Application Note

Surface Mount 3A Chopper Type Switching Regulator IC

SI-8000SD Series

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SANKEN ELECTRIC CO., LTD.

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1. General Description

The SI-8000SD is a chopper type switching regulator IC which is provided with various functions required for the buck switching regulator and protection functions. By using four external components, a highly efficient switching regulator can be configured.

●1-1 Features

- Compact size and large output current of 3A

  The maximum output current of 3A for the outline of TO263-5 (surface mount)
- High efficiency of 84% (SI-8050SD V_{IN}=20V/I_O=1A)

  Heat dissipation is small due to high efficiency to contribute to the downsizing of a heat sink.
- Four external components

  The regulator can be configured by input / output capacitor, diode and coil.
- Internal adjustment of output voltage and phase compensation having been done in production

  Troublesome adjustment of output voltage and phase compensation by external components is no longer required.
- Reference oscillation by a built-in timing capacitor

  No external capacitor for the oscillation frequency setting is required.
- Built-in functions for overcurrent and thermal shutdown

  A current limiting type overcurrent protection circuit and overheat protection are built in.

  (automatic restoration type)

・Soft-start function (output ON/OFF is possible)

It is possible to delay the output voltage rising speed by adding the external capacitor during startup.

In addition, the output can be also ON/OFF-controlled.

●1-2 Applications

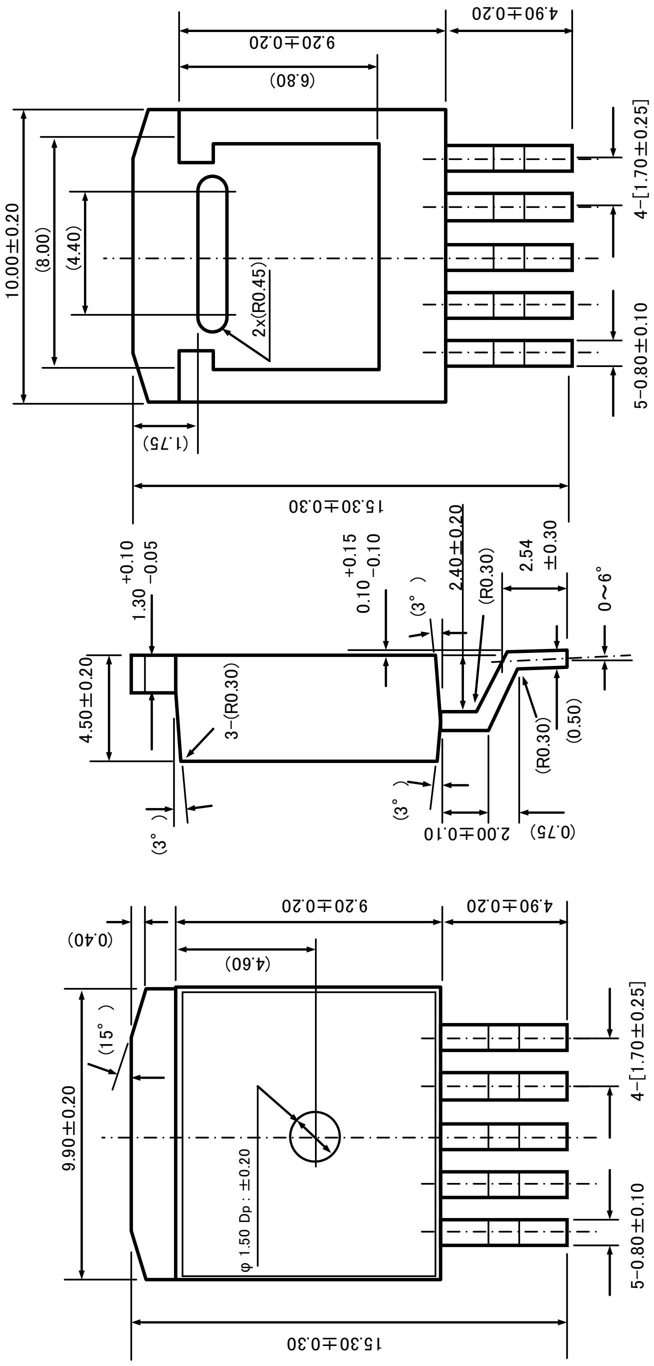
For on-board local power supplies, power supplies for OA equipment, stabilization of secondary output voltage of regulator and power supply for communication equipment

●1-3 Type

- Type: Semiconductor integrated circuits (monolithic IC)
- Structure: Resin molding type (transfer molding)

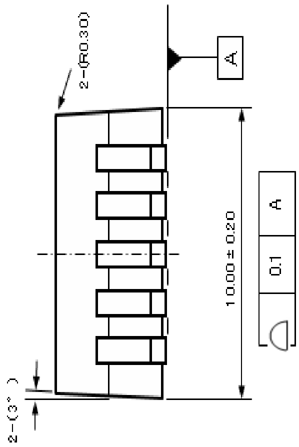
2. Specification

●2-1 Package Information (surface mount: TO263-5)



Notes:
1) Dimensions do not include molding burr.
2) Figures in parentheses ( ) are shown only for reference.
3) Figures in parentheses [ ] are dimensions after lead forming.
4) Backside bumps: 0.8 mm at maximum
5) Unit: mm

PIN assignments
1. VIN
2.SWOUTO
3. GND
4. Vos
5. SS



Products Weight: Approx.1.48g

●2-2 Ratings

Lineup

Product Name	V_{OUT}(V)
SI-8033SD	3.3
SI-8050SD	5

Absolute Maximum Ratings

Parameter	Symbol	Rating	Unit
Input Voltage	V_{IN}	43 *1	V
Allowable Power Dissipation *2	Pd1	3	W
Allowable Power Dissipation without Heat sink	Pd2	1.5	W
Junction Temperature	Tj	125	°C
Storage Temperature	Tstg	-40 - +125	°C
SW to GND Reverse Voltage	[illegible]	[illegible]	V

*1: 35V for SI-8033SD

*2: Glass epoxy single side board 40 × 40

Recommended Conditions

Parameter	Symbol	SI-8033SD	SI-8050SD	Unit
DC Input Voltage	V_{IN}	5.5 - 28	7 - 40	V
Output Current	I_O	0 - 3 *3		A
Junction Temperature in Operation	Tjop	-30 - +125		°C

*3 It should be used within the temperature range which does not exceed Tjmax.

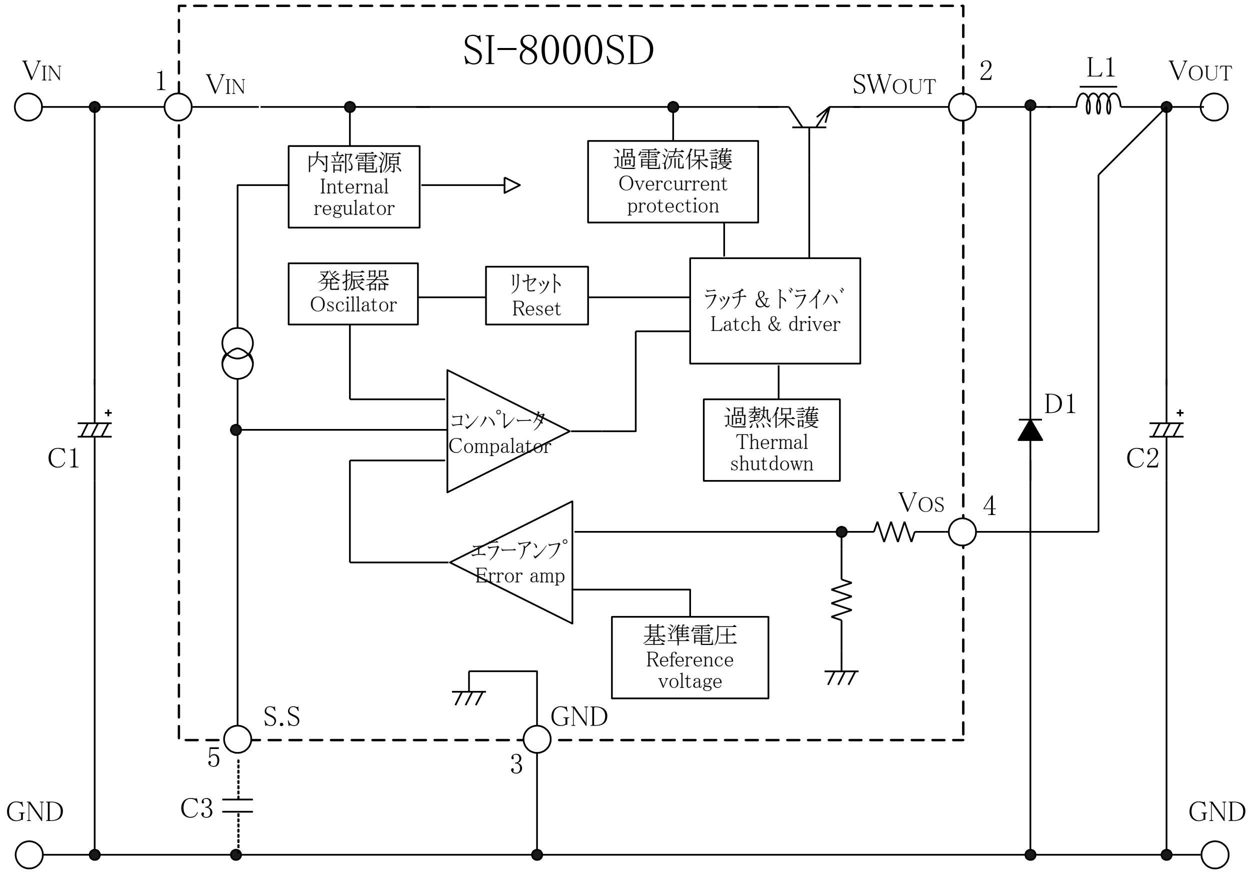
Electrical Characteristics

(Ta=25 °C)

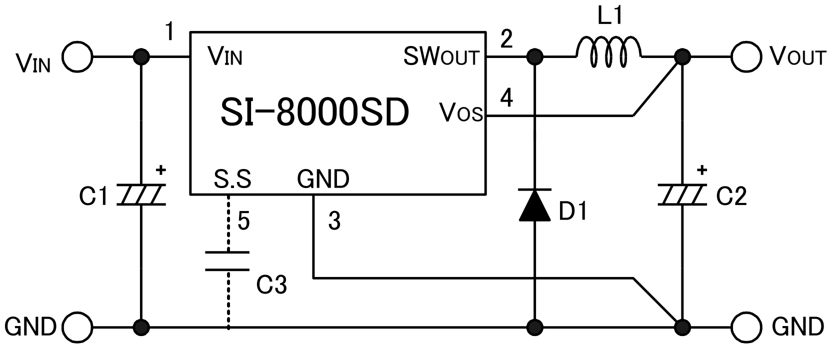
Parameter	Symbol	SI-8033SD			SI-8050SD			Unit
		min	typ	max	min	typ	max	
Set Output Voltage	Vo	3.17	3.30	3.43	4.80	5.00	5.20	V
	conditions	V_{IN}=15V/Io=1A			V_{IN}=20V/Io=1A			
Efficiency	η		79			84		%
	conditions	V_{IN}=15V/Io=1A			V_{IN}=20V/Io=1A			
Operation Frequency	f		60			60		kHZ
	conditions	V_{IN}=15V/Io=1A			V_{IN}=20V/Io=1A			
Input Voltage – Output Voltage (Iout=1A)	⊿Voline		25	80		40	100	mV
	conditions	V_{IN}=8 - 28V			V_{IN}=10 - 30V			
Output Current - Output Voltage (Iout=0.5 - 1.5A)	⊿Voload		10	30		10	40	mV
	conditions	V_{IN}=15V			V_{IN}=20V			
Overcurrent Protection Start Current	Is	3.1			3.1			A
	conditions	V_{IN}=15V			V_{IN}=20V			
Output Voltage Temperature Variation	Kt		±0.5			±0.5		mV/°C

●2-3 Circuit Diagram

2-3-1 Internal Equivalent Circuit



2-3-2 Typical Connection Diagram



C1 : 50V/1000µF

C2 : 50V/1000µF

C3 : 0.01µF

(C3 is necessary when soft-start function is used)

L1 : 150µH

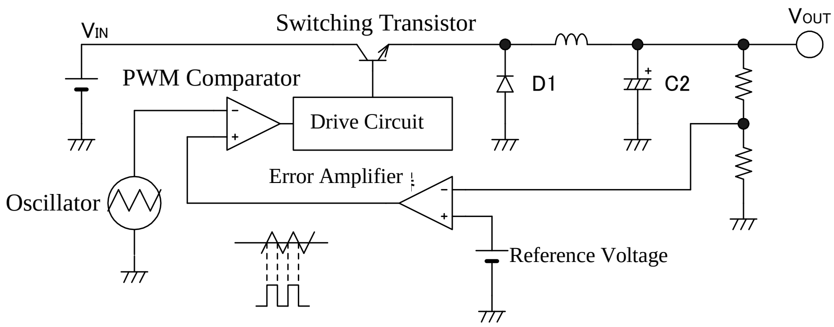
D1 : SPB-G56S (Sanken)

3. Operational Description

●3-1 PWM Output Voltage Control

In the SI-8000SD series, the output voltage is controlled by the PWM system and the IC incorporates the PWM comparator, oscillator, error amplifier, reference voltage, output transistor drive circuit etc. The triangular wave output (≒60KHz) from the oscillator and the output of the error amplifier are given to the input of the PWM comparator. The PWM comparator compares the oscillator output with the error amplifier output to turn on the switching transistor for a time period when the output of the error amplifier exceeds the oscillator output.

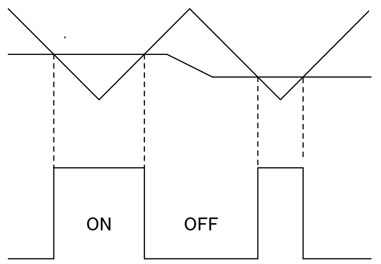
PWM Control Chopper Type Regulator Basic



The error amplifier output and the oscillator output are compared by the PWM comparator to generate the drive signal of rectangular wave and to drive the switching transistor.

On the assumption that the output voltage commences to rise, the output of the error amplifier will drop, because the error amplifier is inverting type. As the error amplifier output falls down, the time period during which it falls below the triangular wave level of the oscillator is increased to shorten the ON time of the switching transistor and as a result, the output voltage is maintained at a certain level. As described above, the output voltage is controlled by varying the ON time of the switching transistor, while fixing the switching frequency.
(the higher Vin is , the shorter the ON time of the switching transistor is.)

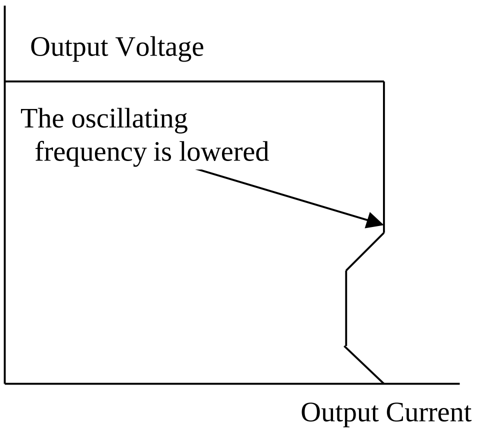
PWM Comparator Operation



The rectangular wave output of the switching transistor is smoothed by the LC low pass filter of a choke coil and capacitor, and the stabilized DC voltage is supplied to the load.

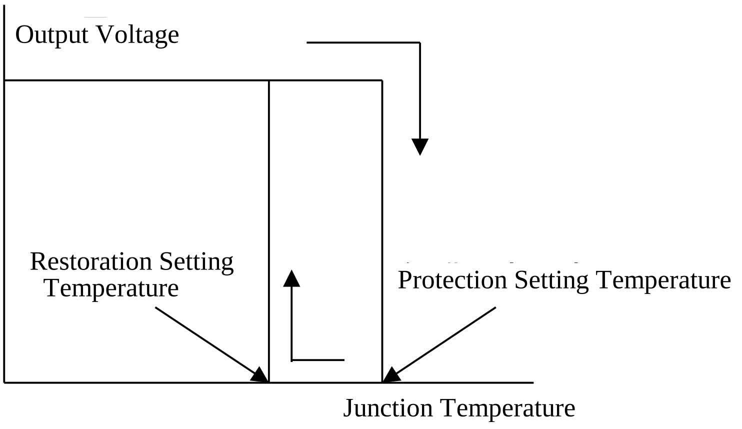
●3-2 Overcurrent Protection / Thermal Shutdown

Output Voltage Characteristics in Overcurrent



The SI-8000SD series incorporates a current limiting type overcurrent protection circuit. The overcurrent protection circuit detects the peak current of a switching transistor and when the peak current exceeds the set value, the ON time of the transistor is compulsorily shortened to limit the current by lowering the output voltage. In addition, when the output voltage is lowered up to the 50% of the rated value, the increase of current at low output voltage is prevented by dropping the switching frequency to about 30kHz. When the overcurrent condition is released, the output voltage will be automatically restored.

Output Voltage Characteristics in Thermal



The thermal shutdown circuit detects the semiconductor junction temperature of the IC and when the junction temperature exceeds the set value, the output transistor is stopped and the output is turned OFF. When the junction temperature drops around 15°C from the set value for overheat protection, the output transistor is automatically restored.

* Note for thermal shutdown characteristic

This circuit protects the IC against overheat resulting from the instantaneous short circuit, but this function does not assure the operation including reliability in the state of continuous overheat due to long time short circuit.

4. Cautions

●4-1 External Components

4-1-1 Choke coil L1

The choke coil L1 is a key component of chopper type switching regulator. In order to maintain the stable operation of the regulator, such dangerous state of operation as saturation state and operation at high temperature due to heat generation must be avoided.

The following points should be taken into consideration for the selection of the choke coil.

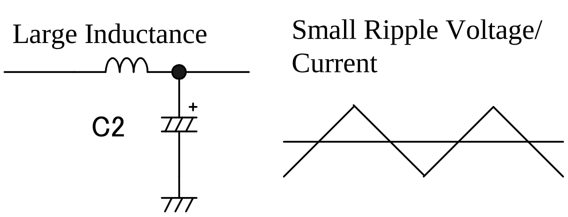
a) The choke coil should be fit for the switching regulator.

The coil for a noise filter should not be used because of large loss and generated heat.

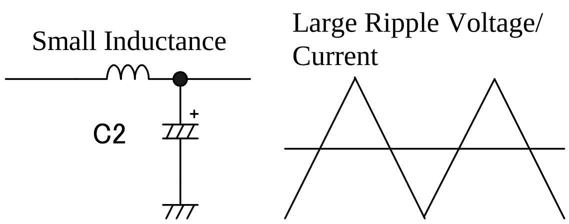
b) The inductance value should be appropriate.

The larger the inductance of the choke coil is, the less the ripple current flowing in the choke coil is, and the output ripple voltage drops. As a result, the overall size of the coil becomes larger.

On the other hand, if the inductance is small, the peak current flowing in the switching transistor and diode is increased and the ripple voltage becomes higher and this operation state is not favorable for maintaining the stable operation.



The larger the inductance is, the smaller the ripple current/voltage is. But the outer size of the coil becomes larger.



The smaller the inductance is, the larger the ripple current/voltage is.
Although the outer size of the coil is smaller, the operation is likely to be unstable.

The inductance value shown in the specifications should be considered as a reference value for the stable operation and the appropriate inductance value can be obtained by the equation (1).

ΔIL shows the ripple current value of the choke coil and the inductance value is set as described in the following.

- In the case that the output current to be used is nearly equal to the maximum rating (3A) of the SI-8000SD: Output current × 0.2 - 0.3
- In the case that the output current to be used is approximately 1A or less: Output current × 0. 3 – 0. 4

$$L1 = \frac{(VIN - VOUT) \cdot VOUT}{\Delta IL \cdot VIN \cdot f} \qquad ---(1)$$

For example, where V_{IN} = 25V, V_{OUT} = 5V, ΔIL = 0.5A, frequency = 60 KHz,

$$L1 = \frac{(25-5)\times 5}{0.5\times 25\times 60\times 10^3} \fallingdotseq 133uH$$

As shown above, the coil of about 130μH may be selected.

However, it is to be noted that the peak current of the switching transistor is increased depending on the calculated inductance value.

Therefore, because the peak current detection system is adopted for overcurrent detection in this case, the overcurrent detection point may become lower.

c) The rated current shall be met.

The rated current of the choke coil must be higher than the maximum load current to be used. When the load current exceeds the rated current of the coil, the inductance is sharply decreased to the extent that it causes saturation state at last. Please note that overcurrent may flow since the high frequency impedance becomes low.

d) Noise shall be low.

In the open magnetic circuit core like drum shape type, since magnetic flux passes outside the coil, the peripheral circuit may be affected by noise. It is recommended to use the toroidal type, EI type or EE type coil which has a closed magnetic circuit type core as much as possible.

4-1-2 Input Capacitor C1

The input capacitor is operated as a bypass capacitor of the input circuit to supply steep current to the regulator during switching and to compensate the voltage drop of the input side. Therefore, the input capacitor should be placed as close as to the regulator IC.

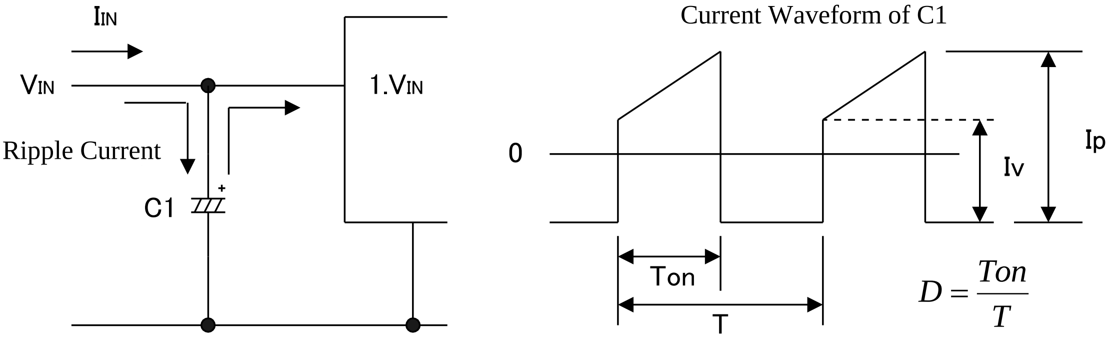
In addition, in the case that the smoothing capacitor of the AC rectifier circuit is located in the input circuit, the input capacitor may be also used as a smoothing capacitor, but similar attention should be paid.

The selection of C1 shall be made in consideration of the following points:

a) The requirement of withstand voltage shall be met.

b) The requirement of the allowable ripple current shall be met.

Current Flow of C1



The ripple current of the input capacitor is increased in accordance with the increase of the load

If the withstanding voltage and allowable ripple current are exceeded or used without derating, it is in danger of causing not only the decreasing the capacitor lifetime (burst, capacitance decrease, equivalent impedance increase, etc) but also the abnormal oscillations of regulator. Therefore, the selection with sufficient margin is needed. The effective value of ripple current flowing across the input capacitor can be obtained by the following equation (2):

$$Irms \approx 1.2 \times \frac{Vo}{Vin} \times Io \quad --(2)$$

For instance, where V_{IN}=20V,Io=3A,Vo=5V

$$Irms \approx 1.2 \times \frac{5}{20} \times 3 = 0.9A$$

Therefore, it is necessary to select the capacitor with the allowable ripple current of 0.9A or higher.

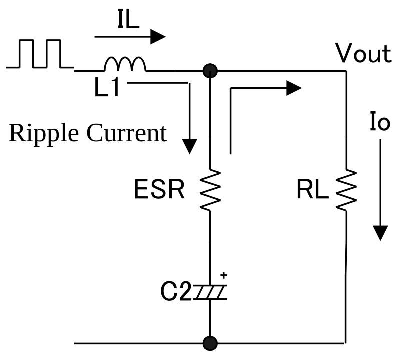
4-1-3 Output Capacitor C2

The output capacitor C2 configures an LC low pass filter together with a choke coil L1 and functions as a rectifying capacitor of switching output.

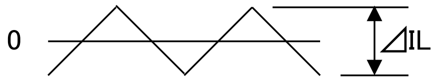
The current equivalent to the pulse current ΔIL of the choke coil current is charged and discharged in the output capacitor.

Therefore, it is necessary to meet the requirements of withstand voltage and allowable ripple current with sufficient margin like the input capacitor.

Current Flow of C2



Current Waveform of C2



The ripple current of the output capacitor is equal to the ripple current of the choke coil and does not vary even if the load current increases or decreases.

The ripple current effective value of the output capacitor is obtained by the equation (3).

$$Irms = \frac{\Delta IL}{2\sqrt{3}} \qquad ---(3)$$

When ΔIL = 0.5A,

$$Irms = \frac{0.5}{2\sqrt{3}} \fallingdotseq 0.14A$$

Therefore a capacitor having the allowable ripple current of 0.14A or higher is required.

In addition, the output ripple voltage Vrip of the regulator is determined by a product of the pulse current ΔIL of the choke coil current (= C2 charging/discharging current) and the equivalent series resistance ESR of the output capacitor C2.

$$Vrip = \Delta IL \cdot C2ESR \qquad ---(4)$$

It is therefore necessary to select a capacitor with low equivalent series resistance ESR in order to lower the output ripple voltage. As for general electrolytic capacitors of same product series, the ESR shall be lower, for the products of higher capacitance with same withstand voltage, or with higher withstand voltage (almost proportional to larger externals) with same capacitance.

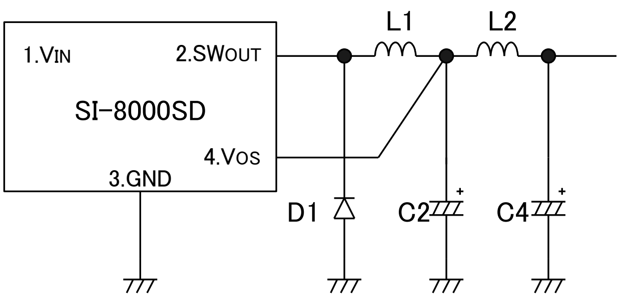
When ΔIL = 0.5A, Vrip = 40mV,

$$C2esr = 40 \div 0.5 = 80m\Omega$$

As shown above, a capacitor with the ESR of 80mΩ or lower should be selected. In addition, since the ESR varies with temperature and increases at low temperature, it is required to examine the ESR at the actual operating temperatures. It is recommended to contact capacitor manufacturers for the ESR value since it is peculiar to capacitors.

However, if the ESR of the output capacitor is too low (10 - 30mΩ or lower), the phase margin within the feedback loop of the regulator will be short to make the operation unstable. Therefore, it is not appropriate that a tantalum capacitor or a laminated ceramic capacitor is used for the output capacitor as an independent component. However, connecting a tantalum capacitor or a laminated ceramic capacitor in parallel with an electrolytic capacitor is effective in reducing the output ripple voltage only when it is used at low temperature (< 0°C).

In addition, in order to further decrease the ripple voltage, as shown below, it is also effective to add one stage of the LC filter to form the π type filter.



Secondary-filter
L2:20µH
C4:200µF

However, if the secondary-filter is added , care must be taken because abnormal oscillation may take place unless the output voltage detecting point (wiring to Vos pin) is on the primary-filter(L1 & C2).

It should be noted that the operating stability is more influenced by the ESR than the capacitance as described above if the requirements of withstand voltage and allowable ripple current are met.

4-1-4 The flywheel Diode D1

The flywheel diode D1 is to discharge the energy which is stored in the choke coil at switching OFF.

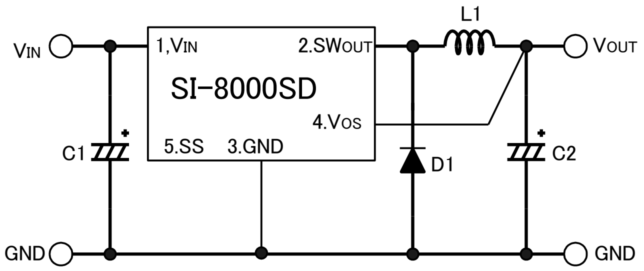
For the flywheel diode, the Schottky barrier diode must be used. If a general rectifying diode or fast recovery diode is used, the IC may be destroyed by applying reverse voltage due to the recovery and ON voltage.

In addition, since the output voltage from the SWOUT terminal (pin 2) of the SI-8000SD series is almost equivalent to the input voltage, the flywheel diode with the reverse withstand voltage of the input voltage or higher should be used.

●4-2 Pattern Design Notes

4-2-1 High Current Line

Since high current flows in the bold lines in the connection diagram, the pattern should be as wide and short as possible.

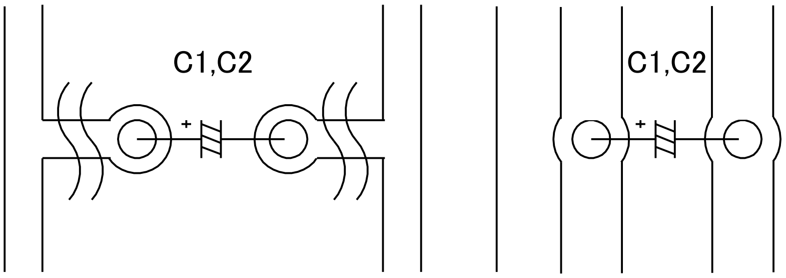


4-2-2 Input / Output Capacitor

The input capacitor C1 and the output capacitor C2 should be placed to the IC as close as possible. If the rectifying capacitor for AC rectifier circuit is on the input side, it can be used as an input capacitor. However, if it is not close to the IC, the input capacitor should be connected in addition to the rectifying capacitor.

Since high current is discharged and charged through the leads of input/output capacitor at high speed, the leads should be as short as possible.

A similar care should be taken for the patterning of the capacitor.

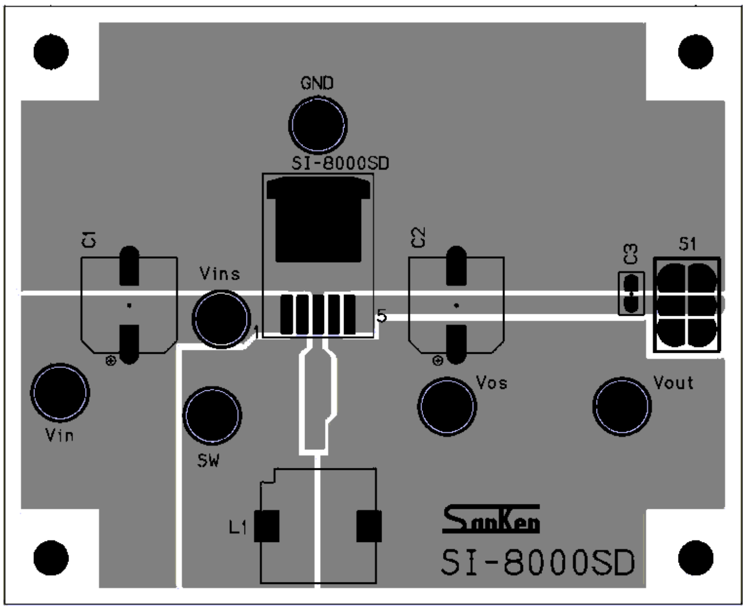


Improper Pattern Example　　　Proper Pattern Example

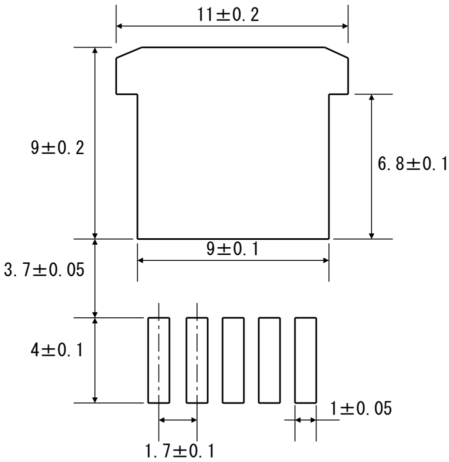
4-2-3 Sensing Terminal

The output voltage sensing terminal Vos shall be connected near the output capacitor C2 as much as possible. (Vos terminal flow-in current is approx. 1mA.) If it is connected far from C2, it should be noted that abnormal oscillation may happen due to the low regulation and increased switching ripple.

Recommended board pattern



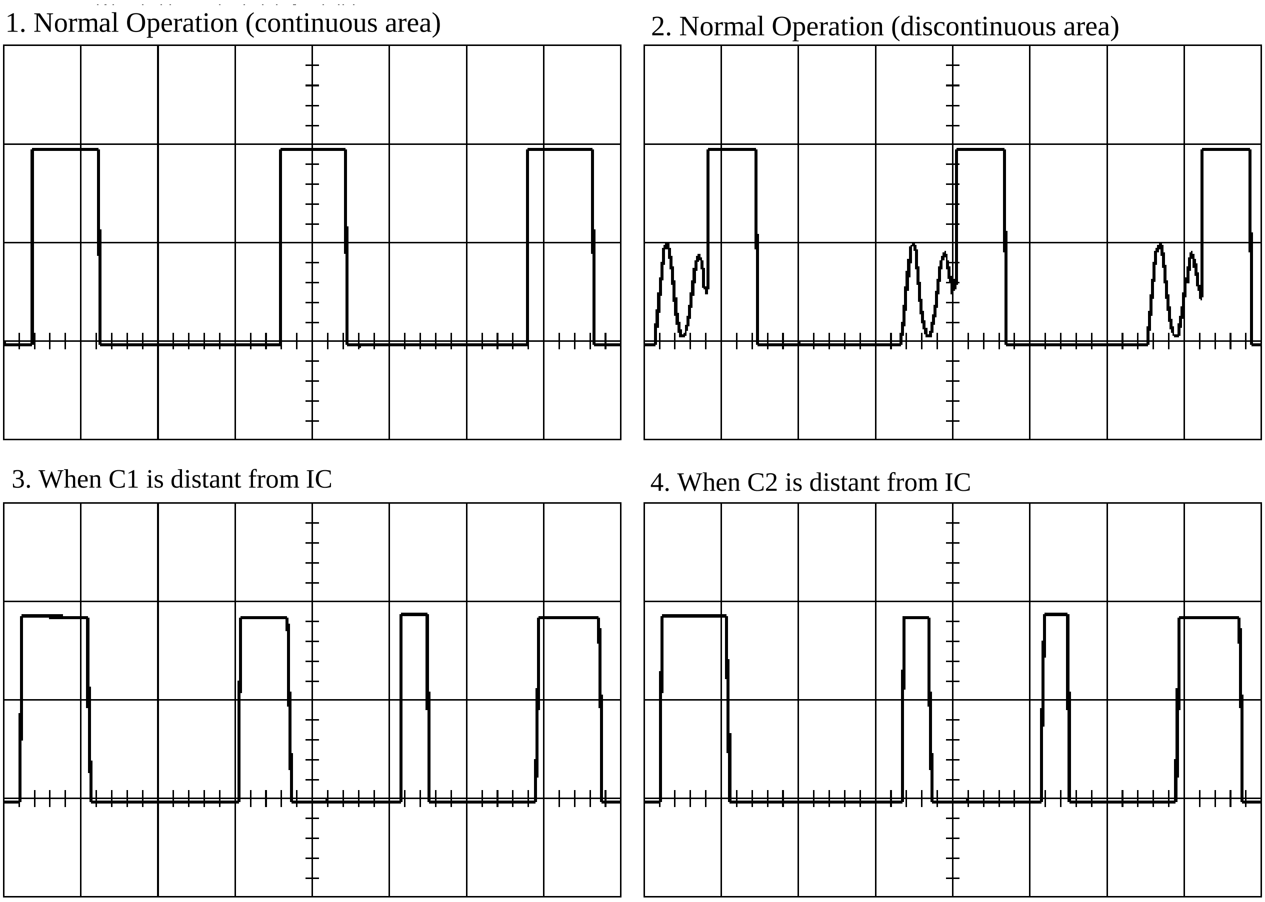
Recommended land pattern



●4-3 Operation Waveform Check

It can be checked by the waveform between the pin 2 and 3 (SWOUT-GND waveform) of the SI-8000SD whether the switching operation is normal or not.

The examples of waveforms at normal and abnormal operations are shown below:



The continuous area is an area where the DC component of the triangular wave is superimposed on the current flowing across the choke coil and the discontinuous area is an area where the current flowing across the choke coil is intermittent (a period of zero current may happen.) because the current flowing across the choke coil is low.

Therefore, when the load current is high, the area is a continuous area and when the same current is low, the area is a discontinuous area.

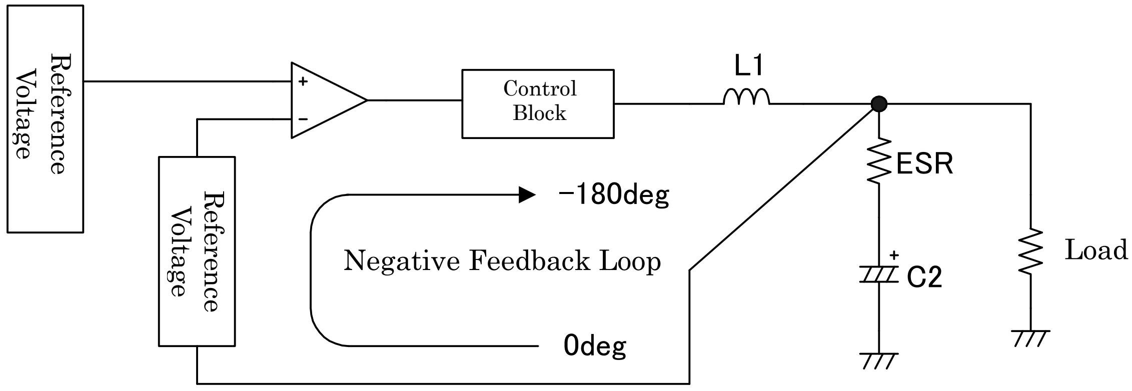
In the continuous area, the switching waveform is formed in the normal rectangular waveform (waveform 1) and in the discontinuous area, damped oscillation is caused in the switching waveform (waveform 2), but this is a normal operation without any problem.

In the meantime, when the IC is far from C1 and C2, jitter which disturbs the ON – OFF time of switching will happen as shown in the waveforms (3, 4). As described above, C1 and C2 should be connected close to the IC.

●4-4 Power Supply Stability

4-4-1 Phase Margin

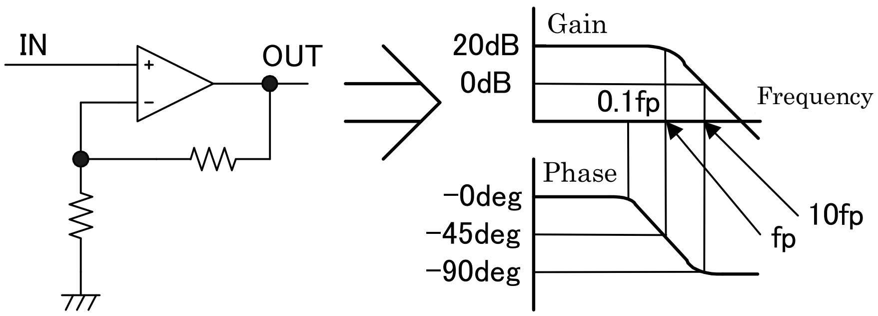
This block diagram shows that the chopper type regulator is a negative feedback amplifier which controls the output voltage by constantly comparing with the output voltage and the reference voltage which is set in advance. Therefore, it has a negative feedback loop to control the output by detecting the variation of output voltage with the error amplifier.



The phase within the negative feedback loop is displaced by 180° to negate the variation of the output voltage, but in the event that the phase is further delayed by 180° in the state that the amplification degree (gain) is 1 or more, the total phase delay amounts to 360° to deviate from the stable operation zone to cause abnormal oscillation. This is called Barkhausen oscillation conditions. Therefore, the oscillation conditions should not be accrued in the actual stabilized power supply.

It is possible to judge whether the Barkhausen oscillation conditions are accrued or not by means of frequency and gain/phase characteristics of the negative feedback loop. The frequency-gain/phase characteristics are called Bode diagram.

1-step Differential Amplifier	Bode Diagram Example

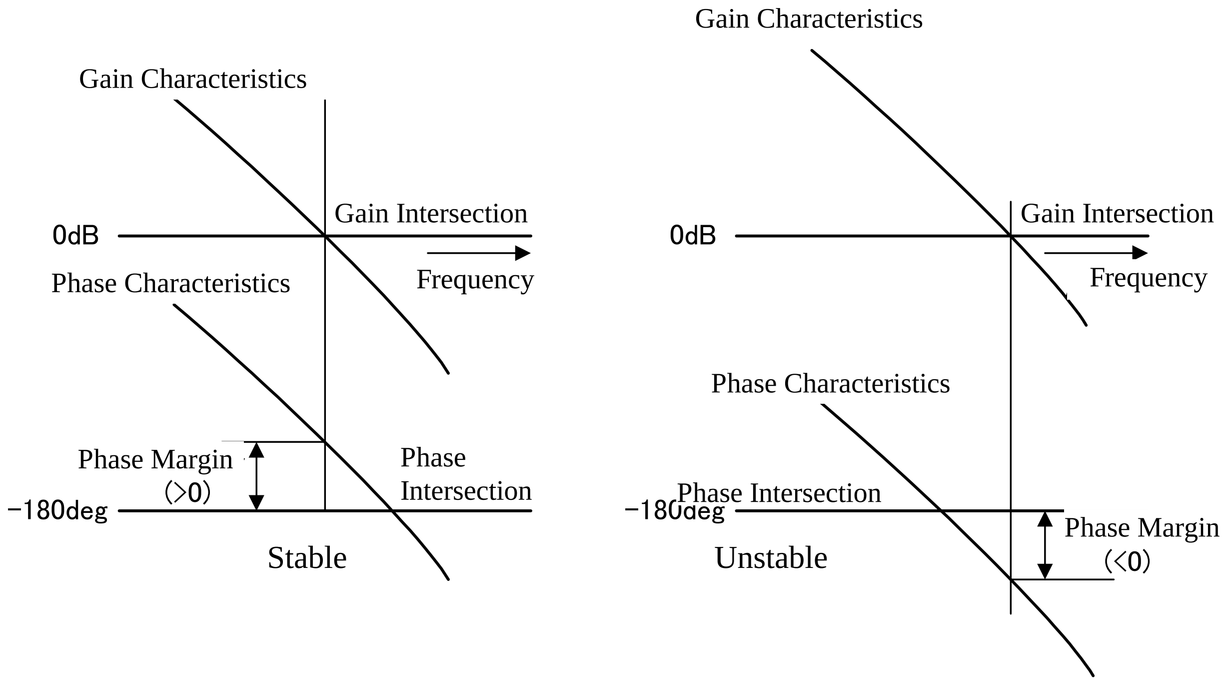


In the Bode diagram, the frequency at which the gain is 1 (0 dB) is called gain intersection and the frequency at which the phase of feedback loop is -180° is called phase intersection.

Unless the phase reaches -180° at the frequency of gain intersection, the oscillation conditions are not met.

In this respect, the phase at gain intersection - (-180°) is equal to the phase at gain intersection + 180° and this value is used as a margin to -180° which is called phase margin. The more the phase margin is, the less likely the abnormal oscillation is to occur against the variation of environmental conditions such as input/output conditions and temperature. Therefore, sufficient phase margin should be taken into consideration in order to maintain the stable operation.

Stability Judgment at Bode Diagram



4-4-2 Phase Characteristics of Regulator IC

The phase characteristics of the chopper type regulator are synthesized by the phase characteristics inside the regulator IC and that of the LC filter.

The phase characteristics inside the regulator IC are generally determined by the delay time of the control block and the phase characteristic of the output error amplifier.

Among these two factors, the phase delay due to the delay time of the control block rarely causes problems in actual use. Therefore, the phase characteristics of the error amplifier are important.

With respect to the compensation of phase characteristics of the output error amplifier, there are two types of regulator ICs. One is that compensation is made in the IC in advance, while another type is that external components such as resistors and capacitors are added to the IC for compensation.

In the former case, it is only a matter of selection of the LC filter described below, but in the latter case, appropriate phase compensation should be made in accordance with the application of the product.

4-4-3 Phase Characteristics of LC Filter

The phase margin of the chopper type regulator depends largely on the phase characteristics of the LC filter for output smoothing. The phase characteristic of the LC filter theoretically shows the characteristics of a secondary delay factor. Resonance is caused at a specific frequency due to the combination of inductance L1 of coil and of capacitance C2 of the capacitor and at frequency higher than the resonance point, the phase is delayed by 180°at a maximum.

The resonance frequency is expressed as shown in the equation (5):

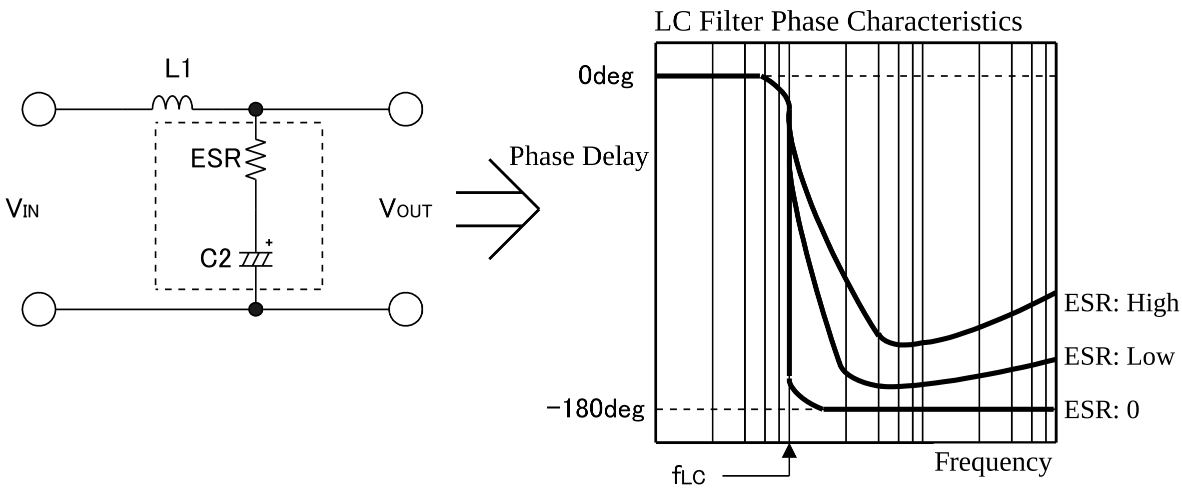
$$\mathrm{f}\,LC = \frac{1}{2\pi\sqrt{LC}} \qquad ---(5)$$

The phase characteristics are 0° if they are lower than the resonance frequency fLC.

The phase characteristics are 180° if they are higher than the resonance frequency fLC.

Accordingly, when the LC filter for output smoothing shows the theoretical phase characteristics, the phase delay reaches -180° in this filter portion and the phase margin will be zero for this regulator.

However, in the actual LC filter, the phase delay of the LC filter is less than 180°because of influence of the equivalent series resistance (ESR) of capacitor. Consequently, the phase margin can be secured for the regulator because of this phase compensation effect of the equivalent series resistance (ESR).



Generally speaking, when such capacitors as tantalum capacitors or laminated capacitors are used for the output LC filter, the phase delay of filters will be large.

Therefore, from the viewpoint of securing the phase margin, use of the electrolytic capacitor is preferable.

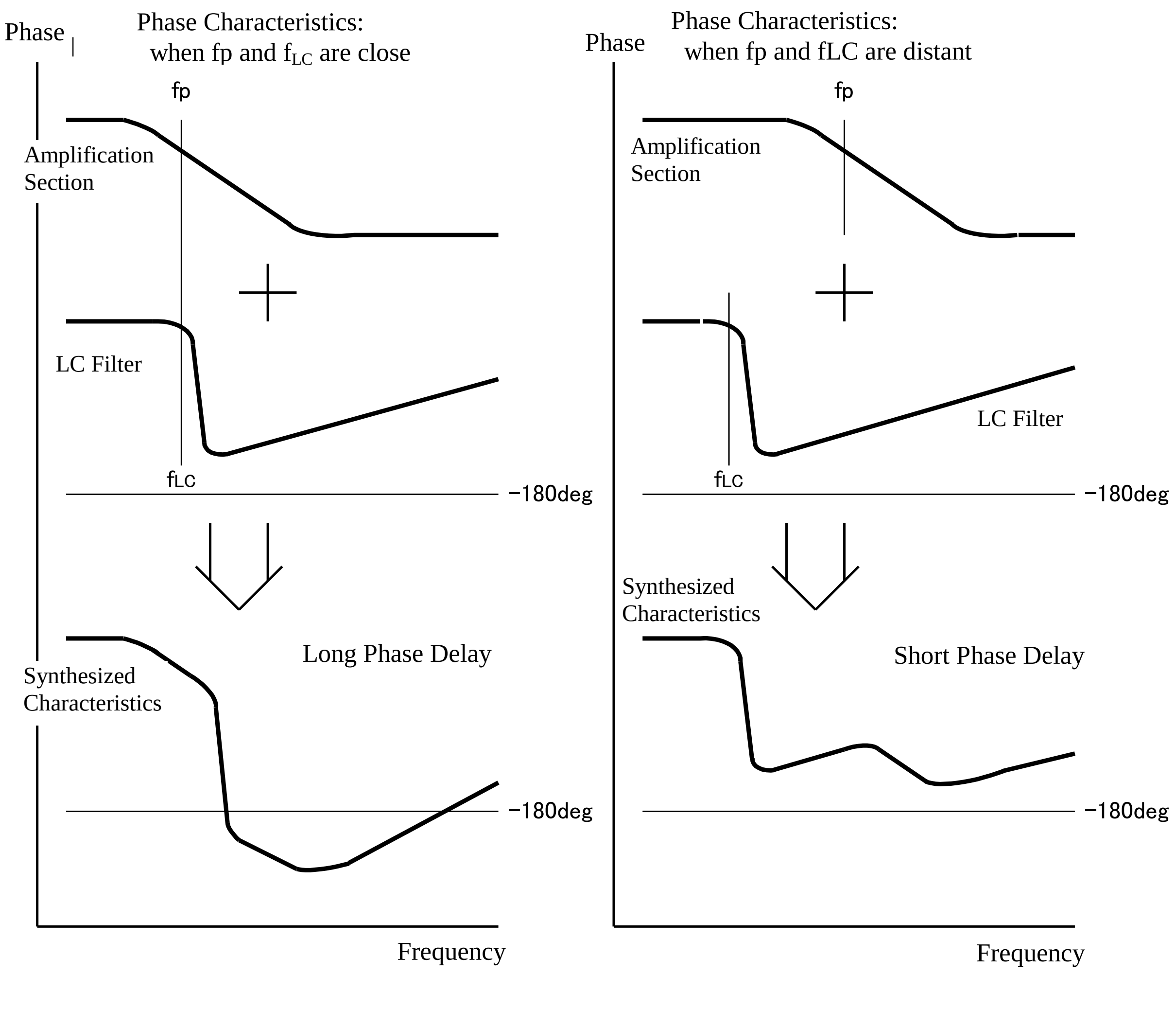
4-4-4 Relation of Phase Characteristics of Internal IC and LC Filter

As described above, the phase characteristics of the chopper type regulator is almost determined by the phase characteristics of the error amplifier and LC filter. In this respect, the relation between these two characteristics is important.

When the gain lowering commencement frequency of the error amplifier, namely the first pole frequency fp and the resonant frequency of the LC filter f_{LC} are closer, the phase margin of the regulator is decreased because of concentrated phase delay. In this respect, the proper distribution of fp and fLC is important.

Normally, the phase delay of error amplifier commences from 0.1 times of the first pole frequency fp.

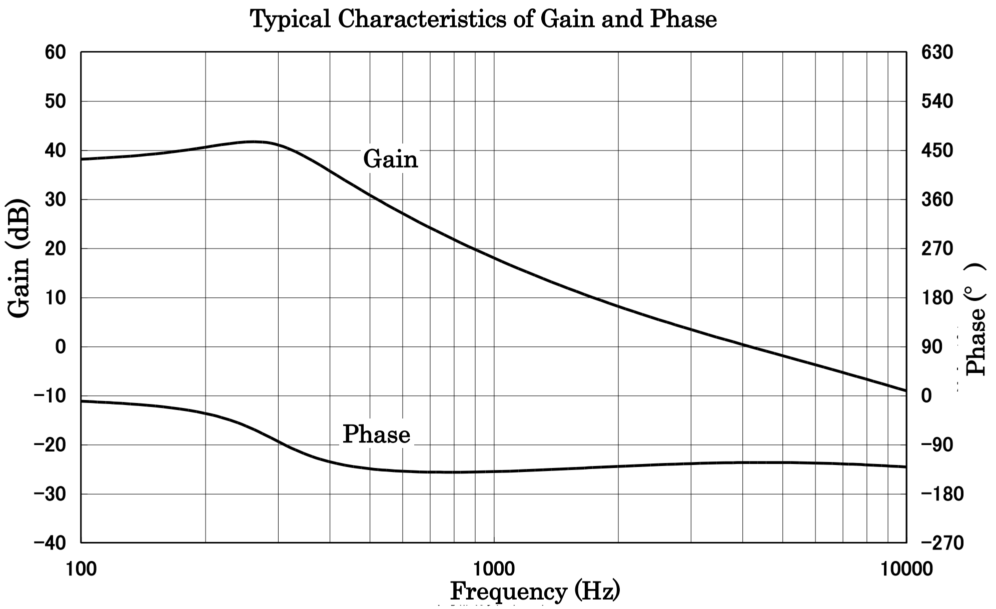
In order to avoid the concentration of phase delay, the resonant frequency of the LC filter f_{LC} should be kept to be less than 0.1 times of the first pole frequency fp of the error amplifier.



Generally, the frequency fp of the chopper type regulator IC is set from several KHz to higher than ten KHz.

With respect to the constants of LC filters described in the applications of each regulator IC, if the inductance of coil or capacitance of the capacitor is set to be less than the recommended values, the resonant frequency f_{LC} of the LC filter may rise to decrease the phase margin. Care should be taken to this phenomenon.

The constants of peripheral components should be properly selected according to the applications of each regulator IC.



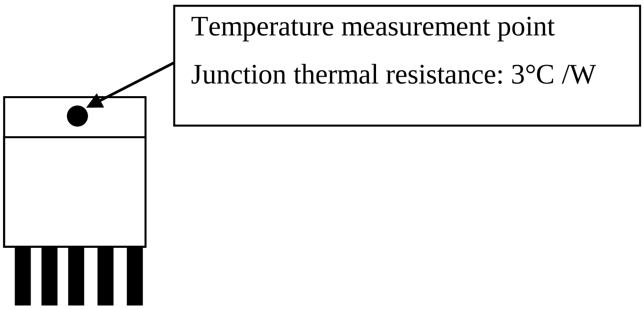
●4 - 5 Thermal Design

In the case of the surface mounting type SI-8000SD, the heat is dissipated toward the copper foil on the mounting board, therefore the thermal design should be made in consideration of copper foil area, board material and number of copper foil layers.

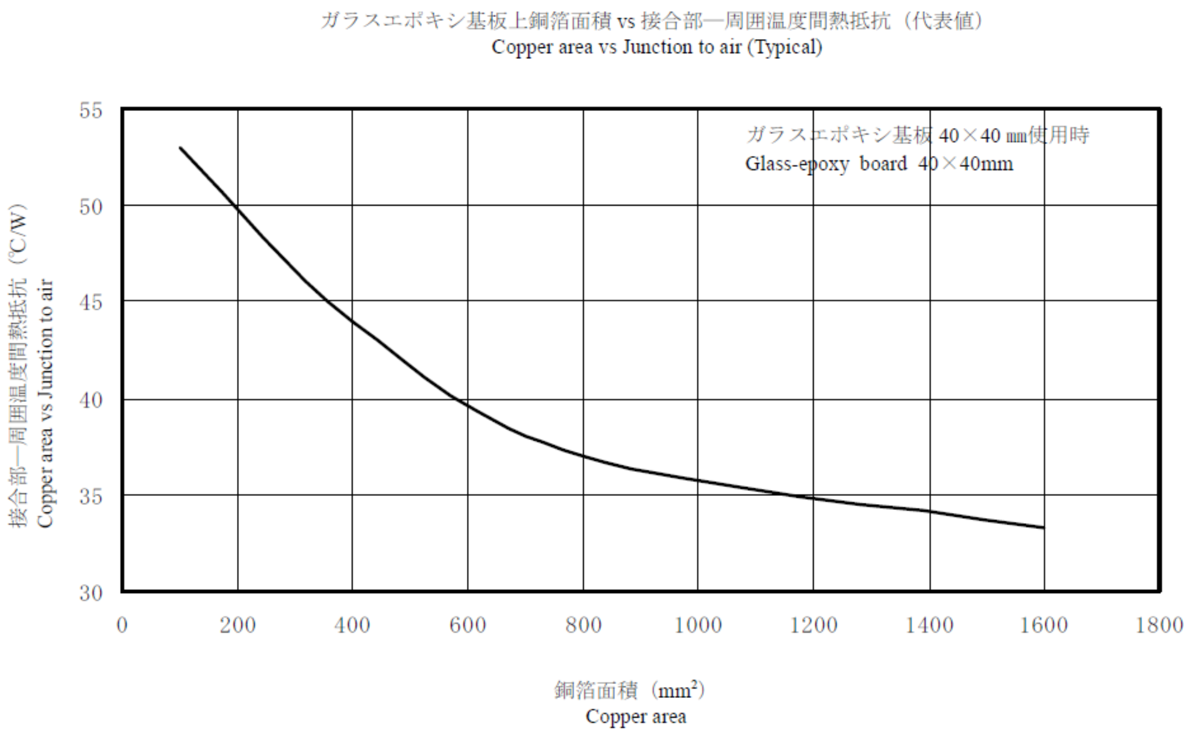
The stem part of the backside of the SI-8000SD is connected with pin 3 (GND) by the inner frame and heat dissipation performance is improved by taking the larger GND pattern which is directly connected with the stem part.

In order to confirm the junction temperature, the temperature of the stem spot shown below should be measured to calculate the temperature by the following equation.

$T_j = T_c + P_d \times 3°C/W$ * Tc = Actually measured stem temperature



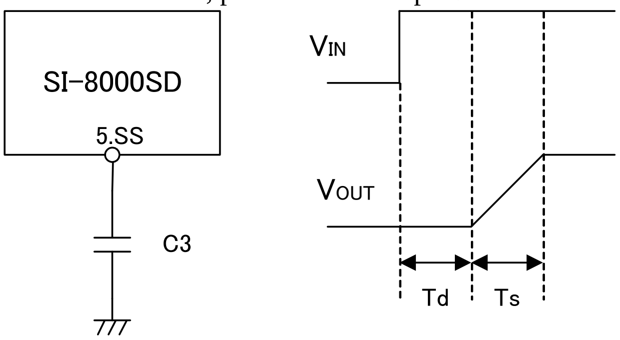
Reference data (Copper foil are vs Thermal resistance on single side copper foil board)



5. Application

●5-1 Soft-start

When a capacitor is connected to the pin 5, the soft-start is applied when input voltage is turned on. The capacitor C3 is intended to control rising time by controlling Off period of PW control. The delay time Td and the rising time Ts can be calculated by the following equation. However, there are some fluctuations in the actual machine because of influence of input power source and rising of load, etc. When not using the soft -start function, pin 5 should be open.



$$Td = \frac{0.7 \times C3}{20 \times 10^{-6}} \quad \text{(Sec)} \qquad -- (11)$$

$$Ts = \frac{Vo \times 0.9 \times C3}{Vin \times 20 \times 10^{-6}} \quad \text{(Sec)} -- (12)$$

For example, when VIN = 20V, Vo = 5v and C3 = 1uF

$$Td = \frac{0.7 \times 1 \times 10^{-6}}{20 \times 10^{-6}} = 35(ms) \qquad Ts = \frac{5 \times 0.9 \times 1 \times 10^{-6}}{20 \times 20 \times 10^{-6}} ≒ 12(ms)$$

$$Td + Ts ≒ 47(ms)$$

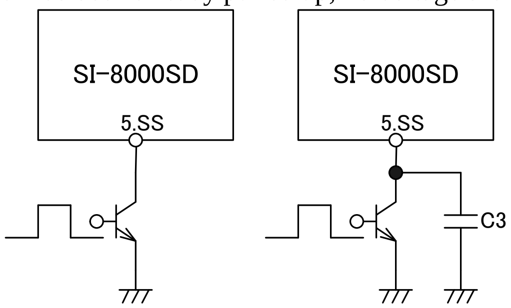
Accordingly, it takes 47ms until output voltage rises after power is turned on.

However, if the capacity of Css is enlarged, the discharge-time of Css becomes slow after VinOFF. It is recommended to use the C3 at 10uF or less.

＊ Ts may be shorter than the above calculated value under the load condition in discontinuous mode (light load).

●5-2 Output ON / OFF Control

The output ON-Off control is possible using the soft-start pin 5. The output is turned OFF when the pin 5 voltage falls to a low level by such as open collector. It is possible to use the soft-start together.
Since the soft-start terminal has been already pulled up, no voltage shall be applied from the external side.

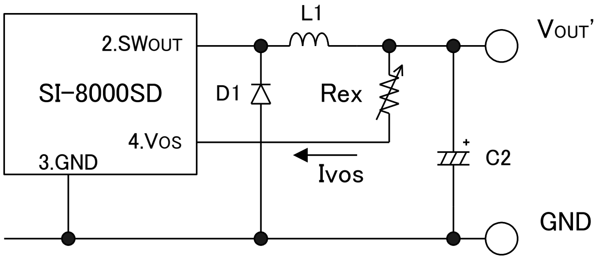


ON/OFF SS+ON/OFF

●5-3 Controllable Output Voltage

The output voltage can be increased by adding a resistor to the Vos terminal (pin 4) (not applicable for voltage fall).

5-3-1 Variable Output Voltage by One External Resistor



The output voltage adjustment resistance Rex is obtained by the following equation.

$$\mathrm{Re}\,x = \frac{Vout' - Vos}{Ivos} \quad ---(13)$$

Vos: Set output voltage for product
Vout: Variable output voltage
Ivos: Vos terminal in-flow current ≒1mA

* Since no temperature compensation is made for Rex, the temperature characteristic of output voltage is lowered. Ivos is variable at maximum ±20% depending on each IC product. Therefore, as the variation range of the output voltage becomes wider, the semi-fixed type resistor is required for the adjustment of accurate output voltage.

The variation range of the output voltage including the variation of Rex, Ivos and Vos is shown as follows:

- Maximum output voltage (VOUT'MAX)

$$\mathrm{VOUT'\,MAX} = \mathrm{VosMAX} + \mathrm{RexMAX} \times \mathrm{IvosMAX} \quad ---(14)$$

VosMAX: The maximum value of set output voltage. The MAX value of the set output voltage should be put, shown in the electrical characteristics in page 6.

RexMAX: The maximum value of Rex. It is obtained from the allowable tolerance.

IvosMAX : The maximum in-flow current of Vos terminal. 1.2mA

- The minimum output voltage (Vout'MIN)

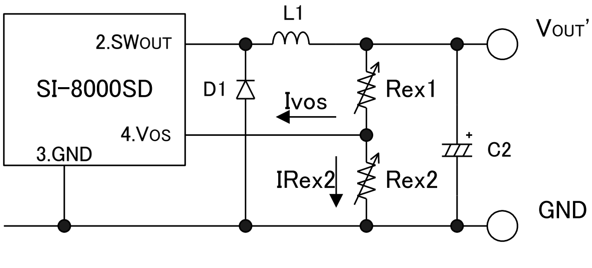
$$\mathrm{Vout'\,MIN} = \mathrm{VosMIN} + \mathrm{RexMIN} \times \mathrm{IvosMIN} \quad ---(15)$$

VosMIN: The minimum value of set output voltage. The MIN value of the set output voltage should be put, shown in the electrical characteristics in page 6.

RexMIN: The minimum value of Rex. It is obtained from the allowable tolerance of resistance.

IvosMIN : The minimum in-flow current of Vos terminal. 0.8mA

5-3-2 Variable Output Voltage by Two External Resistors



The output voltage adjustment resistors Rex1 and 2 are obtained by the following equation.

$$\mathrm{Re}\,x1 = \frac{Vout' - Vos}{S \cdot IVos} \quad ---(16)$$

$$\mathrm{Re}\,x2 = \frac{Vos}{(S-1) \cdot IVos} \quad ---(17)$$

S: Stability coefficient

The tolerance of temperature characteristics and output voltage is improved more by bypassing the current

to Rex2 than the method 5-3-1.
Stability coefficient S means the ratio of Rex 2 to the Vos terminal in-flow current Ivos. The larger S is, the more the variation of temperature characteristic and output voltage are improved. (Normally, about 5 - 10)

The tolerance of the output voltage including variation of Rex 1, Rex 2, Ivos, Vos is shown below.

- Maximum output voltage (Vout'MAX)

$$Vout'MAX = VosMAX + Rex1MAX\left(\frac{VosMAX}{Rex2MIN} + IvosMAX\right) \quad ---(18)$$

VosMAX: The maximum value of set output voltage. The MAX value of set output voltage should be put, shown in the electrical characteristics in page 6.

Rex1MAX: The maximum value of Rex1. It is obtained from the tolerance of the resistor.

Rex2MIN: The minimum value of Rex2. It is obtained from the tolerance of the resistor.

IvosMAX: The maximum in-flow current of Vos terminal. 1.2mA

- The minimum output voltage (Vout'MIN)

$$Vout'MIN = VosMIN + Rex1MIN\left(\frac{VosMIN}{Rex2MAX} + IvosMIN\right) \quad ---(19)$$

VosMIN: The minimum value of the set output voltage. Please fill in the MIN value of the set output voltage which is shown in the electrical characteristics in page 6.

Rex1MIN: The minimum value of Rex1. It is obtained from the tolerance of the resistor.

Rex2MAX: The maximum value of Rex2. It is obtained from the tolerance of the resistor.

IvosMIN: The minimum in-flow current of Vos terminal. 0.8mA

5-3-3 Cautions for variation of output voltages

The degradation of regulation and the increase in the output voltage temperature coefficient are assumed when the output voltage is varied.

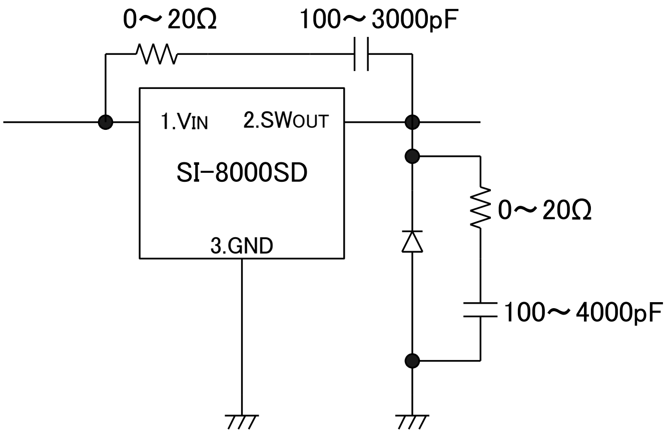
If it is varied drastically, the increase of coil capacitance value may be required since the overcurrent protection current is assumed to be lowered due to the increase in coil current.

Therefore, the use within the set output voltage +5V is recommended as for the upper limit of output voltage variation.

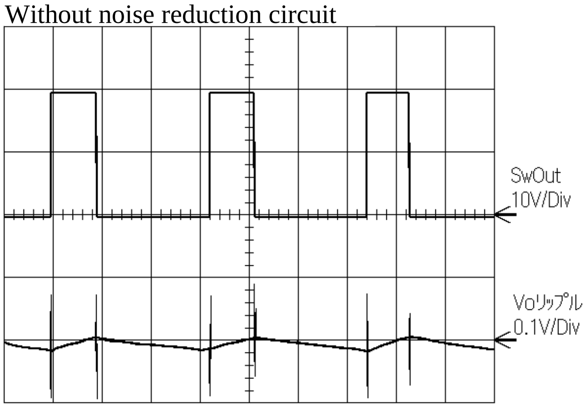
In addition, the MAX value of the set output voltage is recommended as for the lower limit of output voltage variation.

●5-4 Spike Noise Reduction

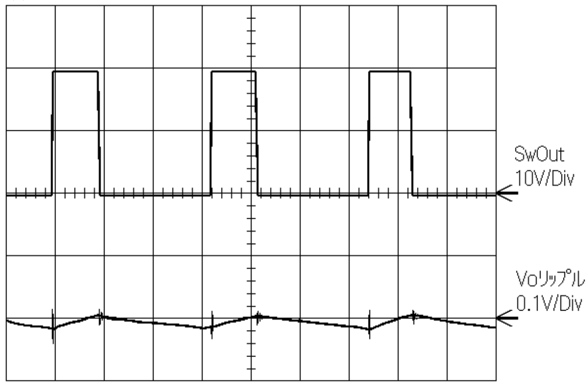
In order to reduce the spike noise, it is possible to compensate the output waveform of the SI-8000SD and the recovery time of the diode by a capacitor, but it should be noted that the efficiency is also slightly reduced.



Without noise reduction circuit



With noise reduction circuit

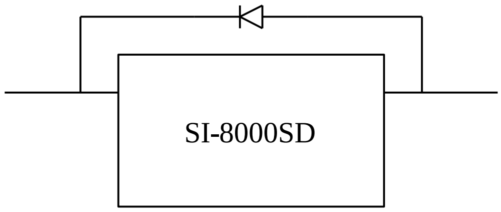


A resistor of 10Ω and a capacitor of 2200pF are connected to external resistor

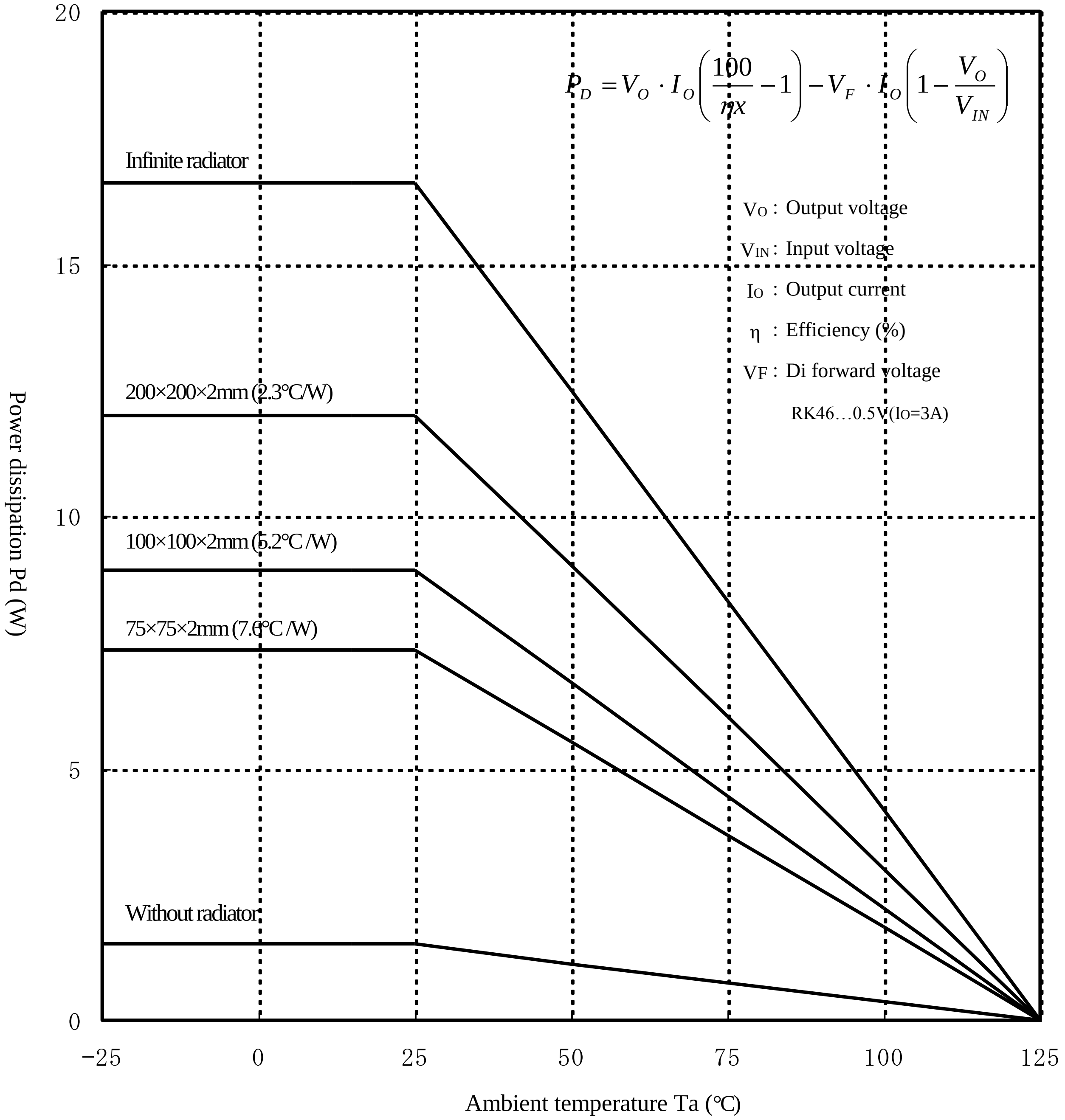
*When the spike noise is observed with an oscilloscope, the lead wire may function as an antenna and the spike noise may be observed extremely higher than usual if the probe GND lead wire is too long. In the observation of spike noise, the probe lead wire should be made as short as possible and be connected with the root of the output capacitor.

●5-5 Reverse Bias Protection

A diode for reverse bias protection is required between input and output when the output voltage is higher than the input terminal voltage, such as in battery chargers.



6. Thermal derating Curve



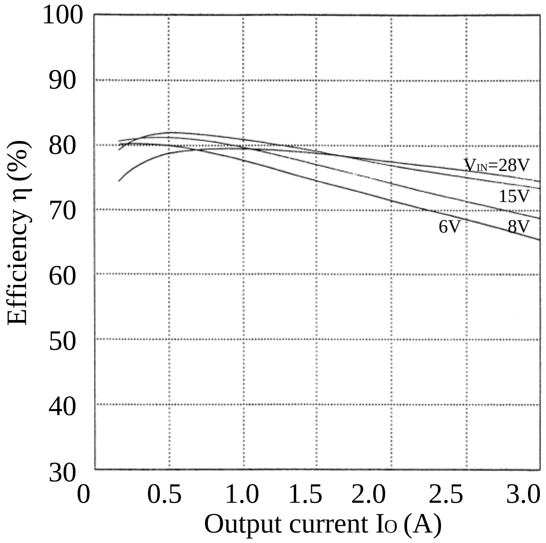
Note1 : As the efficiency varies subject to the input voltage and output current, it shall be obtained from the efficiency curve in 4-2 and substituted in percent.

Note2 : Thermal design for Di shall be made separately

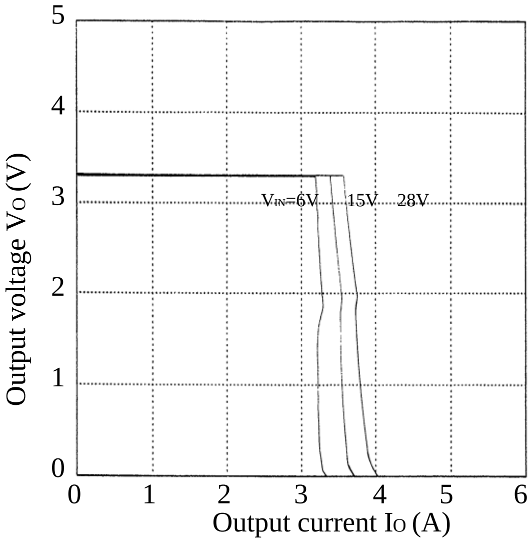
7. Typical Characteristics

SI-8033SD

(1) Efficiency

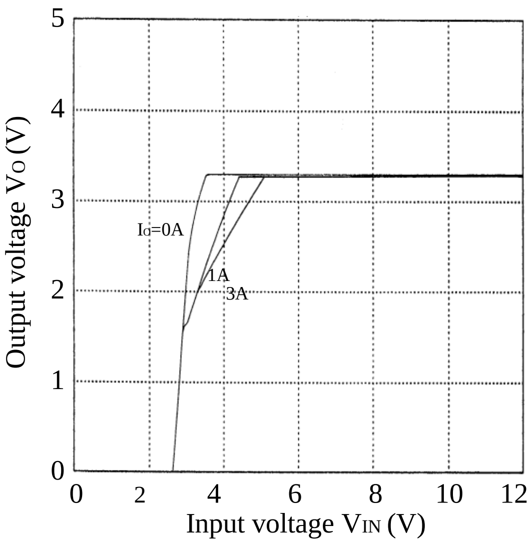


(4) Overcurrent protection characteristics

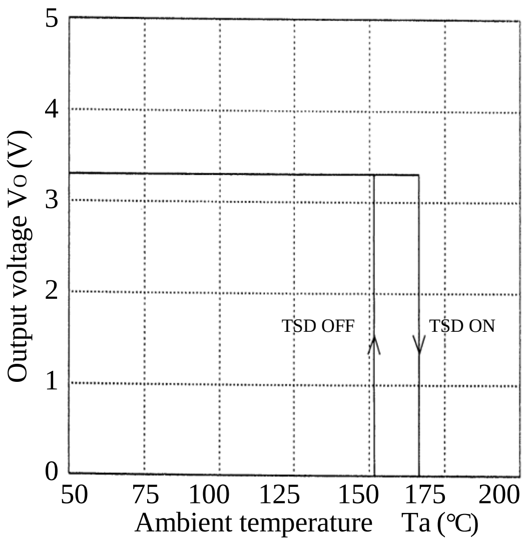


(2) Startup of output voltage * Load=C.C

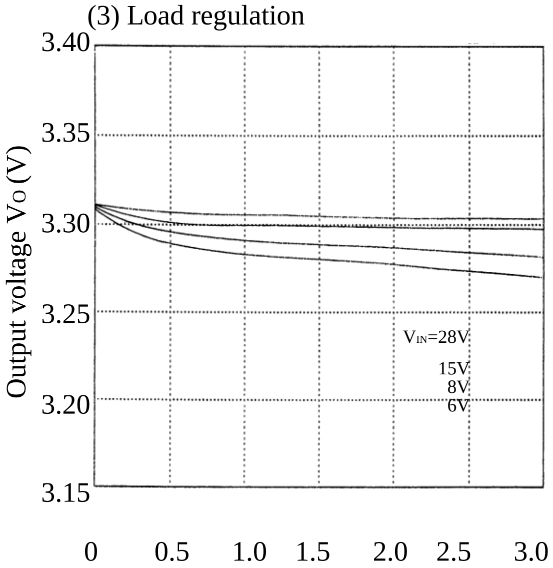
Io=0A



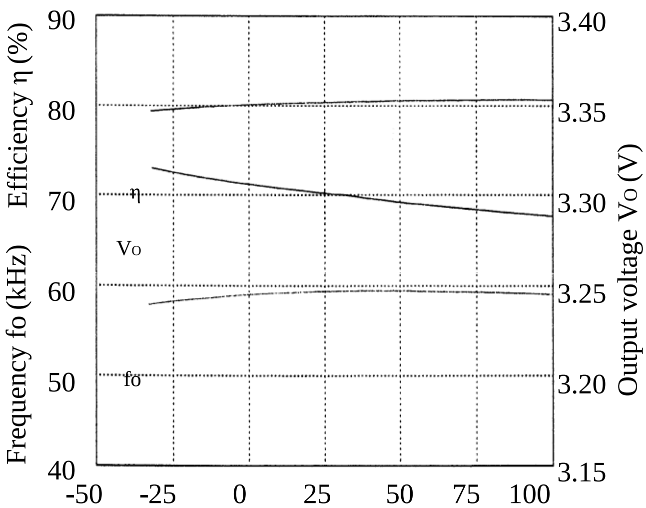
(5) Thermal shutdown VIN=15V,



(3) Load regulation



(6) Temperature characteristics

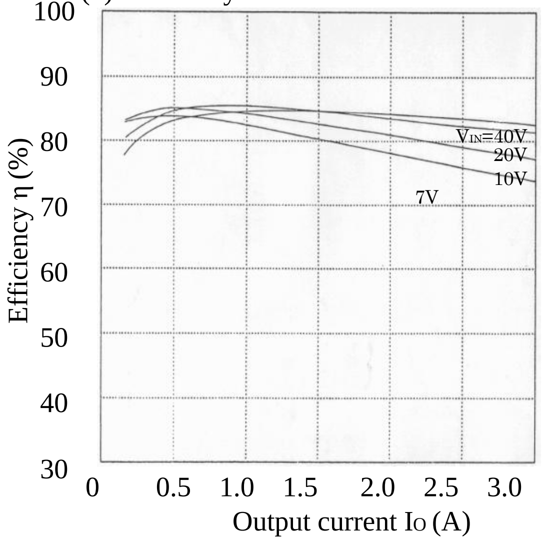


Output current IO (A)

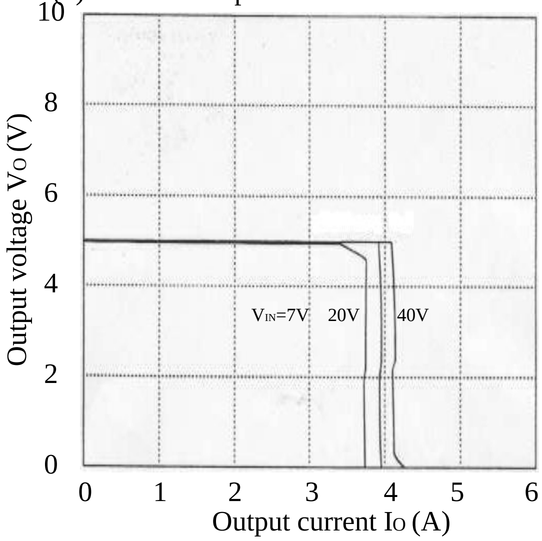
Ambient temperature Ta (℃)

SI-8050SD

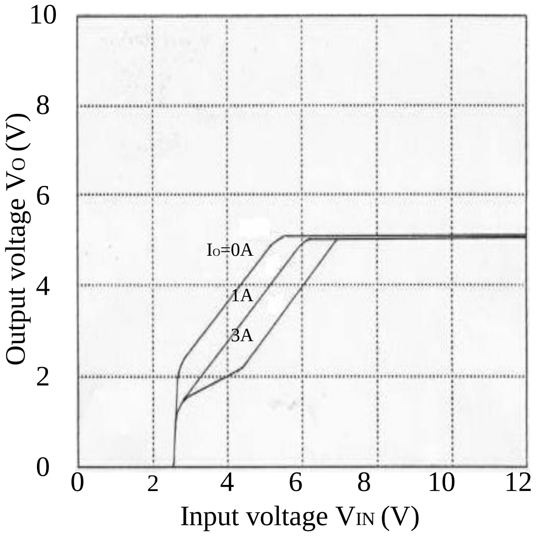
(1) Efficiency



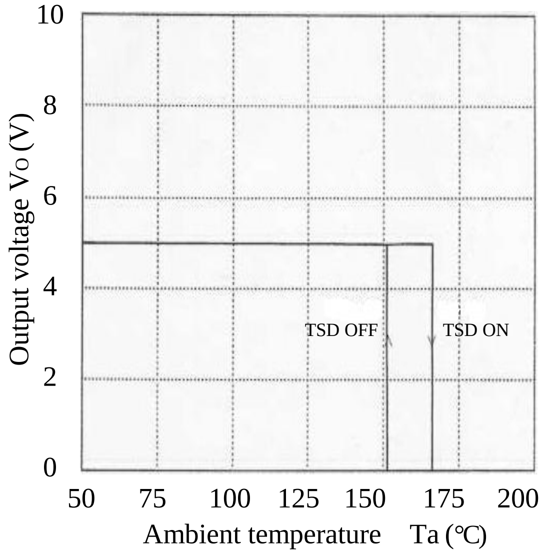
(4) Overcurrent protection characteristics



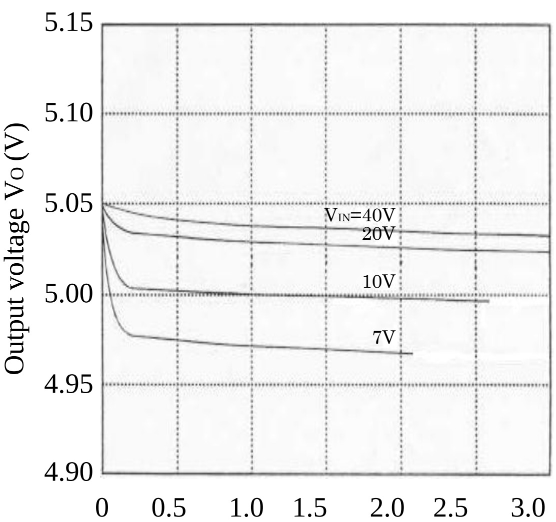
(2) Rising of output voltage *Load=C.C
IO=0A



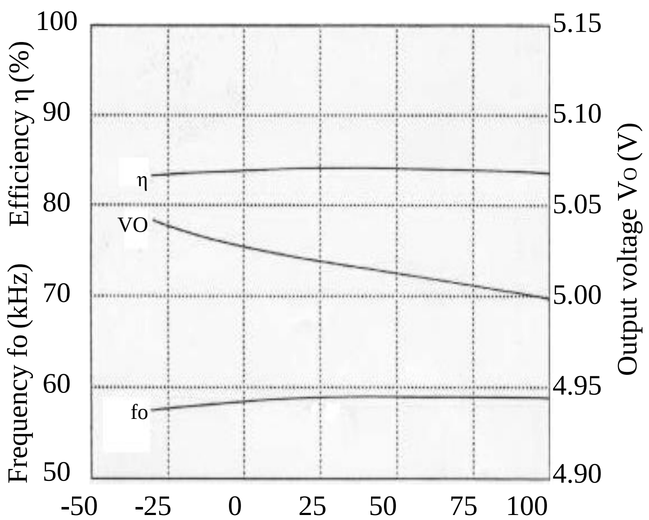
(5) Thermal shutdown VIN=20V,



(3) Load regulation



(6) Temperature characteristics VIN=20V, IO=1A



Output current I_O (A) Ambient temperature Ta (℃)

8. Terminology

- Jitter

It is a kind of abnormal switching operations and is a phenomenon that the switching pulse width varies in spite of the constant condition of input and output. The output ripple voltage peak width is increased when a jitter occurs.

- Recommended Conditions

It shows the operation conditions required for maintaining normal circuit functions. It is required to meet the conditions in actual operations.

- Absolute Maximum Ratings

It shows the destruction limits. It is required to take care so that even one item does not exceed the pacified value for a moment during instantaneous or normal operation.

- Electrical Characteristics

It is the specified characteristic value in the operation under the conditions shown in each item. If the operating conditions are different, it may be out of the specifications.

- PWM (Pulse Width Modulation))

It is a kind of pulse modulation systems. The modulation is achieved by changing the pulse width in accordance with the variation of modulation signal waveform (the output voltage for chopper type switching regulator).

- ESR (Equivalent Series Resistance)

It is the equivalent series resistance of a capacitor. It acts in a similar manner to the resistor series-connected to the capacitor.

Notice

・The contents of this description are subject to change without prior notice for improvement etc. Please make sure that any information to be used is the latest one.

・Any example of operation or circuitry described in this application note is only for reference, and we are not liable to any infringement of industrial property rights, intellectual property rights or any other rights owned by third parties resulting from such examples.

・In the event that you use any product described here in combination with other products, please review the feasibility of combination at your responsibility.

・Although we endeavor to improve the quality and reliability of our product, in the case of semi-conductor components, defects or failures which occur at a certain rate of probability are inevitable.

The user should take into adequate consideration the safety design in the equipment or the system in order to prevent accidents causing death or injury, fires, social harms etc..

・Products described here are designed to be used in the general-purpose electronic equipment (home appliances, office equipment, communication terminals, measuring equipment etc.).

If used in the equipment or system requiring super-high reliability (transport machinery and its control equipment, traffic signal control equipment, disaster/crime prevention system, various safety apparatus etc.), please consult with our sales office. Please do not use our product for the equipment requiring ultrahigh reliability (aerospace equipment, atomic control, medical equipment for life support etc.) without our written consent.

・The products described here are not of radiation proof type.