ROHM SEMICONDUCTOR

Application Note

Quasi-Resonant type AC/DC converter IC

BD768xFJ-LB series Quasi-Resonant converter Technical Design

24V / 1A (SIC TO-3PFM SCT2H12NZ)

This application note describes the design of Quasi-Resonant converters using ROHM's AC/DC converter IC BD768xFJ-LB series devices. It explains the selection of external components and PCB layout guidelines.

● Description

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.

● Key features

Quasi-resonant method(Maximum frequency control 120kHz)/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

● Basic specifications

Operating power supply voltage range(VCC):		: VCC : 15.0V～27.5V
Operating current	Normal mode	: 0.80mA (Typ.)
	Burst mode	: 0.50mA(Typ.)
Maximum frequency		: 120kHz(Typ.)
Operating temperature range		: -40℃ to +105℃

(∗) 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.

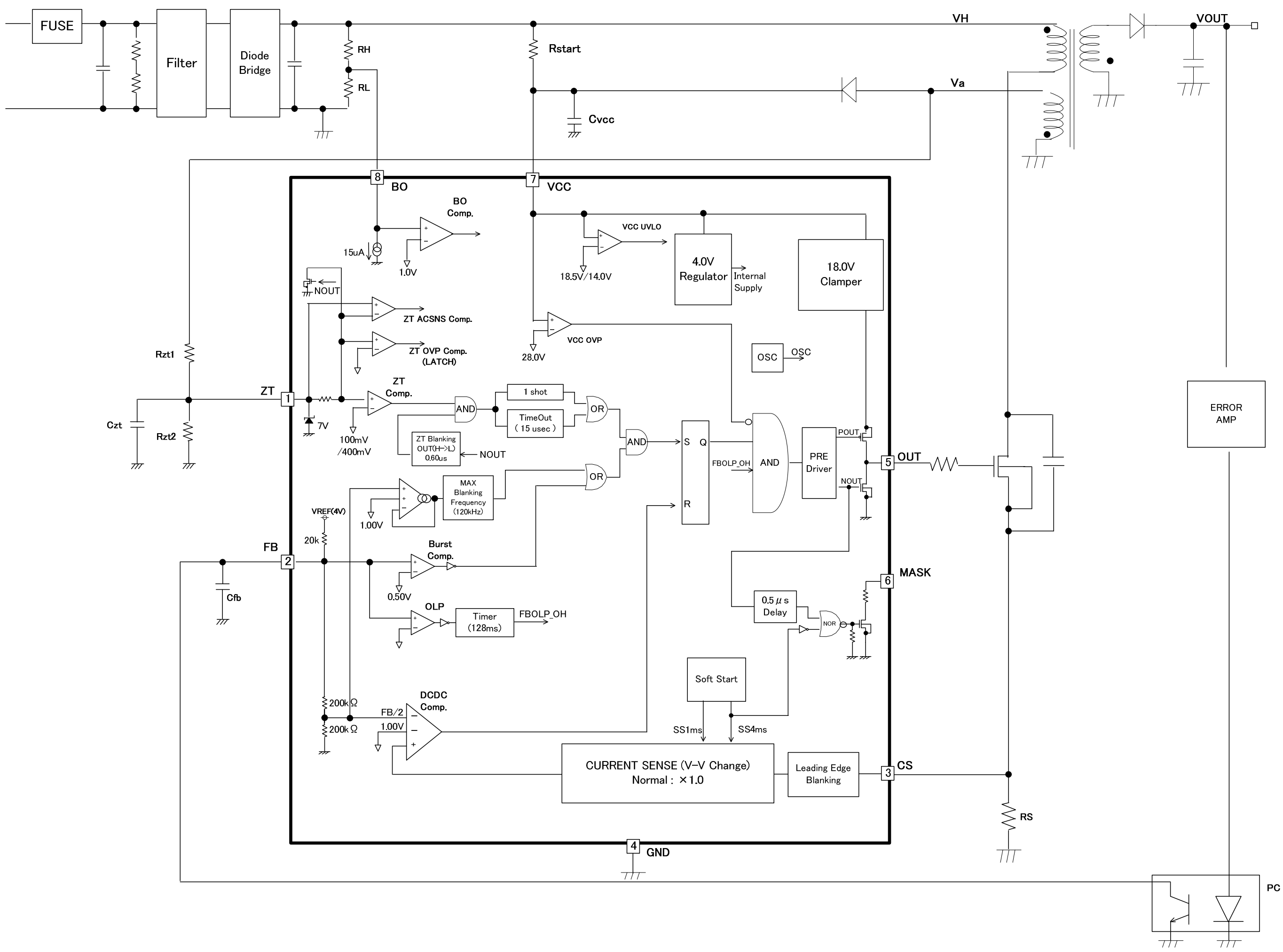
● BD768xFJ-LB Series line-up

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

● Applications

Industrial equipment, AC Adaptor, Household appliances

● **Block Diagram**



Contents

1. Design of Isolated Fly-buck Quasi-Resonant convertor

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 1-2. The Switching waveform at DCM and CCM is shown in Figure 1-2.

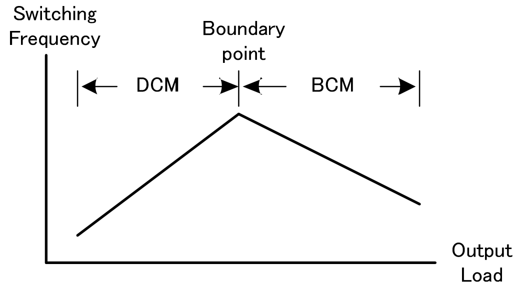


Figure 1-1.Switching Frequency – Output Load Characteristics

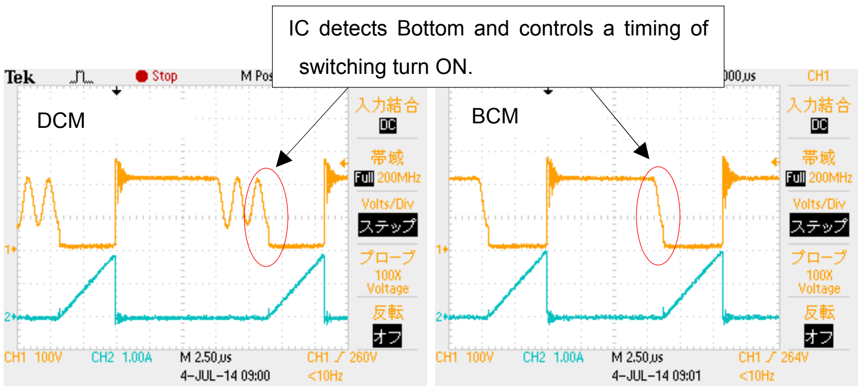


Figure 1-2.Switching waveform (MOSFET Vds,Ids)

1-1. Transformer T1 design (24V1A, Vin(DC)=300V～900V)

1-1-1. Determination of fly-back voltage VOR

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

$$\mathrm{VOR} = \mathrm{VO} \times \frac{\mathrm{Np}}{\mathrm{Ns}} = \frac{\mathrm{ton}}{\mathrm{toff}} \times \mathrm{VIN}$$

$$\Rightarrow \frac{\mathrm{Np}}{\mathrm{Ns}} = \frac{\mathrm{VOR}}{\mathrm{VO}}$$

$$\Rightarrow \mathrm{Duty} = \frac{\mathrm{VOR}}{\mathrm{VIN} + \mathrm{VOR}}$$

When VIN(MIN)=300V, VOR=204V, Vf=1.5V:

$$\frac{\mathrm{Np}}{\mathrm{Ns}} = \frac{\mathrm{VOR}}{\mathrm{VO}} = \frac{\mathrm{VOR}}{\mathrm{Vout} + \mathrm{Vf}} = \frac{204\mathrm{V}}{24\mathrm{V} + 1.5\mathrm{V}} = 8.0$$

$$\mathrm{Duty(max)} = \frac{\mathrm{VOR}}{\mathrm{VIN(min)} + \mathrm{VOR}} = \frac{204\mathrm{V}}{300\mathrm{V} + 204\mathrm{V}} = 0.405$$

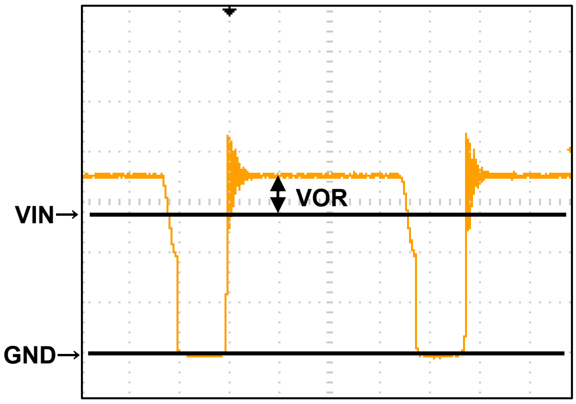


Figure1-3. MOSFET Vds

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

1-1-2. 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=300V） and the minimum frequency (Fsw=92kHz).

Other's parameter is following:

Po=24V × 1A=24W, Po (max)=30W(de-rating 0.8) in consideration of over current protection.

Transformer efficiency: η =85%

Resonance capacitor: Cv=100pF

$$Lp = \left[\frac{VIN(\min) \times Duty(\max)}{\sqrt{\frac{2 \times \mathrm{Po(max)} \times \mathrm{fsw}}{\eta}} + \mathrm{VIN(min)} \times Duty(\max) \times fsw \times \pi \times \sqrt{Cv}} \right]^2 = 1755uH$$

$$Ippk = \sqrt{\frac{2 \times Po(\max)}{\eta \times Lp \times fsw}} = 0.662A$$

1-1-3. Determination of transformer size

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

Table 1-1. Output Voltage and Transformer Core

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

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

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

Generally, the maximum magnetic flux density B(T) for an ordinary ferrite core is 0.4T @100°C, so Bsat = 0.3T.

$$\mathrm{Np} > \frac{\mathrm{Lp} \times \mathrm{Ippk}}{\mathrm{Ae} \times \mathrm{Bsat}} = \frac{1750\mathrm{uH} \times 0.66\mathrm{A}}{68\mathrm{mm}^2 \times 0.3\mathrm{T}} = 57\mathrm{turns}$$

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=50 turns:

$$AL-Value = \frac{Lp}{Np^2} = \frac{1750uH}{50turns^2} = 700nH/turns^2$$

$$\mathrm{NI} = \mathrm{Np} \times \mathrm{Ippk} = 50\mathrm{turns} \times 0.66\mathrm{A} = 33\mathrm{A \cdot turns}$$

Transformer is saturated based on the AL-value－NI characteristics.

Set the number of primary winding so as not to be saturation region.
In the case of Np=64 turns:

$$AL-Value = \frac{Lp}{Np^2} = \frac{1750uH}{64turns^2} = 427nH/turns^2$$

$$\mathrm{NI} = \mathrm{Np} \times \mathrm{Ippk} = 64\mathrm{turns} \times 0.66\mathrm{A} = 42.2\mathrm{A \cdot turns}$$

In this case, this point is within the tolerance range
Np = 64 turns is determined

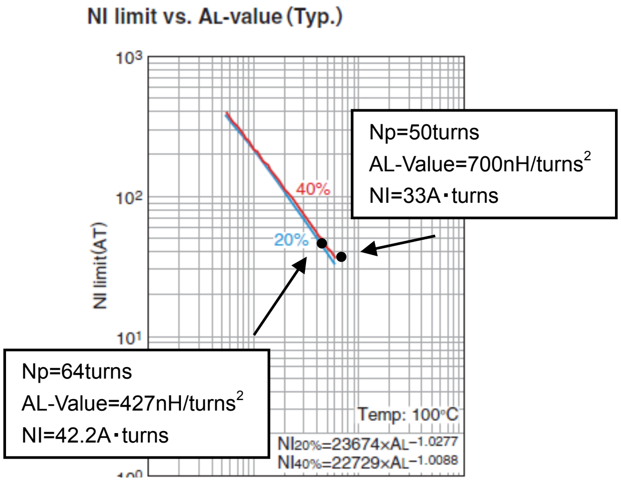


Figure 1-4.
AL-Value－NI Limit
Reference Characteristics

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

$$\frac{\mathrm{Np}}{\mathrm{Ns}} = 8 \quad \rightarrow \quad \mathrm{Ns} = \frac{64}{8} = 8 \ \mathrm{turns}$$

1-1-6. Calculation of VCC turn count Nd

When VCC=24V, Vf_vcc=1V,

$$\mathrm{Nd} = \mathrm{Ns} \times \frac{\mathrm{VCC} + \mathrm{Vf\_vcc}}{\mathrm{Vout} + \mathrm{V\ f}} = 8\mathrm{turns} \times \frac{24\mathrm{V} + 1.0\mathrm{V}}{24\mathrm{V} + 1.5\mathrm{V}} = 7.8\mathrm{turns}$$

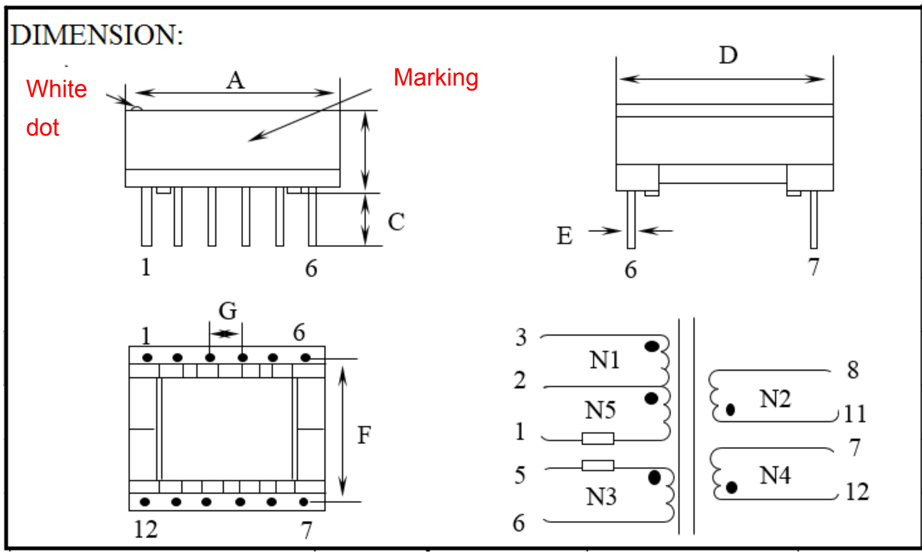
(*)In the case of driving SiC-MOSFET, since it is necessary to control the Gate voltage, VCC is required more than 22V.

As a result, the transformer specifications are as follows.

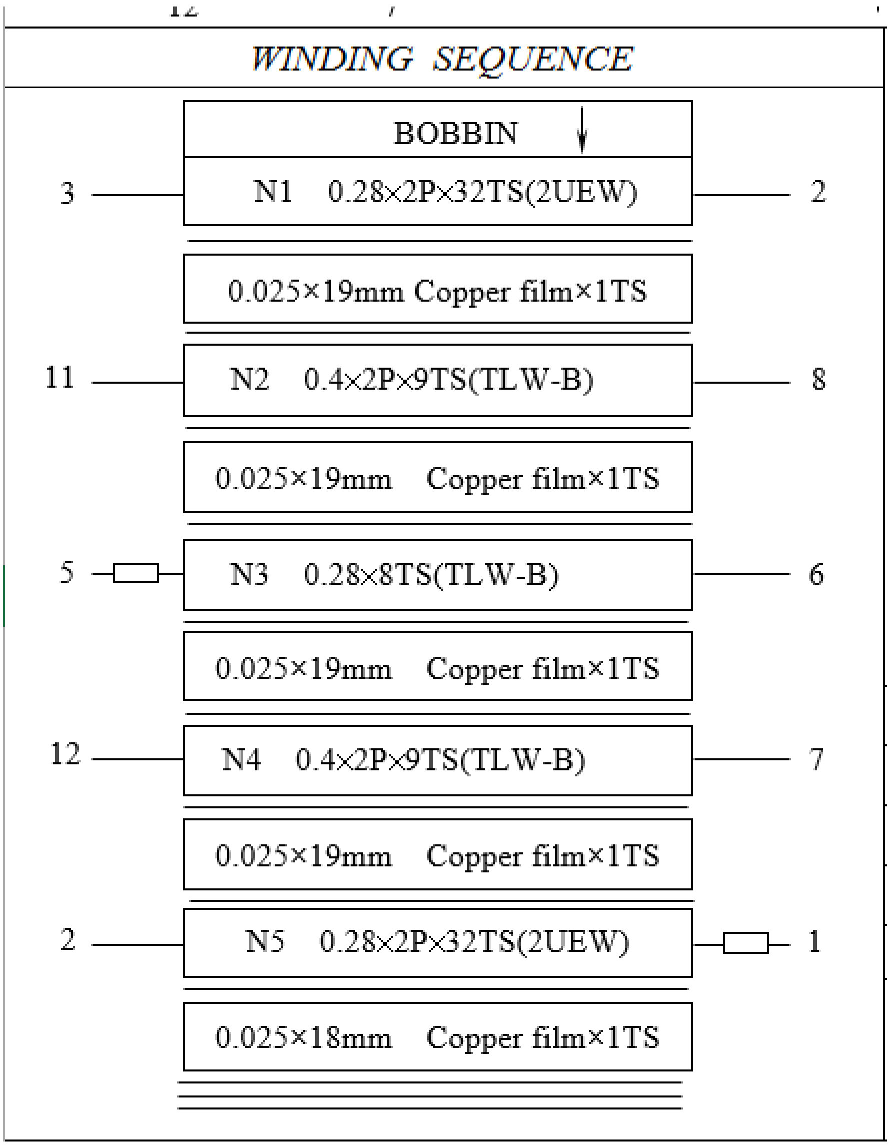
Table 1-2. Transformer Specifications

Core	EFD30 compatible
Lp	1750uH
Np	64 turns
Ns	8 turns
Nd	8 turns

1-1-7. 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



1-2. Selection of main components

1-2-1. MOSFET:Q1

For MOSFET selection, it must be considered maximum voltage between the drain and source, peak current, 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.

$$Vds(\max) = VIN(\max) + VOR + Vspike = VIN(\max) + (Vout + Vf) \times \frac{Np}{Ns} + Vspike = DC900V + (24V + 1.5V) \times \frac{64turns}{8turns} + Vspike$$
$$= 1104V + Vspike$$

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

In this design example, ROHM's MOSFET SCT2H12NZ(1700V 4A 1.15Ω) is selected .

Below show the typical characteristics of SCT2H12NY. Please refer to the SCT2H12NY data sheet for formal data.

○ABSOLUTE MAXIMUM RATINGS [Tj=25°C]

DRAIN-SOURCE VOLTAGE	V_{DSS}	・・・	1700V
GATE-SOURCE VOLTAGE	V_{GSS}	・・・	-6V ～ +22V
DRAIN CURRENT CONTINUOUS	I_D	・・・	±4A （Limited by Tj）
RAIN CURRENT PULSED	I_{DP}	・・・	±10A PW≦10μs DUTY CYCLE≦1%
SOURCE CURRENT CONTINUOUS	I_S	・・・	4A （BODY DIODE. Limited by Tj.）
SOURCE CURRENT PULSED	I_{SP}	・・・	10A PW≦10μs DUTY CYCLE≦1% （BODY DIODE.）
TOTAL POWER DISSIPATION	P_D	・・・	44W
JUNCTION TEMPERATURE	T_j	・・・	175°C
RANGE OF STORAGE TEMPERATURE	T_{stg}	・・・	-55～175°C

PARAMETER	ITEM	CONDITION	MIN.	TYP.	MAX.
GATE-SOURCE LEAKAGE CURRENT	I_{GSS+}	V_{GS}=+22V/V_{DS}=0V	—	—	100nA
GATE-SOURCE LEAKAGE CURRENT	I_{GSS-}	V_{GS}=-6V/V_{DS}=0V	—	—	-100nA
DRAIN-SOURCE BREAKDOWN VOLTAGE	$V_{(BR)DSS}$	I_D=1mA/V_{GS}=0V	1700V	—	—
ZERO GATE VOLTAGE DRAIN CURRENT	I_{DSS}	V_{DS}=1700V/V_{GS}=0V	—	0.1μA	10μA
GATE THRESHOLD VOLTAGE	$V_{GS(th)}$	V_{DS}= V_{GS} /I_D=410μA	1.6V	—	4.0V
STATIC DRAIN-SOURCE ON-STATE RESISTANCE	$R_{DS(on)}$ *PULSED	I_D=1.1A/V_{GS}=18V Tj=25°C	0.80Ω	1.15Ω	1.50Ω
		I_D=1.1A/V_{GS}=18V Tj=125°C	—	1.71Ω	—
TRANSCONDUCTANCE	g_{fs} *PULSED	V_{DS}=10V/I_D=1.1A	—	0.4S	—
INPUT CAPACITANCE	C_{iss}	V_{DS}=800V/V_{GS}=0V f=1MHz	—	184pF	—
OUTPUT CAPACITANCE	C_{oss}		—	16pF	—
REVERSE TRANSFER CAPACITANCE	C_{rss}		—	6pF	—
GATE INPUT RESISTANCE	Rg	f=1MHz open Drain	—	64Ω	—
TURN-ON DELAY TIME	$t_{d(on)}$ *PULSED	V_{DD}=500V I_D=1.1A V_{GS}=18V/0V R_L=455Ω R_G=0Ω	—	16.3ns	—
RISE TIME	t_r *PULSED		—	20.9ns	—
TURN-OFF DELAY TIME	$t_{d(off)}$ *PULSED		—	35.1ns	—
FALL TIME	t_f *PULSED		—	73.8ns	—
TOTAL GATE CHARGE	Q_g *PULSED	V_{DD}=500V I_D=1A V_{GS}=18V R_L=500Ω	—	14nC	—
GATE-SOURCE CHARGE	Q_{gs} *PULSED		—	4nC	—
GATE-DRAIN CHARGE	Q_{gd} *PULSED		—	5nC	—

1-2-2. Input capacitor: C2,C3,C4 Balance resistance: R1,R2,R3,R4,R5,R6

Use Table 1-3 to select the capacitance of the input capacitor.

Since Pout=24Vx1.1A≒25W Cmain: 1x25=25 → 33uF

Table 1-3. Input Capacitor

Input voltage (Vdc)	Cin (uF)
< 300	2 x Pout(W)
300<	1 x Pout(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=900V/0.8=1125V

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

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 470kohm.

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

P11_12_13_14_15_16=VN(MAX) × VIN(MAX)/R=900V × 900V/2.82Mohm=0.287W

It is shown in Figure 1-5.

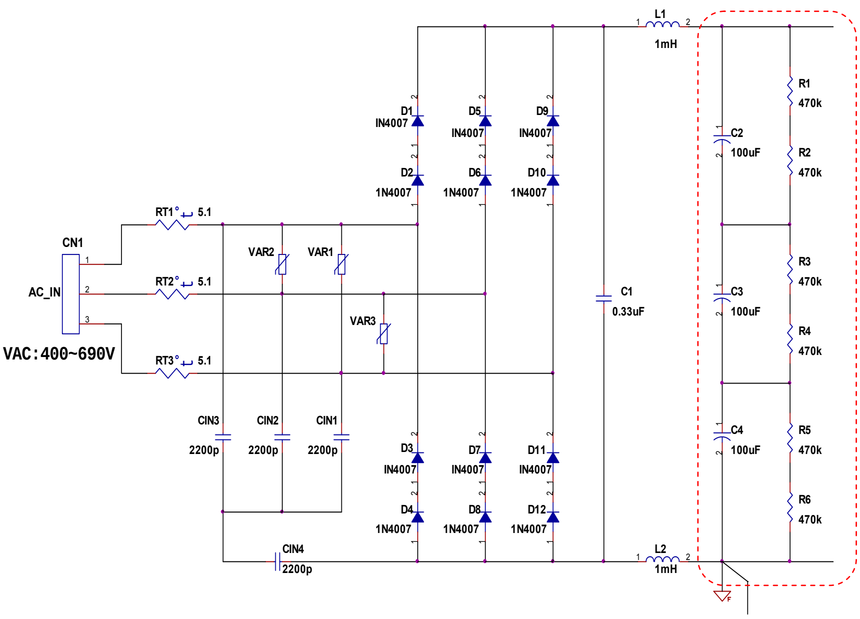


Figure 1-5. Input capacitor and Balance resistance

1-2-3. 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.

$$R19 = \frac{Vcs}{Ippk} = \frac{1.0V}{0.66A} = 1.515\Omega$$

Sensing resistor loss P_R19:

$$\mathrm{P\_R19(peak)} = \mathrm{Ippk}^2 \times \mathrm{R19} = 0.66A^2 \times 1.5\Omega = 0.6534\mathrm{W}$$

$$\mathrm{P\_R19(rms)} = \mathrm{Iprms}^2 \times \mathrm{R19} = \left(\mathrm{Ippk} \times \sqrt{\frac{\mathrm{Duty(max)}}{3}}\right)^2 \times \mathrm{R19} = \left(0.66\mathrm{A} \times \sqrt{\frac{0.404}{3}}\right)^2 \times 1.0 = 0.0586\mathrm{W}$$

Set the value 1W 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.

1-2-4. 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. This function corrects the overload.

Since the input voltage range is DC300V ~ DC900V, switching voltage is set to DC400V. 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 1mA, overload protection point is lowered.

$$R20 = VIN(change) \times \frac{Nd}{Np} \times \frac{1}{Izt} = 500V \times \frac{8turns}{64turns} \times \frac{1}{1mA} = 62.5k\Omega$$

Check whether the rating load can be taken after the point of over load protection is switched.
When the IC switches CS over current voltage level, it is changed from 1.0V to 0.7V.

$$VIN(change) = R20 \times \frac{Np}{Nd} \times Izt = 56k\Omega \times \frac{64turns}{8turns} \times 1mA = 448V$$

$$Ippk' = \frac{Vcs}{R19} = \frac{0.70V}{1.5\Omega} = 0.466A$$

$$ton' = \frac{Lp \times Ippk'}{VIN(change)} = \frac{1750uH \times 0.466A}{496V} = 1.64us$$

$$Ispk' = \frac{Np}{Ns} \times Ippk' = \frac{64turns}{8turns} \times 0.466A = 3.728A$$

$$Ls = Lp \times \left(\frac{Ns}{Np}\right)^2 = 1750uH \times \left(\frac{8turns}{64turns}\right)^2 = 27.34uH$$

$$toff' = \frac{Ls \times Ispk'}{Vout + Vf} = \frac{27.34uH \times 3.728A}{24V + 1.5V} = 3.997us$$

$$tdelay = \pi \times \sqrt{Lp \times Cv} = 3.14 \times \sqrt{1750uH \times 100pF} = 1.31us$$

$$fsw' = \frac{1}{ton' + toff' + tdelay} = \frac{1}{1.64us + 3.997us + 1.31us} = 143kHz$$

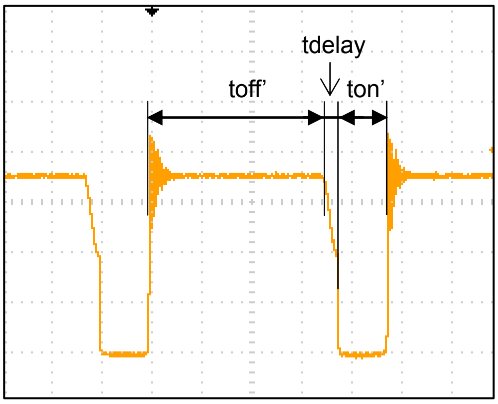


Figure 1-6. The waveform of Switching

$$Po' = \frac{1}{2} \times Lp \times Ippk'^2 \times fsw' \times \eta = \frac{1}{2} \times 1750uH \times 0.466A^2 \times 120kHz \times 0.85 = 19.38W$$

Transformer efficiency: η =0.85

When Po' is under the rated output power, R19 has to be adjusted.
In this board, furthermore, if the over load point is adjusted by a resistor of 100 kHz, the point is changed to 816V because the maximum frequency of the IC is restricted to 120 kHz. Regarding the over load protection point, please check in an actual product.

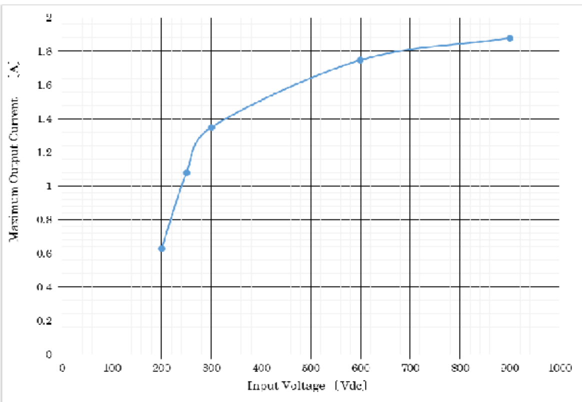


Figure 1-7. Input voltage correction circuit of overcurrent detection (reference value)

1-2-5. Setting resistor for ZT terminal voltage: R21

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

$$Vzt = (V\text{out} + Vf) \times \frac{Nd}{Ns} \times \frac{R21}{R20 + R21} = 2.7V \; --> R21 = 11.84k\Omega$$

1-2-6. 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.

1-2-7. VCC-diode: D18

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

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

$$\mathrm{Vdr} = \mathrm{VCC(max)} + \mathrm{Vf} + \mathrm{VINmax} \times \frac{\mathrm{Nd}}{\mathrm{Np}}$$

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

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

$$\mathrm{Vdr} = 31.5\mathrm{V} + 1.0V + 900\mathrm{V} \times \frac{8\mathrm{turns}}{64\mathrm{turns}} = 145\mathrm{V}$$

With a design-margin taken into account, 145V/0.7≒ 200V → 200V component is selected.

（Example: ROHM’s RF05VAM2S 200V 0.5A）

1-2-8. 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 5Ω to 22Ω) 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.

1-2-9. VCC starter resistance ;R11,R12,R13,R14 capacitance;C5,C6 and Rectifier diode;D18, D19

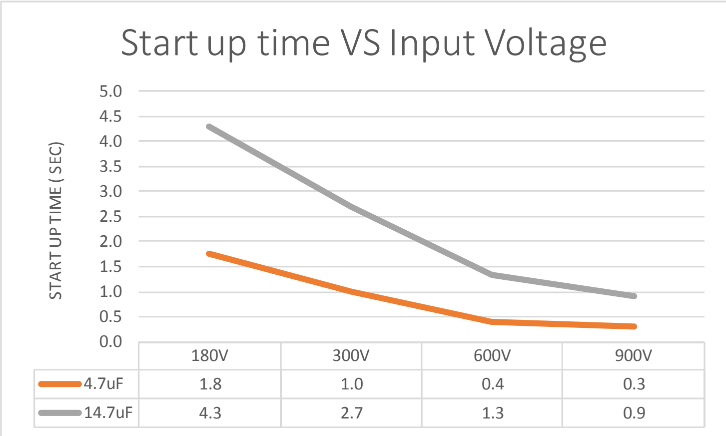
Start resistance R_{START} is the resistance required to start the IC.
When the start resistance R_{START} value is reduced, the standby power is increased and the startup time is shortened.
Conversely, when the start resistance R_{START} value is increased, the standby power is reduced and the startup time is lengthened. When BD768xFJ is in standby mode, current I_{OFF} becomes 40μA (Max)
However, this is the minimum current required to start the IC. In this case current I_{OFF} is 40μA(Max) with margin.
Input voltage VIN_start=180V: VCCUVLO(max)=20V: Ivcc-protected(min)=0.3mA:

$$\mathrm{Rstart} < (Vcc\_start - VCCuvlo(\mathrm{min})) / Istart(\mathrm{max}) = (180V - 20V) / 40uA = 4000kohm$$

$$\mathrm{Rstart} > (Vin\_\mathrm{max} - Vcc\_ovp(\mathrm{max})) / Icc\_protect = (900V - 31.5V) / 0.3mA = 2895kohm$$

$$2895\mathrm{kohm} < \mathrm{Rstart} < 4000kohm$$

From the above results, set Rstart = 2940kohm (1Mohm × 2 + 470kohm × 2 series).
Start-up time is shown in Figure 1-8.



	180V	300V	600V	900V
4.7uF	1.8	1.0	0.4	0.3
14.7uF	4.3	2.7	1.3	0.9

Figure 1-8. Start up time

A VCC capacitor is needed to stabilize the IC's VCC voltage.
Capacitance of 2.2μF or above is recommended.
This example is recommended circuit of Figure 1-9 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.
D18 is recommended Low IR Switching diode. (Example Rohm 1SS355VM)

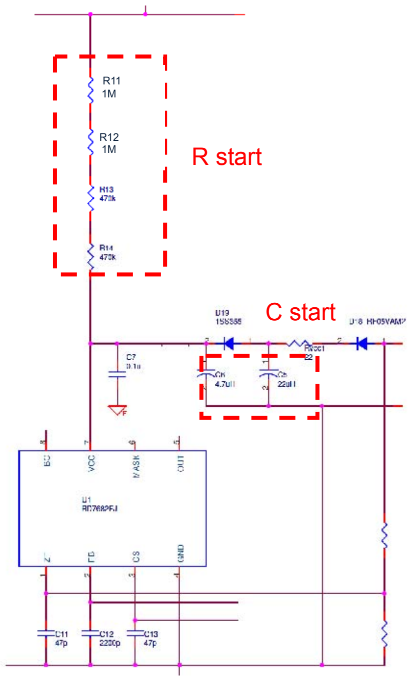


Figure1-9. resistance of Starter and VCC capacitor

1-2-10. Brown IN/OUT resistance: R7,R8,R9,R10,R15 and BO capacitor: C8

When the input VH 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 operation start (OFF => ON) $(V_{HON}-1.0)/R_H = 1.0/R_L + 15*10e-6$

IC operation stop (ON => OFF) $(V_{HOFF}-1.0)/R_H = 1.0/R_L$

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

$R_H = (V_{HON} - V_{HOFF}) / (15 * 10e-6)$, $R_L = 1.0 / (V_{HOFF} - 1.0) * R_H$

V_{HON}=90V、V_{HOFF}=60V: It becomes the circuit shown in Figure 1-10.

It should be noted that the BO terminal is required capacitor C8.

BO line is weak in noise for high impedance. Recommended is 0.01uF ~ 0.1uF.

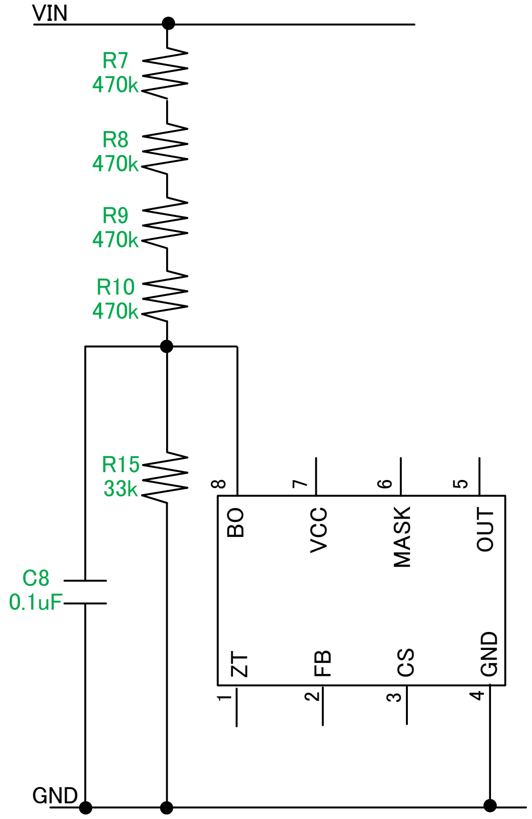


Figure 1-10. Broun IN/OUT setting

1-2-11. 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.

(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 = 1700V × 0.8 = 1360V

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

(2) Determination of R snubber 1

R snubber 1 is selected according to the following conditions.

$$\mathrm{R\ snubber\ 1} < 2 \times \mathrm{Vclamp} \times \frac{\mathrm{Vclamp} - \mathrm{VOR}}{\mathrm{Lleak} \times \mathrm{Ip}^2 \times \mathrm{fsw(max)}}$$

Lleak = Lp x 10% = 1750uH x 10% = 175uH

In the case of Po=25W, VIN(max)=900V, Ip、fsw is calculated

$$\mathrm{Po} = \frac{1}{2} \times \mathrm{Lp} \times \mathrm{Ip}^2 \times \mathrm{fsw} \times \eta$$

$$\mathrm{Ip} = \frac{\mathrm{Vcs}}{\mathrm{Rcs}} \qquad \mathrm{fsw} = \frac{1}{\mathrm{ton} + \mathrm{toff} + \mathrm{tdelay}} = \frac{1}{\left(\frac{\mathrm{Lp}}{\mathrm{VIN}} \times \mathrm{Ip}\right) + \left(\frac{\mathrm{Ls}}{\mathrm{Vo} + \mathrm{Vf}} \times \frac{\mathrm{Np}}{\mathrm{Ns}} \times \mathrm{Ip}\right) + \pi \times \sqrt{\mathrm{Lp} \times \mathrm{Cv}}}$$

⇒ Vcs=0.7V, Ip=0.466A, fsw=161kHz

$$\mathrm{Rsnubber\ 1} < 2 \times 1360\mathrm{V} \times \frac{1360\mathrm{V} - 204\mathrm{V}}{175\mathrm{uH} \times 0.466^2 \times 120\mathrm{kHz}} = 253\mathrm{k}\ \Omega$$

R snubber 1 loss P_ R snubber 1 is expressed as

$$\mathrm{P\_R\ snubber\ 1} = \frac{(\mathrm{Vclamp} - \mathrm{VIN})^2}{\mathrm{R\ snubber\ 1}} = \frac{(1360 - 900)^2}{200\mathrm{k}\ \Omega} = 1.05\mathrm{W}$$

A more than 2W component is determined with consideration for design margin.

(3) Determination of C snubber 1

$$\mathrm{Csnubber1} > \frac{\mathrm{Vclamp}}{\mathrm{Vripple} \times \mathrm{fsw(min)} \times \mathrm{Rsnubber}} = \frac{1360\mathrm{V}}{50\mathrm{V} \times 120\mathrm{kHz} \times 200\mathrm{k}\ \Omega} = 1607\mathrm{pF}$$

The voltage applied to C snubber 1 is 1360V-900=460V.

C snubber 1 is set 600V or above with design margin.

(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.

(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.

1-2-12. FB terminal capacitor: C12

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

1-2-13. 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: R16：10Ω 0.25W、R17：150Ω、D17：SBD 60V 1A)

In the case of Quasi-Resonant converters, switching-loss basically does not occur during turn-on, but it occurs predominantly during turn-off. 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 10kohm ~ 100kohm.

1-2-14. Output rectification diode: DN1

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

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

$$\mathrm{Vdr} = \mathrm{Vout(max)} + \mathrm{Vf} + \mathrm{VINmax} \times \frac{\mathrm{Ns}}{\mathrm{Np}}$$

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

$$\mathrm{Vdr} = 25.2\mathrm{V} + 1.5V + 900\mathrm{V} \times \frac{8}{64} = 139.2\mathrm{V}$$

139.2V/0.7=198V → 200V component is determined with consideration for design margin.

Also, diode loss (approximate value) becomes Pd=Vf x Iout=1.5V x 1.0A=1.5W

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

Using a voltage margin of 70% 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.

1-2-15. Output capacitors: C out 1,C out 2,C out 3, C out 4

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 = 200mV,

$$Z\_C < \frac{\Delta \mathrm{Vpp}}{\mathrm{Ispk}} = \frac{\Delta \mathrm{Vpp}}{\frac{\mathrm{Np}}{\mathrm{Ns}} \times Ippk} = \frac{0.2\mathrm{V}}{\frac{64}{8} \times 0.66A} = 0.0379\ \Omega \quad \text{at} \quad 60\text{kHz (fsw min)}$$

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

$$Z\_C < 0.0379\ \Omega \times \frac{60}{100} = 0.02274\ \Omega \quad \text{at} \quad 100\text{kHz}$$

Ripple-current Is (rms):

$$\mathrm{Is(rms)} = \mathrm{Ispk} \times \sqrt{\frac{1 - \mathrm{Duty}}{3}} = \frac{64}{8} \times 0.66\mathrm{A} \times \sqrt{\frac{1 - 0.261}{3}} = 2.62\mathrm{A}$$

The capacitor's withstand voltage should be set to about twice the output voltage.

Vout x 2 = 24V x 2 = 48V → 50V over

Select an electrolytic capacitor that is suitable for these conditions.

(Example: low impedance type 50V, 470 μF × 3 parallel for switching power supply)

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

1-2-16. Output voltage setting resistors: R25,R26,R28

When Shunt regulator IC2:Vref=2.495V,

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

1-2-17. Parts for adjustment of control circuit: R24,R27,R32,C15

R27 and C15 are parts for phase compensation. Approximately R27=1k～30kΩ、C15=0.1uF, and adjust them while they are assembled in the product.

R32 is a resistor which limits a control circuit current. Approximately R32:300 to 2kΩ, 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 1mA. And when Optocoupler:PC1_Vf is 1V,

R24 = 1V / 1mA = 1kΩ

1-3. 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: Y-Cap 2200pF)
- Addition of RC snubber to secondary diode

1-4. Output noise countermeasures

As an output noise countermeasure, add an LC filter (approximately L:10µH, C: 10µF to 100µF) to the output.

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

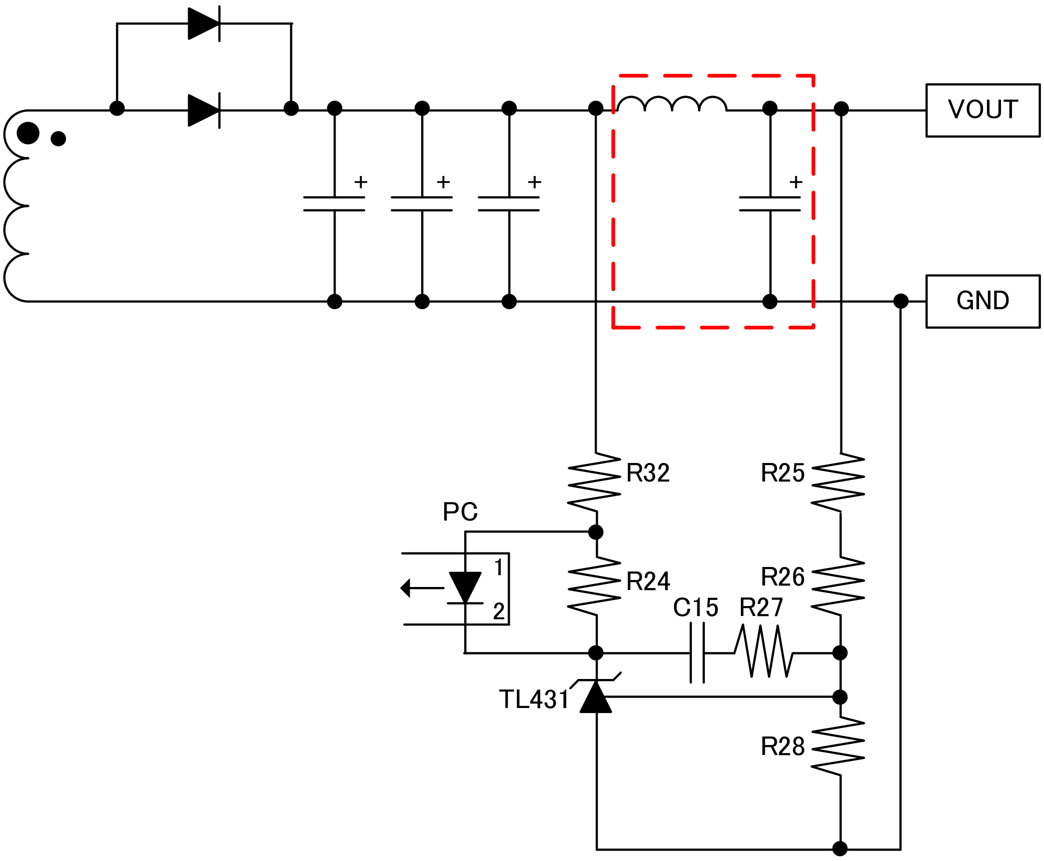


Figure1-11. LC Filter Circuit

1-5. Proposed PCB layout

A proposed layout (example) for these circuits is shown in Figure 1-12.

・Double-sided board, lead component view

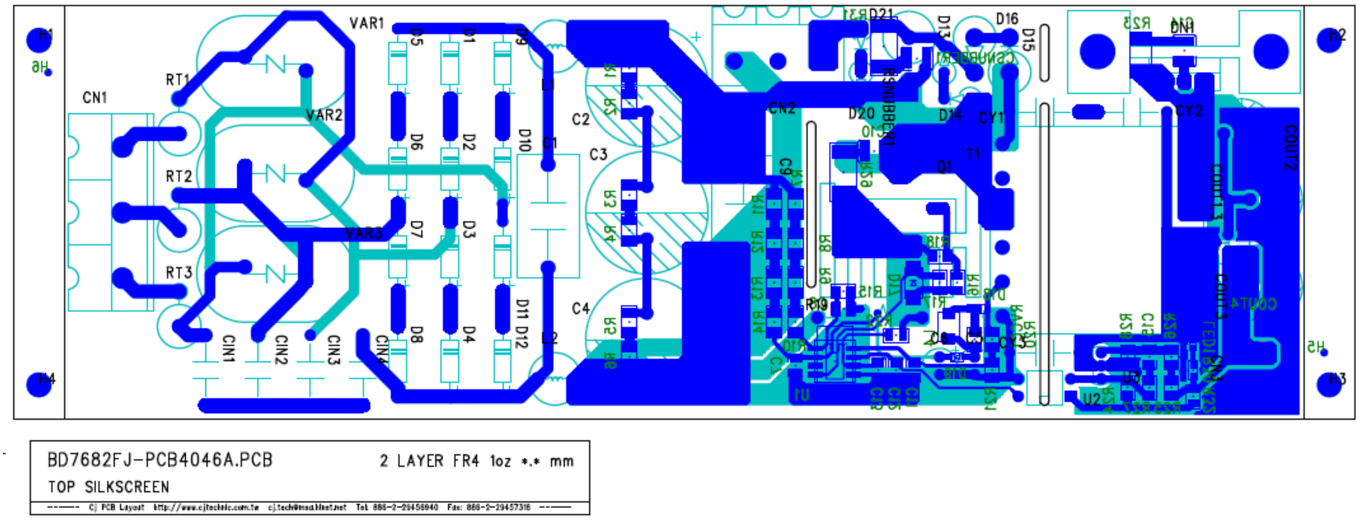


Figure 1-12. Proposed PCB Layout (Example)

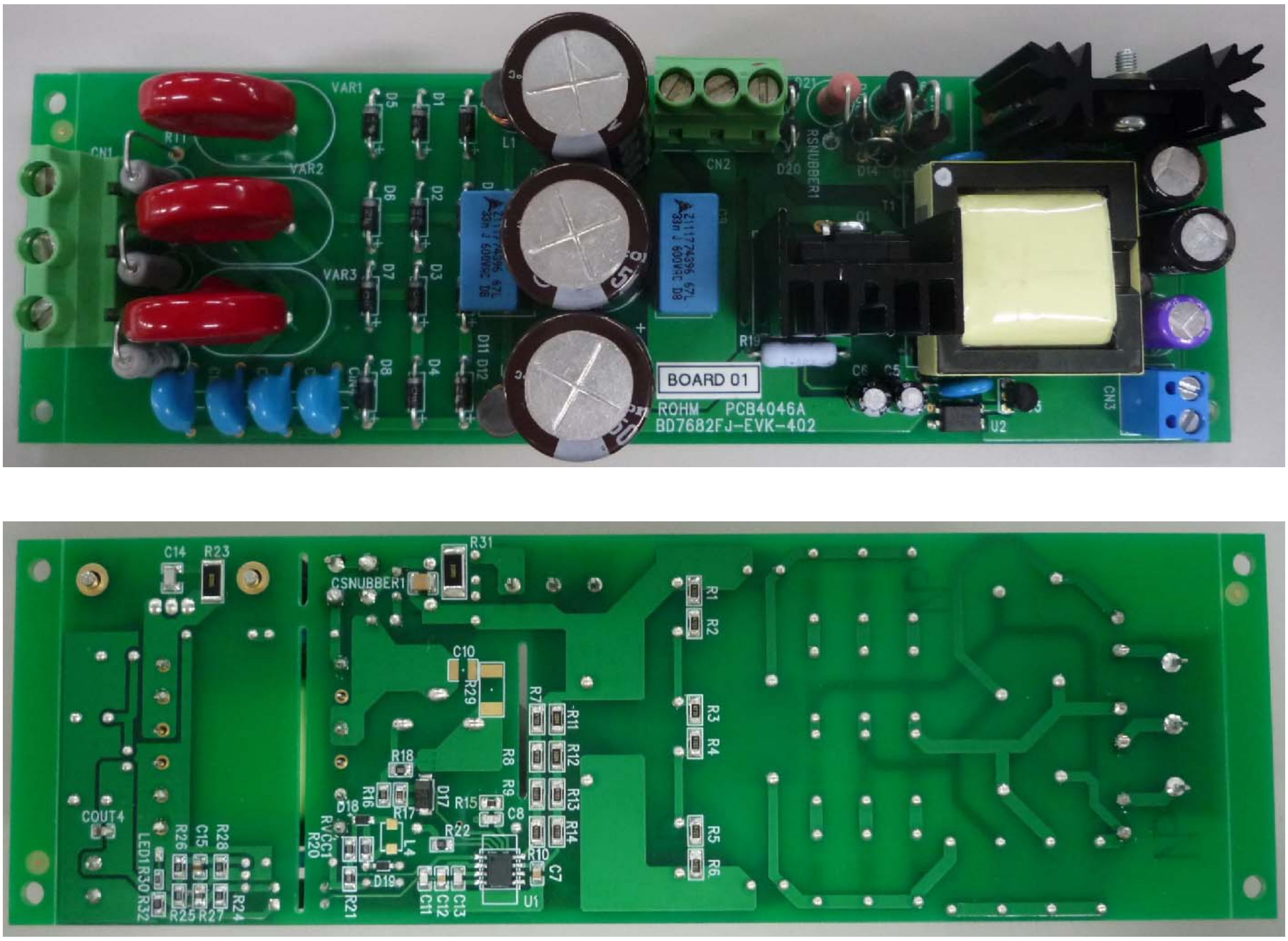


Figure 1-13. Evaluation board

2. Evaluation result

2.1. Evaluation circuit and parts list

The evaluation circuit is shown in Figure 2-1, parts list is shown in Table 2-1.

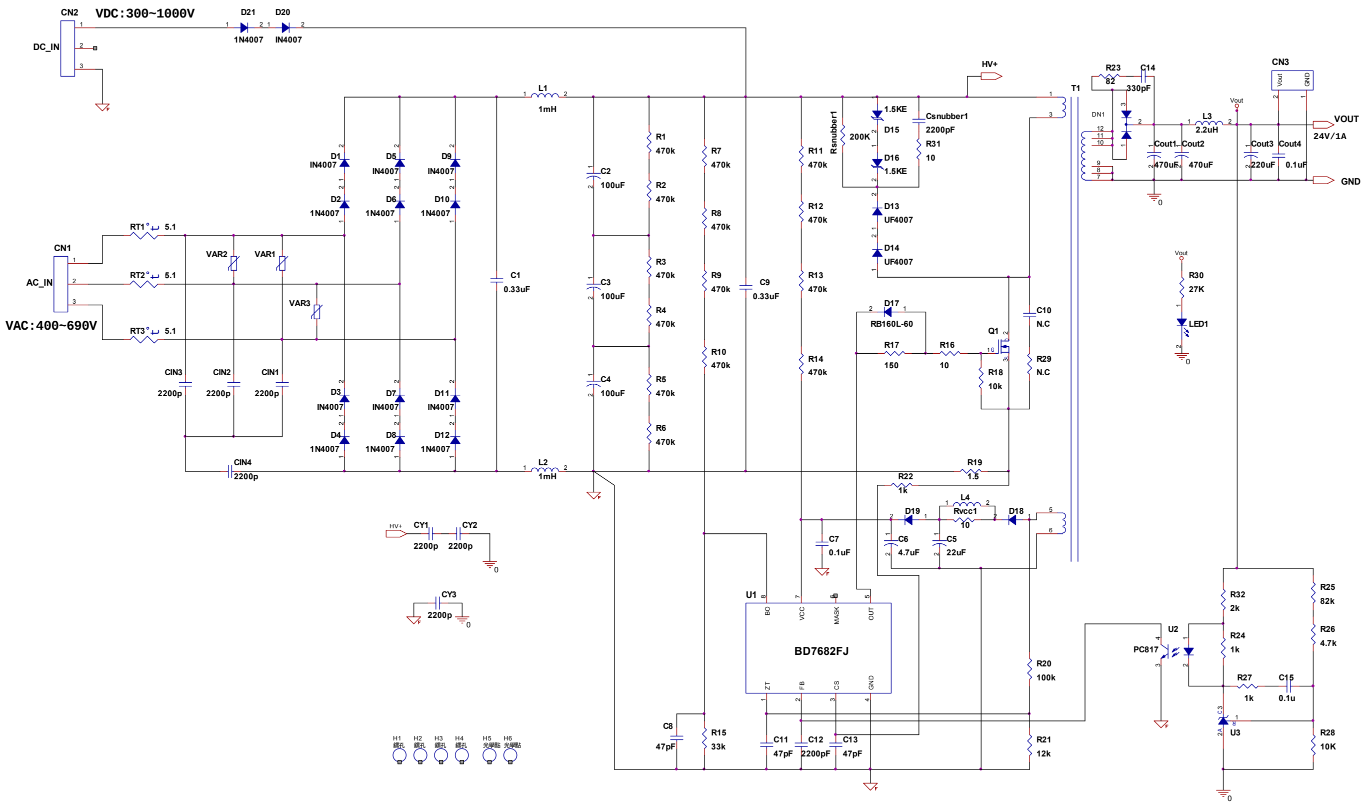


Figure 2-1. Isolated Fly-buck Quasi-Resonant convertor（24V1A=24W）

Table 2-1. Isolated Fly-buck Quasi-Resonant convertor（24V1A=24W）

ROHM BD7682FJ-LB Application Board				
Bill of Materials # 1				
Item	Part Description	Quantity	Manufacturer	Manufacturer part number
CN1	Terminal Block, 3x1, 9.52MM, TH	1	Phoenix Contact	1714984
CN2	Terminal Block, 3x1, 9.52MM, TH	1	Phoenix Contact	1714968
CN3	WR-TBL_5.0mm_Horizontal Serie101_THT	1	WURTH ELECTRONIK	69110171002
VAR1	VARISTOR 1080V 10KA DISC 20MM	1	Littelfuse Inc	TMOV20RP750E
VAR2	VARISTOR 1080V 10KA DISC 20MM	1	Littelfuse Inc	TMOV20RP750E
VAR3	VARISTOR 1080V 10KA DISC 20MM	1	Littelfuse Inc	TMOV20RP750E
RT1,RT2,RT3	Fusible ResistorResistor, 2W, 5%	3	Max-Quality Co., LTD	FKN2W10JTB
C1,C9	Film Cap 0.033UF 1.6KV_DC TH	2	TDK_EPCOS Inc	B32672L1333J
CIN1, CIN2, CIN3,CIN4	CAP, X1Y1, 250VAC	3	Rise Power Corp	WDE222M9HL
C2,C3,C4	AL CAP, 100uF, 450V, +/-20%	3	Nichicon	UPT2W101MHD
CY1,CY2,CY3	CAP, X1Y1, 1KV	3	Shinyspace Co.,Ltd	DY5P222K1K08D
L1,L2	HV Inductor, Shielded , 1mH, TH	2	Wurth Elektronik	768772102
Rsnubber1	RES 200K OHM 3W 1% AXIAL	1	Faithful link corp	CFSJ100K
RVCC1	RES, 11 ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF11R0
R1	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	MCR18ERTF4703
R2	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	MCR18ERTF4703
R3	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	MCR18ERTF4703
R4	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	MCR18ERTF4703
R5	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	MCR18ERTF4703
R6	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	MCR18ERTF4703
R7	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	KTR18EZPF4703
R8	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	KTR18EZPF4703
R9	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	KTR18EZPF4703
R10	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	KTR18EZPF4703
R11	RES, 1M ohm, 1%, 0.25W, 1206	1	ROHM	KTR18EZPF1004
R12	RES, 1M ohm, 1%, 0.25W, 1206	1	ROHM	KTR18EZPF1004
R13	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	KTR18EZPF4703
R14	RES, 470k ohm, 1%, 0.25W, 1206	1	ROHM	KTR18EZPF4703
R15	RES, 33k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF3302
R16	RES, 10 ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF10R0
R17	RES, 150 ohm, 1%, 0.125W, 0805	1	ROHM	MCR10PZPZF1000
R18	RES, 10k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF1002
R19	RES, 1 ohm, 5%, 2W, DIP	1	Panasonic	ERX-2SJ1R0

R20	RES, 100k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF1003
R21	RES, 12k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF1202
R22	RES, 1k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF1001
R23	RES, 82 ohm, 1%, 0.75W, 1210	1	ROHM	MCR100PZHZF82R0
R24	RES, 1k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF1001
R25	RES, 82k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF8202
R26	RES, 4.7k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF4701
R27	RES, 1k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF1001
R28	RES, 10k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF1002
R29	N.C	1	ROHM	
R30	RES, 30k ohm, 1%, 0.1W, 0603	1	ROHM	MCR03ERTF3002
R31	RES, 10 ohm, 1%, 1W, 2512	1	ROHM	MCR100JZHF10R0
R32	RES, 1k ohm, 1%, 0.125W, 0805	1	ROHM	MCR10ERTF1001
D1,D2,D3,D4,D5,D6,D7,D8,D9,D10,D11,D12,D20,D21	Diode, P-N, 1000V, 1A, TH	14	Pan Jit Inc	1N4007
D13,D14	DIODE FAST REC 1KV 1A DO41	2	Taiwan Semiconductor	UF4007
D15,D16	TVS DIODE 274VC AXIAL	2	Micro Commercial Components	1.5KE200A
D17	Schottky diode 40V 1A PMDS	1	ROHM	RB160L-40TE25
D18	Super fast diode 200V 0.5A TUMD2M	1	ROHM	RF05VAM2STR
D19	Diode 90V 0.1A UMD2	1	ROHM	1SS355VMTE17
DN1	Schottky Diode 200V 10A ITO-220AB	1	Diodes, Inc	MBR20200CT
Csnubber1	Cerm CAP,2200pF, 2 KV, 10%, X7R, 1210	1	JOHANSON DIELECTRICS INC	202S41W222KV4E.
C5	AL CAP, 22uF, 35V, +/-20%, TH	1	Nichicon	UVR1V220MDD1TD
C6	AL CAP, 4.7uF, 35V, +/-20%, TH	1	Nichicon	UVR1V4R7MDD1TD
C7	Cerm CAP, 0.1uF, 35V, +/-10%, X7R, 0805	1	Murata	GRM21BR71H104JA01L
C8	Cerm CAP, 47pF, 50V, +/-5%, X7R, 0805	1	Murata	GQM2195C1H470JB01D
C10	N.C			
C11	Cerm CAP, 47pF, 50V, +/-5%, X7R, 0805	1	Murata	GQM2195C1H470JB01D
C12	Cerm CAP, 2200pF, 50V, +/-5%, X7R, 0805	1	AVX	08055C222JAT2A
C13	Cerm CAP, 47pF, 50V, +/-5%, X7R, 0805	1	Murata	GQM2195C1H470JB01D
C14	Cerm CAP, 330pF, 1KV, +/-5%, X7R, 1206	1	Yageo	225000111543
C15	Cerm CAP, 0.1uF, 50V, +/-10%, X5R, 0805	1	Taiyo Yuden	UMK212BJ104KGHT
Cout1	AL CAP 470uF 35V +/-20% RADIAL	1	HERMEI CORP., LTD	LER471M1VG16VR6
Cout2	AL CAP 470uF 35V +/-20% RADIAL	1	HERMEI CORP., LTD	LER471M1VG16VR6

Cout3	AL CAP 220uF 35V +/-20% RADIAL	1	HERMEI CORP., LTD	LER221M1VG16VR6
Cout4	Cerm CAP, 1uF, 50V, +/-10%, X5R, 0805	1	Taiyo Yuden	UMK212BJ105KG-T
U1	IC QR-flyback controller 7SOIC	1	ROHM	BD7682FJ-LB
U2	Photocoupler 5mA DIP4	1	SHARP	PC817
U3	TL431 TO-92	1	UNISONIC CO., LTD	TL431
T1	EFD-30 10pin	1	G-CHAN CO., LTD	GC-1528
L3	Inductor, Shielded core, Metal, 2.2uH 4.3A	1	Wurth Elektronik	7447462022
L4	NC	1	Wurth Elektronik	74476626
HS1	HEATSINK	1	MEICON. CO., LTD.	MI-301G-25.4
HS1	HEATSINK	1	MEICON. CO., LTD.	MB-217-25
LED1	Smart LED RED 569NM	1	ROHM	SML-P11UTT86-RG
Q1	SIC MOSFET N-CH 1700V 4A TO-3PFM	1	ROHM	SCT2H12NZ

2.2. Evaluation Result (Efficiency, switching frequency)

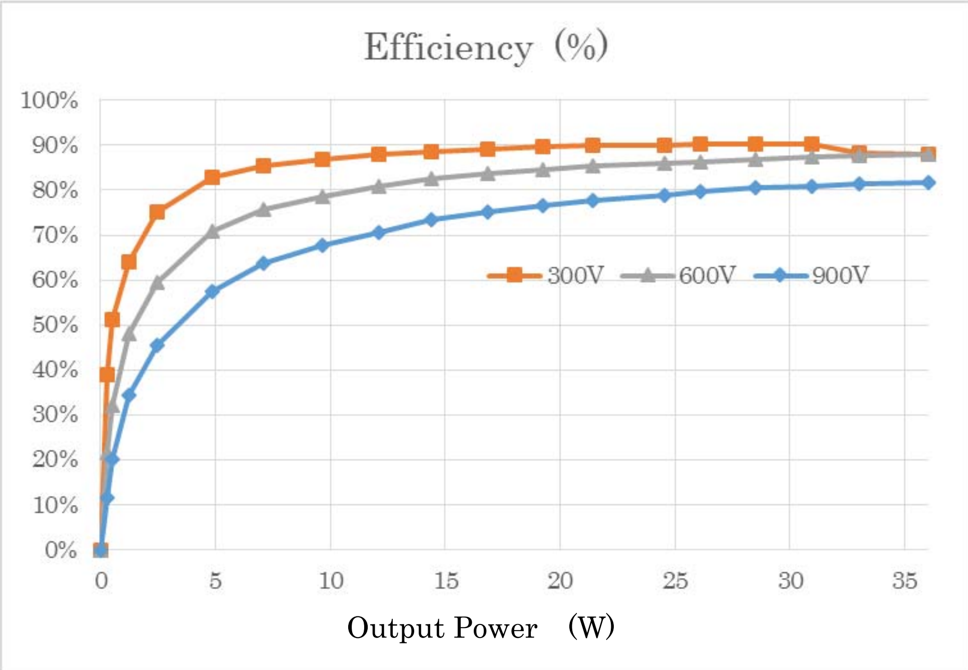


Figure 2-2. Efficiency vs Output Power

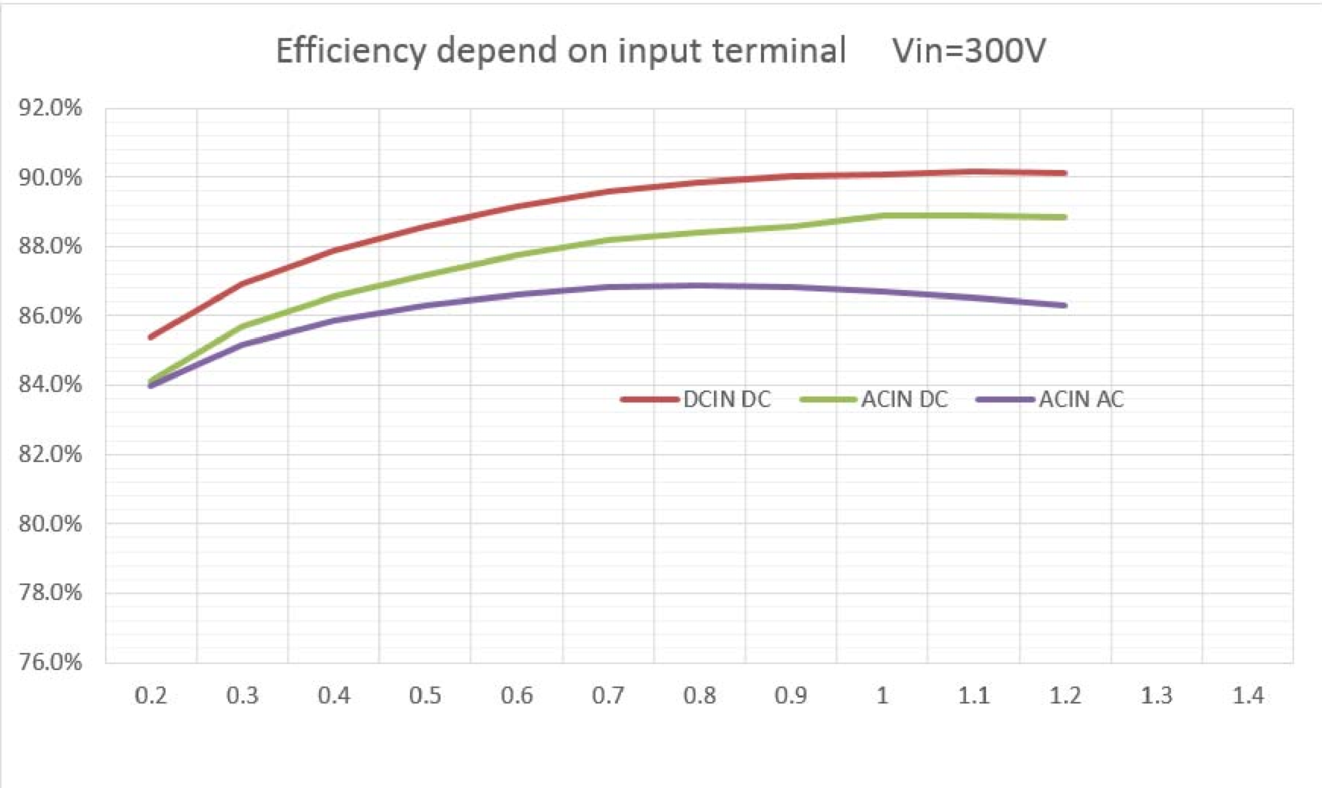
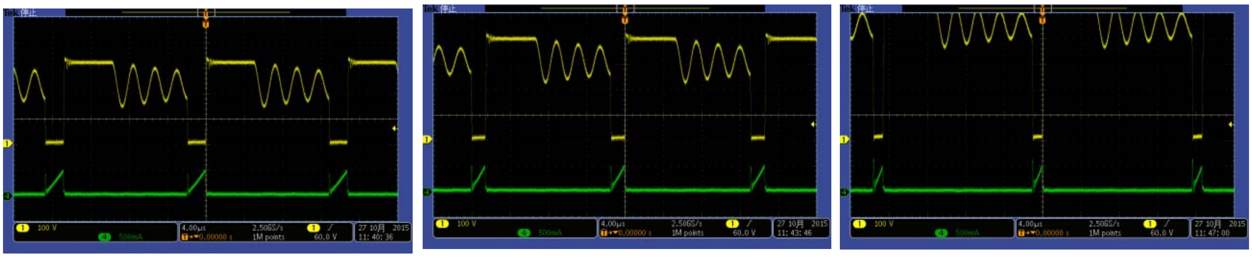


Figure 2-3 Switching Frequency vs Output Power

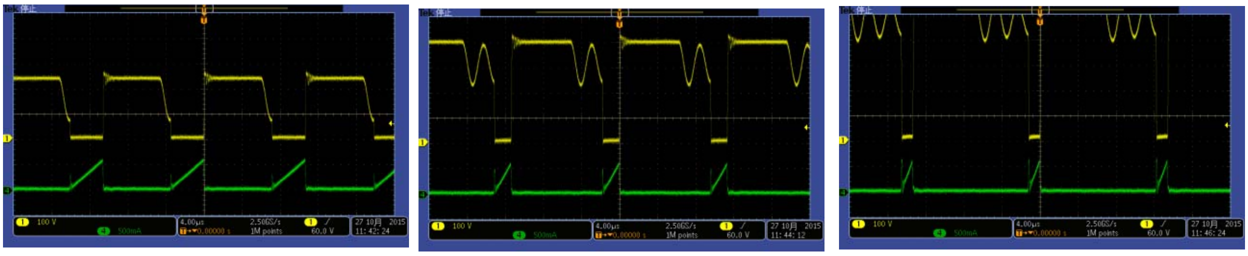
2.3. Evaluation Result (Waveform)



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

Figure 2-4. Drain Voltage and Drain current waveform （VO=24V,IO=1.0A, PO=24W）

CH1: Vdrain (200V/div), CH4: Idrain (200mA/div)



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

Figure 2-5. Drain Voltage and Drain current waveform （VO=24V,IO=2.1A, PO=50W）

CH1: Vdrain (200V/div), CH4: Idrain (500mA/div)

Notice

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1. Our Products are designed and manufactured for application in ordinary electronic equipments (such as AV equipment, OA equipment, telecommunication equipment, home electronic appliances, amusement equipment, etc.). If you intend to use our Products in devices requiring extremely high reliability (such as medical equipment (Note 1), transport equipment, traffic equipment, aircraft/spacecraft, nuclear power controllers, fuel controllers, car equipment including car accessories, safety devices, etc.) and whose malfunction or failure may cause loss of human life, bodily injury or serious damage to property ("Specific Applications"), please consult with the ROHM sales representative in advance. Unless otherwise agreed in writing by ROHM in advance, ROHM shall not be in any way responsible or liable for any damages, expenses or losses incurred by you or third parties arising from the use of any ROHM's Products for Specific Applications.

(Note1) Medical Equipment Classification of the Specific Applications

JAPAN	USA	EU	CHINA
CLASSⅢ	CLASSⅢ	CLASSⅡb	CLASSⅢ
CLASSⅣ		CLASSⅢ	

2. ROHM designs and manufactures its Products subject to strict quality control system. However, semiconductor products can fail or malfunction at a certain rate. Please be sure to implement, at your own responsibilities, adequate safety measures including but not limited to fail-safe design against the physical injury, damage to any property, which a failure or malfunction of our Products may cause. The following are examples of safety measures:
   [a] Installation of protection circuits or other protective devices to improve system safety
   [b] Installation of redundant circuits to reduce the impact of single or multiple circuit failure

3. Our Products are designed and manufactured for use under standard conditions and not under any special or extraordinary environments or conditions, as exemplified below. Accordingly, ROHM shall not be in any way responsible or liable for any damages, expenses or losses arising from the use of any ROHM's Products under any special or extraordinary environments or conditions. If you intend to use our Products under any special or extraordinary environments or conditions (as exemplified below), your independent verification and confirmation of product performance, reliability, etc, prior to use, must be necessary:
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   [b] Use of our Products outdoors or in places where the Products are exposed to direct sunlight or dust
   [c] Use of our Products in places where the Products are exposed to sea wind or corrosive gases, including Cl_2, H_2S, NH_3, SO_2, and NO_2
   [d] Use of our Products in places where the Products are exposed to static electricity or electromagnetic waves
   [e] Use of our Products in proximity to heat-producing components, plastic cords, or other flammable items
   [f] Sealing or coating our Products with resin or other coating materials
   [g] Use of our Products without cleaning residue of flux (even if you use no-clean type fluxes, cleaning residue of flux is recommended); or Washing our Products by using water or water-soluble cleaning agents for cleaning residue after soldering
   [h] Use of the Products in places subject to dew condensation

4. The Products are not subject to radiation-proof design.

5. Please verify and confirm characteristics of the final or mounted products in using the Products.

6. In particular, if a transient load (a large amount of load applied in a short period of time, such as pulse. is applied, confirmation of performance characteristics after on-board mounting is strongly recommended. Avoid applying power exceeding normal rated power; exceeding the power rating under steady-state loading condition may negatively affect product performance and reliability.

7. De-rate Power Dissipation depending on ambient temperature. When used in sealed area, confirm that it is the use in the range that does not exceed the maximum junction temperature.

8. Confirm that operation temperature is within the specified range described in the product specification.

9. ROHM shall not be in any way responsible or liable for failure induced under deviant condition from what is defined in this document.

Precaution for Mounting / Circuit board design

1. When a highly active halogenous (chlorine, bromine, etc.) flux is used, the residue of flux may negatively affect product performance and reliability.

2. In principle, the reflow soldering method must be used on a surface-mount products, the flow soldering method must be used on a through hole mount products. If the flow soldering method is preferred on a surface-mount products, please consult with the ROHM representative in advance.

For details, please refer to ROHM Mounting specification

Precautions Regarding Application Examples and External Circuits

1. If change is made to the constant of an external circuit, please allow a sufficient margin considering variations of the characteristics of the Products and external components, including transient characteristics, as well as static characteristics.

2. You agree that application notes, reference designs, and associated data and information contained in this document are presented only as guidance for Products use. Therefore, in case you use such information, you are solely responsible for it and you must exercise your own independent verification and judgment in the use of such information contained in this document. ROHM shall not be in any way responsible or liable for any damages, expenses or losses incurred by you or third parties arising from the use of such information.

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This Product is electrostatic sensitive product, which may be damaged due to electrostatic discharge. Please take proper caution in your manufacturing process and storage so that voltage exceeding the Products maximum rating will not be applied to Products. Please take special care under dry condition (e.g. Grounding of human body / equipment / solder iron, isolation from charged objects, setting of Ionizer, friction prevention and temperature / humidity control).

Precaution for Storage / Transportation

1. Product performance and soldered connections may deteriorate if the Products are stored in the places where:
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   [b] the temperature or humidity exceeds those recommended by ROHM
   [c] the Products are exposed to direct sunshine or condensation
   [d] the Products are exposed to high Electrostatic

2. Even under ROHM recommended storage condition, solderability of products out of recommended storage time period may be degraded. It is strongly recommended to confirm solderability before using Products of which storage time is exceeding the recommended storage time period.

3. Store / transport cartons in the correct direction, which is indicated on a carton with a symbol. Otherwise bent leads may occur due to excessive stress applied when dropping of a carton.

4. Use Products within the specified time after opening a humidity barrier bag. Baking is required before using Products of which storage time is exceeding the recommended storage time period.

Precaution for Product Label

A two-dimensional barcode printed on ROHM Products label is for ROHM's internal use only.

Precaution for Disposition

When disposing Products please dispose them properly using an authorized industry waste company.

Precaution for Foreign Exchange and Foreign Trade act

Since concerned goods might be fallen under listed items of export control prescribed by Foreign exchange and Foreign trade act, please consult with ROHM in case of export.

Precaution Regarding Intellectual Property Rights

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Other Precaution

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