V)} \times R_H \text{ [Ω]}$$

Set V_{HON} = 90 V, V_{HOFF} = 60 V, R_H and R_L is calculated R_L = 33.89 kΩ, R_H = 2 MΩ.

It becomes the circuit shown in Figure 13.

(In this EVK, Brown Out function is set low so that operation can be checked even at low voltage)

It should be noted that the BO terminal is required capacitor C8. BO line is weak in noise for high impedance. Recommended is 0.01 μF to 1 μF.

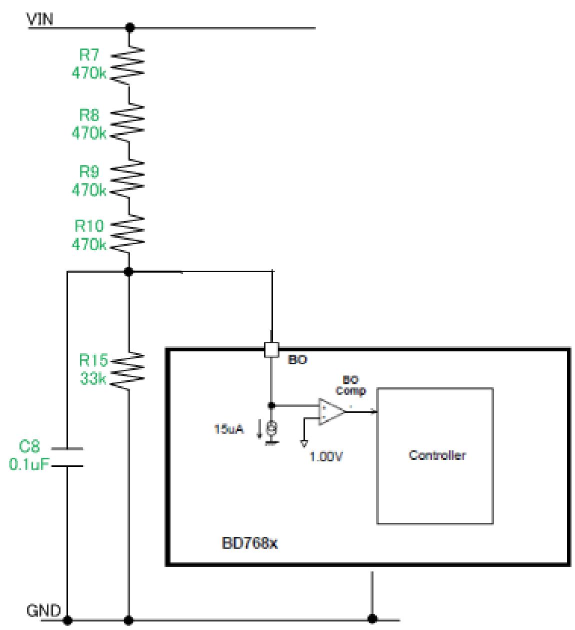


Figure 13. Broun IN/OUT setting capacitor

2. Section of main components - Continued

2-11. Snubber circuits: C snubber 1, R snubber1, D13,D14, D15,D16

Based on the transformer's leakage inductance (Lleak), a large surge-voltage (spike noise) may occur during the instant when the MOSFET is switched from ON to OFF. This surge-voltage is applied between the MOSFET's Drain and Source, so in the worst case damage to MOSFET might occur. RCD snubber circuits are recommended to suppress this surge-voltage.

2-11-1 Determination of clamp voltage (Vclamp) and clamp ripple-voltage (Vripple)

The clamp voltage is determined by the MOSFET's withstand voltage considering a design margin.

Vclamp = 1700 V x 0.8 = 1360 V

The clamp ripple-voltage (Vripple) is set about 50 V.

2-11-2 Determination of R snubber 1

R snubber 1 is selected according to the following conditions.

$$Rsnubber1 < 2 \times Vclamp \times \frac{Vclamp - VOR}{Lleak \times Ip^2 \times fsw(max)} \text{ [Ω]}$$

Lleak = Lp x 10 % = 1718 μH x 10 % = 172 μH

Peak Current Ip is as follow at Rcs = 1.5 Ω, Vcs = 1.0 V.

$$Ip = \frac{Vcs}{Rcs} = \frac{1.0V}{1.5\Omega} = 0.667 \text{ [A]}$$

At Fsw (max) = 120 kHz,

$$Rsnbber1 < 2 \times 1360V \times \frac{1360V - 200V}{172\mu H \times 0.667A^2 \times 120kHz} = 404 \text{ [kΩ]}$$

In this case, set Rsnubber1 = 200 kΩ.

Power dissipation of Rsnubber1 = P_Rsnubber1 is

$$P\_Rsnubber > \frac{(Vclamp - VIN)^2}{Rsnubber1} = \frac{(1360V - 900V)^2}{200k\Omega} = 1.06 \text{ [W]}$$

It select power dissipation of Rsunubber1 to 2W or more.

2-11-3 Determination of Csnubber1

$$Csnubber1 > \frac{Vclamp}{Vripple \times fsw(max) \times Rsnubber1} = \frac{1360V}{50V \times 120kHz \times 200k\Omega} = 1133 \text{ [pF]}$$

→Csnubber1 = 2200 pF is determined.

The voltage applied to Csnubber1 is 1360 V - 900 V = 460 V.

Csnubber1 is set 600 V or more with design margin.

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2-11. Snubber circuits: C snubber 1, R snubber1, D13,D14, D15,D16 - Continued

2-11-4 Determination of D13,D14

Choose a fast recovery diode as the diode, with a withstand voltage that is at or above the MOSFET's Vds (max) value.

The surge-voltage affects not only the transformer's leakage inductance but also the PCB substrate's pattern.

Confirm the Vds voltage while assembled in the product, and adjust the snubber circuit as necessary.

2-11-5 TVS: D15, D16

For excellent protection performance, it is possible to cramp the transient noises. Please determine after checking

the withstand voltage and operation waveform.

2-12. FB terminal capacitor: C12

C12 is a capacitor for stability of FB voltage (approximately 1000 pF to 0.01 μF).

2-13. MOSFET gate circuit: R16,R17,R18,D17

The MOSFET's gate circuits affect the MOSFET's loss and the generation of noise. The Switching speed for turn-on is adjusted using R16+R17, and for turn-off is adjusted using R16, via the drawing diode D17.

(Example: R16 : 10 Ω 0.25 W, R17 : 150 Ω, D17 : SBD 60 V 1 A)

In the case of Quasi-Resonant converters, switching-loss is dominated by the turn-off loss rather than the turn-on loss. To reduce switching-loss when the IC turned off, turn-off speed can be increased by reducing R16 value, but sharp changes in current will occur, which increases the switching-noise. Since there is a trade-off relation between loss (heat generation) and noise, measure the MOSFET's temperature rise and noise while it is assembled in the product, and adjust it as necessary.

Also, since a pulse current flows to R16, check the pulse resistance of the resistors being used.

R18 is the resistance to pull down the gate of the MOSFET. The recommended value is 10 kΩ to 100 kΩ.

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2. Section of main components - Continued

2-14. Output rectification diode: DN1

Choose a high-speed diode (Schottky barrier diode or fast recovery diode) as the output rectification diode.

When Vf = 1.5 V, reverse voltage applied to output diode is

$$Vdr = Vout(max) + Vf + VIN(max) \times \frac{Ns}{Np} \text{ [V]}$$

When Vout (max) = 24.0 V+5 % = 25.2 V:

$$Vdr = 25.2V + 1.5V + 900V \times \frac{9}{64} = 153.3 \text{ [V]}$$

153.3 V / 0.8 = 191.6 V→ 200 V component is determined with consideration for design margin.

Diode Current ; Is (Arms)

$$Ispk = \frac{2 \times Io(max)}{1 - Duty(max)} = \frac{2 \times 1A}{1 - 0.4} = 3.33 \text{ [A]}$$

$$Is(Arms) = Ispk \times \sqrt{\frac{1 - Duty}{3}} = 3.33A \times \sqrt{\frac{1 - 0.4}{3}} = 1.49 \text{ [Arms]}$$

Also, diode loss (approximate value) becomes Pd = Vf x Iout = 1.5 V x 1.49 Arms = 2.24 W

(Example: ROHM's RFN10T2D : 200 V 10 A, TO-220FN package)

Using a voltage margin of 80 % or less and current of 50 % or less is recommended.

Check the rise in temperature while assembled in the product. If necessary, reconsider the component and radiate heat by a heat sink or similar to dissipate the heat.

2.Section of main components - Continued

2-15. Output capacitors: Cout1, Cout2, Cout3, Cout4

The output capacitor has a resistance component ZC [Ω] which causes a ripple voltage. This ZC [Ω] determine the output capacitors based on the output load's allowable peak-to-peak ripple voltage (ΔVpp) and ripple-current.

When the MOSFET is ON, the output diode is OFF. At that time, current is supplied to the load from the output capacitors.

When the MOSFET is OFF, the output diode is ON. At that time, the output capacitors are charged and a load current is also supplied. When ΔVpp = 200 mV,

$$ZC < \frac{\Delta Vpp}{Ispk} = \frac{0.2V}{3.33A} = 0.06$$ [Ω] at 120 kHz

With an ordinary switching power supply electrolytic-capacitor (low-impedance component), impedance is rated at 100 kHz, so it is converted to 100 kHz.

$$ZC < 0.06\Omega \times \frac{120kHz}{100kHz} = 0.072$$ [Ω] at 100 kHz

Ripple current of output Capacitor Ic (Arms) :

$$Ic = \sqrt{Is^2 - Io^2} = \sqrt{1.49A^2 - 1A^2} = 1.11$$ [Arms]

The capacitor's withstand voltage should be set to 80% of the output voltage.

$$Vout \times 2 = 24V \div 0.8 = 30$$ [V]

→35 V select.

Select an electrolytic capacitor that is suitable for these conditions.

(Example: low impedance type 35 V, 470 µF // 2 + 220 µF parallel for switching power supply.)

(*) Use the actual equipment to confirm the actual ripple-voltage and ripple-current.

2-16. Output voltage setting resistors: R25,R26,R28

When Shunt regulator IC2 : Vref = 2.495 V,

$$Vout = \left(1 + \frac{R25+R26}{R28}\right) \times Vref = \left(1 + \frac{82k\Omega+4.3k\Omega}{10k\Omega}\right) \times 2.495V = 24.02$$ [V]

2-17. Parts for adjustment of control circuit: R24,R27,R32,C15

R27 and C15 are parts for phase compensation. Approximately R27 = 1 k to30 kΩ, C15 = 0.1 µF, and adjust them while they are assembled in the product.

R32 is a resistor which limits a control circuit current. Approximately R32 : 300 to 2 kΩ, and adjust it while it assembled in the product. R24 is a resistor for adjustment of minimum operating current of shunt regulator IC2.

In case of IC2: TL431, minimum operating current is 1 mA. And when Optocoupler : PC1_Vf is 1 V,

R24 = 1 V / 1 mA = 1 kΩ

Overview design - Continued

3. EMI countermeasures

Confirm the following with regard to EMI countermeasures.

(*) Constants are reference values. Need to be adjusted based on noise effects.

- Addition of filter to input block
- Addition of capacitor between primary-side and secondary-side (approximately CY1, CY2, CY3 = 2200 pF)
- Addition of RC snubber to secondary diode

4. Output noise countermeasures

As an output noise countermeasure, add an LC filter

(approximately L : 10 µH, C: 10 µF to 100 µF) to the output.

(*) Constants are reference values.

Need to be adjusted based on noise effects.

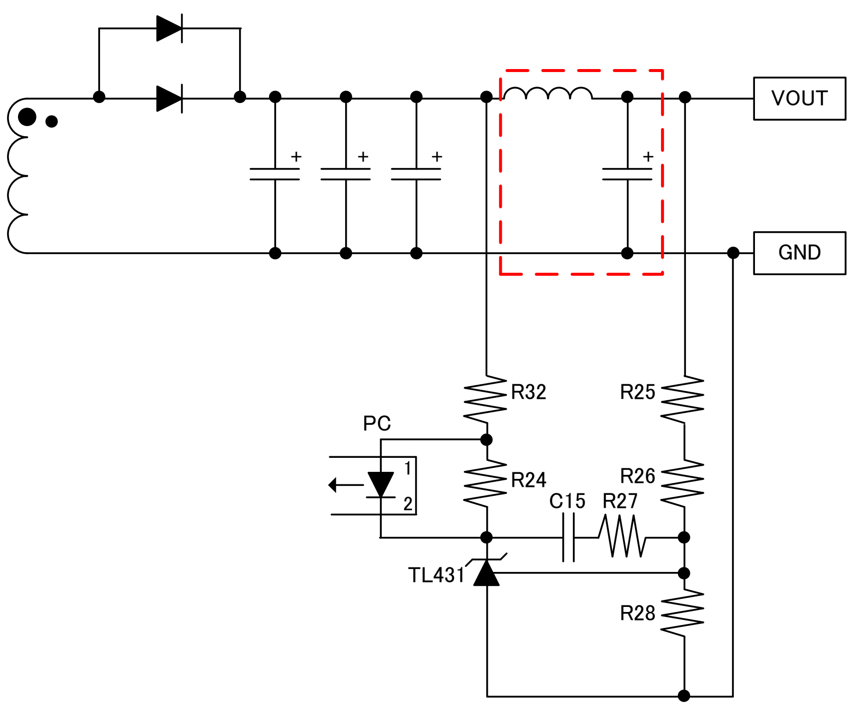


Figure 14. LC Filter Circuit

Performance Data

Efficiency

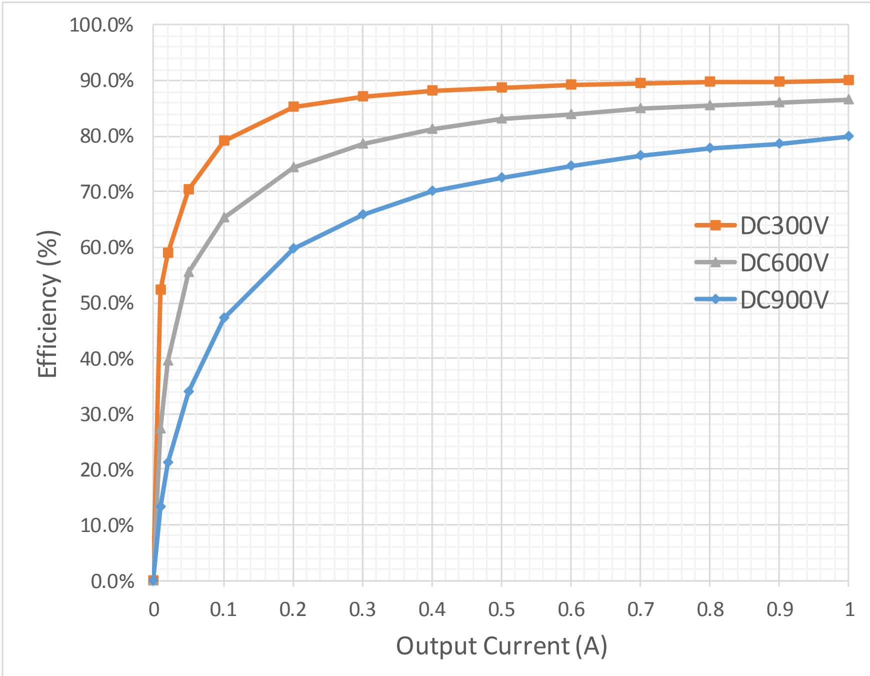


Figure 15. Efficiency Vs Output Current (A) Input Voltage (V)

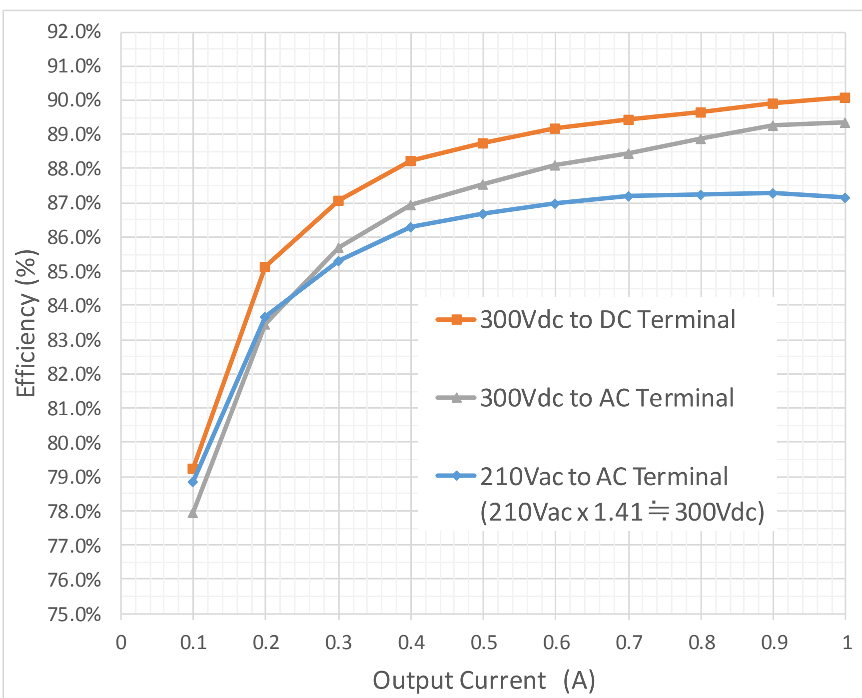
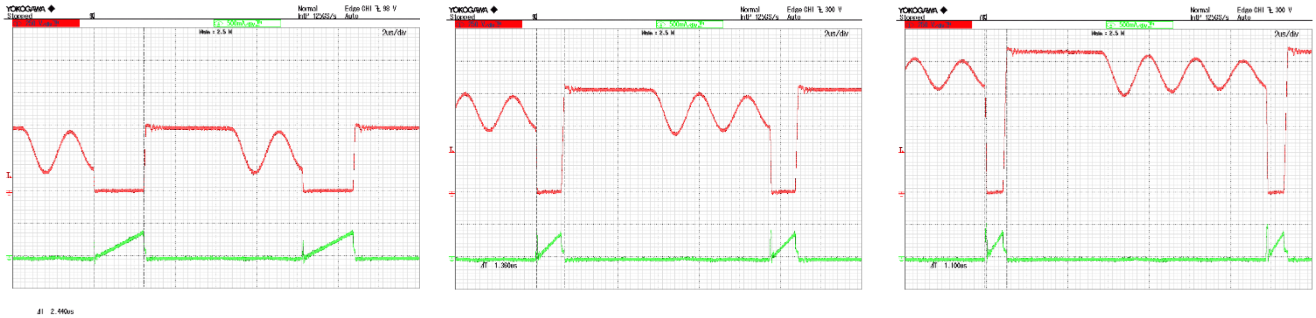


Figure 16. Efficiency vs Output Current (Each input terminal)

Performance Data - Continued

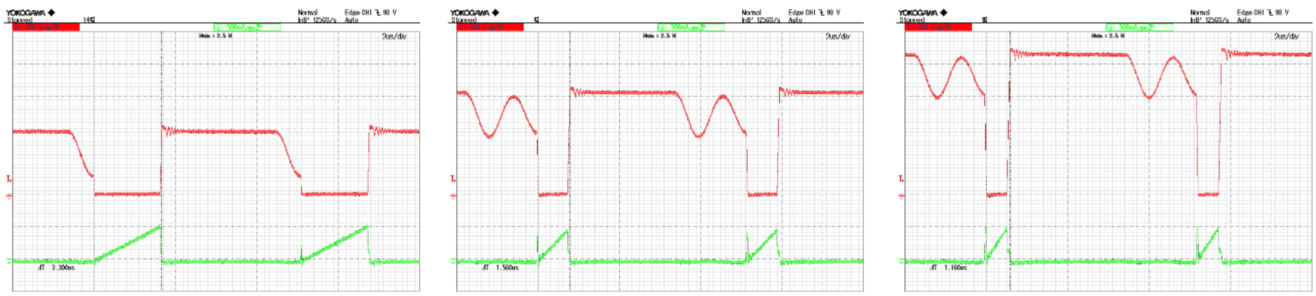
Waveform



VIN (DC): 300 V VIN (DC): 600 V VIN (DC): 900 V

CH1: Vdrain (250 V/div), CH4: Idrain (500 mA/div)

Figure 17. Drain voltage/Current wave form (VO=24 V, IO=0.5 A, PO=12 W)



VIN (DC): 300 V VIN (DC): 600 V VIN (DC): 900 V

CH1: Vdrain (250 V/div), CH4: Idrain (500 mA/div)

Figure 18. Drain voltage/Current wave form (VO=24 V, IO=1.0 A, PO=24 W)

Schematic

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

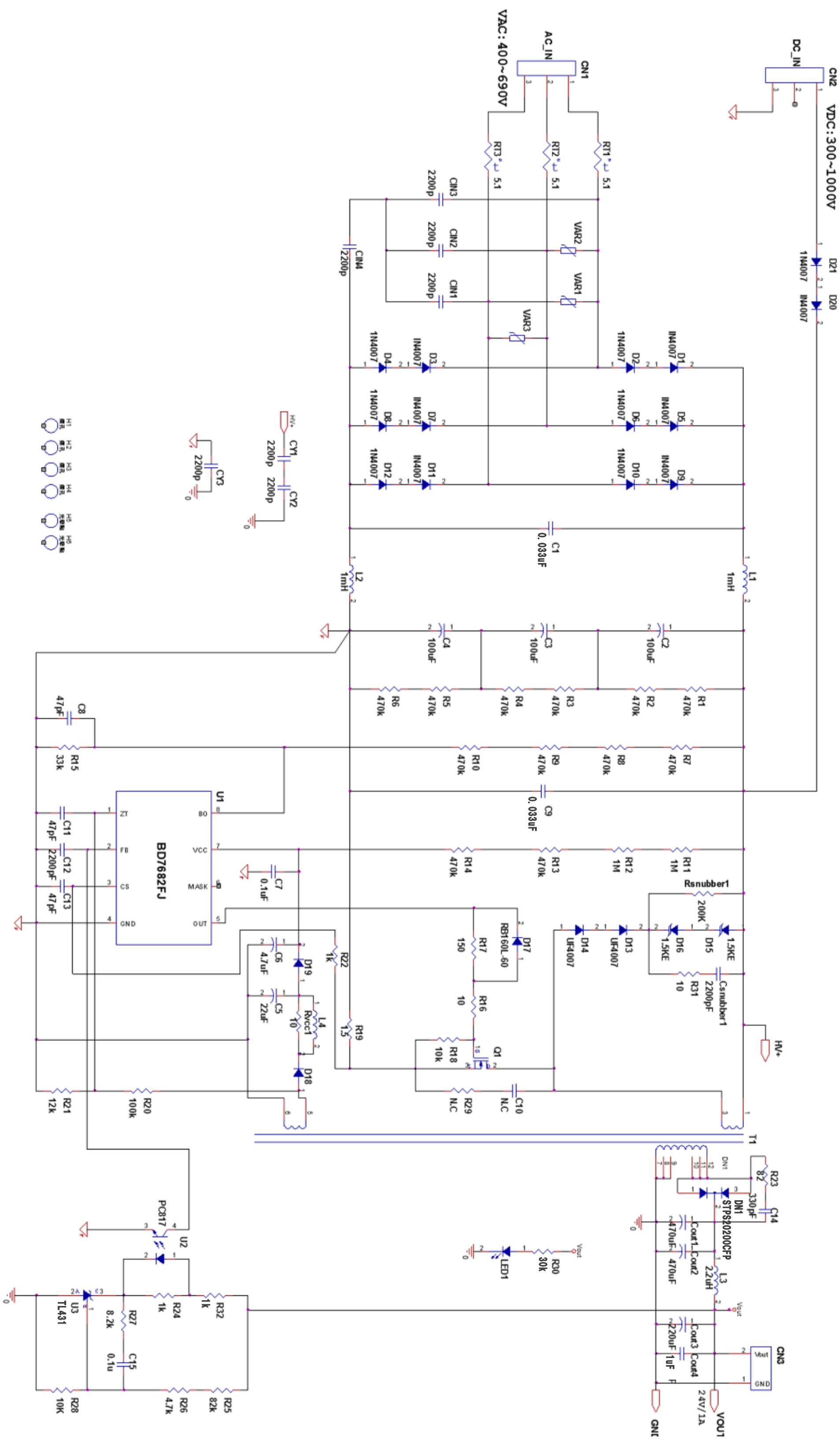


Figure 19. BD7682FJ-LB-EVK-402 Schematics

Parts List

Table 5. BD7682FJ-LB-EVK-402 Parts List

Item		Specifications	Parts name	Manufacture
Capacitor	C1, C9	0.033 µF, 650 Vac	PHE450RB5330J	KEMET
	C10	N.C.	-	-
	C12	2200 pF, 50 V	08055C222JAT2A	AVX
	C14	330 pF, 1 kV	225000111543	YAGEO
	C15	0.1 µF, 50 V	UMK212BJ104KGHT	TAIYO YUDEN
	C2, C3, C4	100 µF, 450 V	450BXW100MEFR18X30	RUBYCON
	C5	22 µF, 35 V	UVR1V220MDD1TD	NICHICON
	C6	4.7 µF, 35 V	UVR1V4R7MDD1TD	NICHICON
	C7	0.1 µF, 35 V	GRM21BR71H104JA01L	MURATA
	C8, C11, C13	47 pF, 50 V	GQM2195C1H470JB01D	MURATA
	CIN1, CIN2, CIN3, CIN4	2200 pF, X1:760 Vac, Y1:500 Vac	DE1E3RB222MJ4BR01F	MURATA
Connector	CN1		691250910003	WURTH ELECTRONIK
	CN2		691250610003	WURTH ELECTRONIK
	CN3		69110171002	WURTH ELECTRONIK
Capacitor	Cout1, Cout2	470 µF, 35 V	LER471M1VG16VR6	HERMEI Corp., LTD
	Cout3	220 µF, 35 V	UPS1V221MPD	NICHICON
	Cout4	1 µF, 50 V	UMK212B7105KG-T	TAIYO YUDEN
	Csnubber1	2200 pF, 2 kV	202S41W222KV4E.	JOHANSON DIELECTRICS INC
	CY1, CY2, CY3	2200 pF, X1:760 Vac, Y1:500 Vac	DE1E3RB222MJ4BR01F	MURATA
Diode	D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D20, D21	1 A, 1 kV	1N4007	
	D13, D14	1 A, 1 kV	UF4007	
	D15, D16	5.5 A, 200 V	1.5KE200A	
	D17	1 A, 40 V	RB160L-40TE25	ROHM
	D18	0.5 A, 200 V	RF05VAM2S	ROHM
	D19	0.1 A, 90 V	1SS355VM	ROHM
	DN1	SBD, 10 A x 2, 200 V	STPS20200CFP	ST-MICRO
Heat Sink	HS1	Heat Sink	MI-217-25	MEICON. Co., LTD.
	HS2	Heat Sink	MI-301G-25.4	MEICON. Co., LTD.
Inductor	L1, L2	1 mH	768772102	WURTH ELECTRONIK
	L3	2.2 µH, 4.3 A	7447462022	WURTH ELECTRONIK
	L4	N.C.	-	-
LED	LED1	RED 1 mA	SML-P11UTT86RK	ROHM
FET	Q1	1700 V, 4 A	SCT2H12NZ	ROHM
Resistor	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R13, R14	470 kΩ	MCR18ERTF4703	ROHM
	R11, R12	1 MΩ	KTR18EZPF1004	ROHM
	R15	33 kΩ	MCR10ERTF3302	ROHM
	R16	10 Ω	MCR10ERTF10R0	ROHM
	R17	150 Ω	MCR10EZPF1500	ROHM
	R18, R28	10 kΩ	MCR10ERTF1002	ROHM
	R19	1.5 Ω	ERX2SJ1R5	PANASONIC
	R20	150 kΩ	MCR10ERTF1503	ROHM
	R21	20 kΩ	MCR10ERTF2002	ROHM
	R22, R24, R32	1 kΩ	MCR10ERTF1001	ROHM
	R23	82 Ω	MCR100JZHF82R0	ROHM
	R25	82 kΩ	MCR10ERTF8202	ROHM
	R26	4.7 kΩ	MCR10ERTF4701	ROHM
	R27	8.2 kΩ	MCR10ERTF8201	ROHM
	R29	N.C.	-	-
	R30	30 kΩ	MCR03ERTF3002	ROHM
	R31	10 Ω	MCR100JZHF10R0	ROHM
	Rsnubber1	200 kΩ	RSF3WS-200KRJT	MAX-QUALITY Co., LTD
	RT1, RT2, RT3	5.1 Ω	FKN2W5R1J	MAX-QUALITY Co., LTD
	RVCC1	11 Ω	MCR10ERTF11R0	ROHM
Trans	T1	EFD-30	GC-FED30-172K	G-CHAN Co., LTD
IC	U1		BD7682FJ-LB	ROHM
PhotoCoupler	U2		LTV-817-B	LITEON
IC	U3		TL431BQ	TI
varistor	VAR1, VAR2, VAR3	1080 V, 10 KA, φ 20 mm	TMOV20RP750E	LITTELFUSE

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Layout

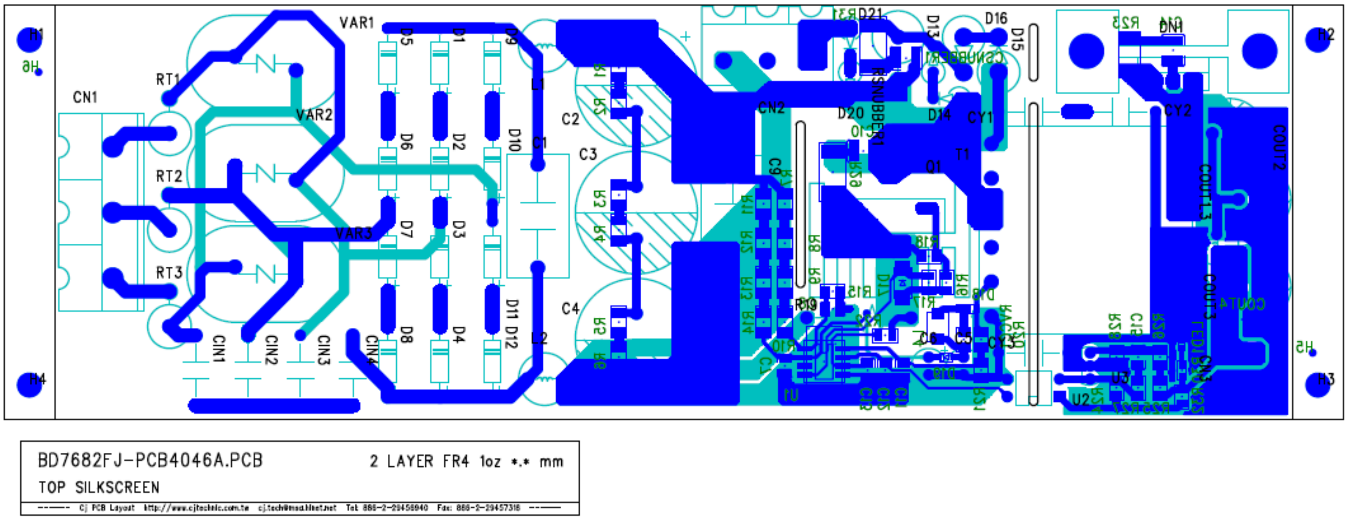

Figure 20. Proposed PCB Layout (Top view)

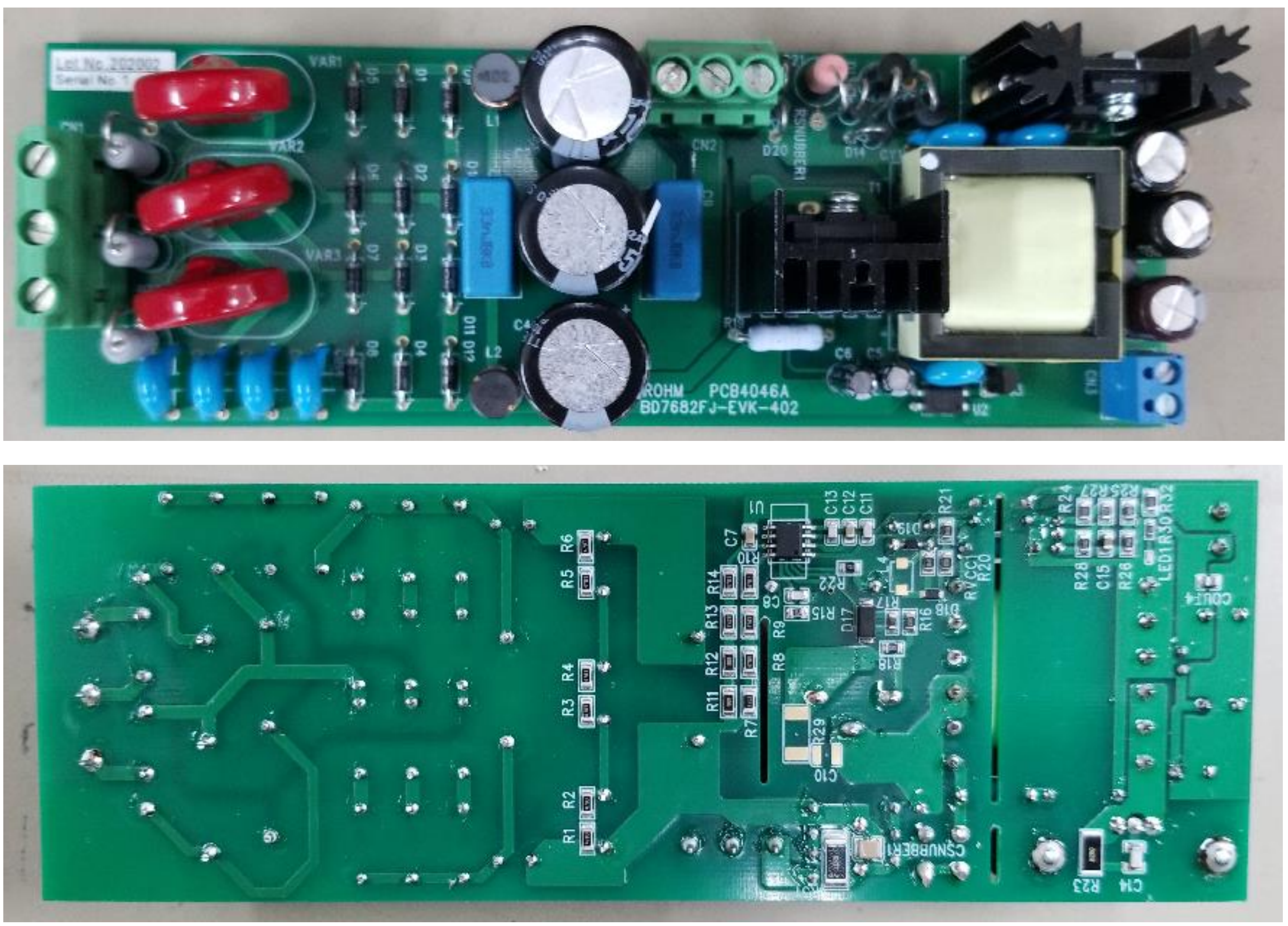

Figure 21.PCB Picture

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