Application Note

Full Mold Type Chopper Type Switching Regulator IC

SI-8000S, SS Series

9th Edition April 2010

SANKEN ELECTRIC CO., LTD.

——— Contents ———

1. General Description

The SI-8000S, SS series 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 composed. Products of this series are screened from those of the SI-8000S series for the output voltage.

● 1-1 Features

- Compact size and large output current of 3A
  The maximum output current of 3A for the outline of TO220F class.
- High efficiency of 84% (SI-8050S, SS Vin = 20V / Io = 1A)
  Heat dissipation is small due to high efficiency to allow for the downsizing of a heat sink.
- Four external components
  The regulator can be composed of 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 means of external components is no longer required.
- Reference oscillation by a built-in timing capacitor
  No external capacitor for setting the oscillation frequency is required.
- Built-in functions for overcurrent and thermal shutdown
  A current limiting type protection circuit against overcurrent and overheat is built in.
  (automatic restoration type)
- Soft start function (capable of ON / OFF output)
  By adding an external capacitor, it is possible to delay the rise speed of the output voltage. ON/OFF control of the output is also possible.
- No insulation plate required
  No insulation plate is required, when it is fitted to the heat sink, because it is of full molding type.

● 1-2 Application

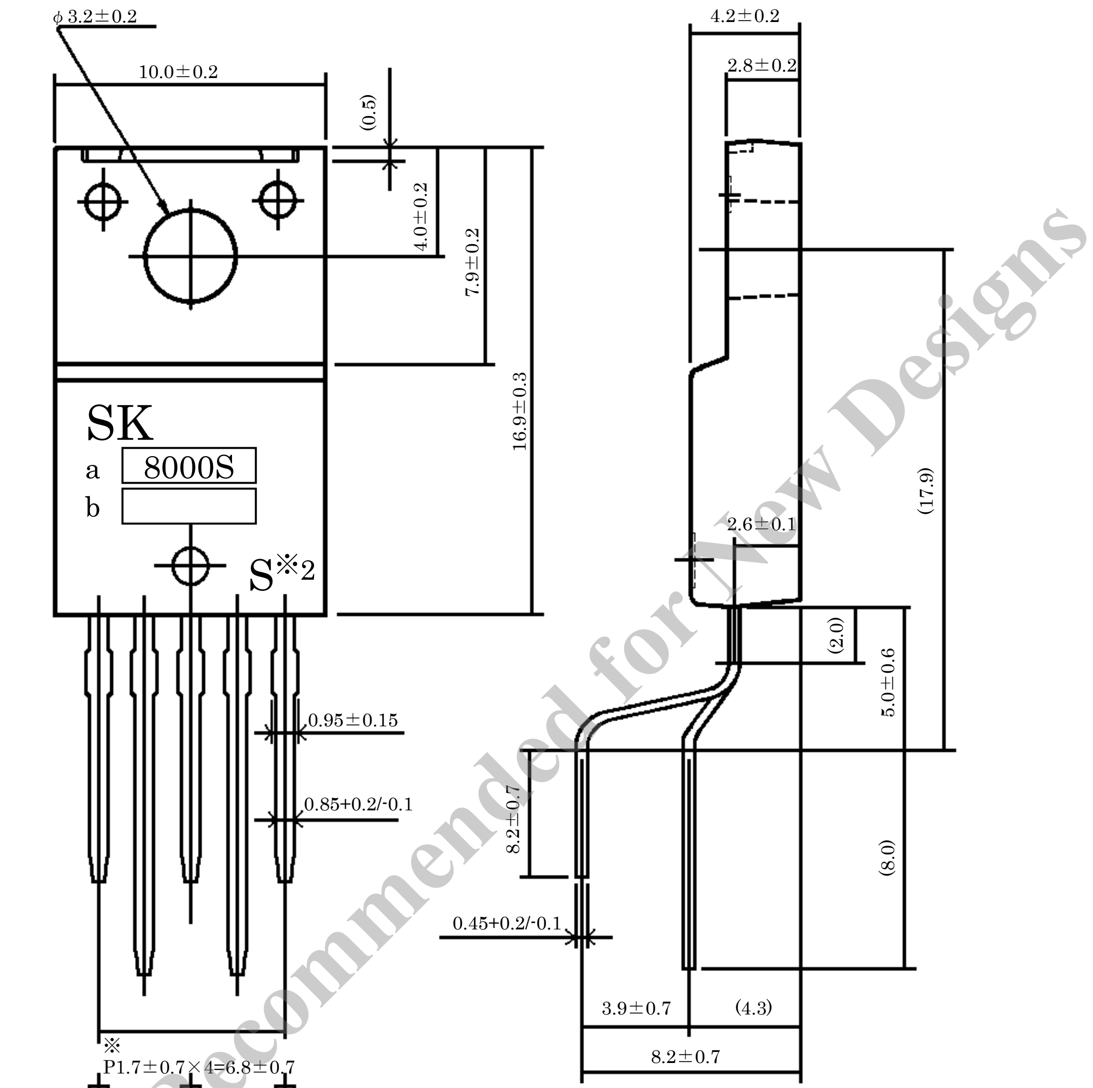
For on-board local power supplies, power supplies for OA equipment, stabilization of secondary output voltage of regulator and power supply for communication equipment

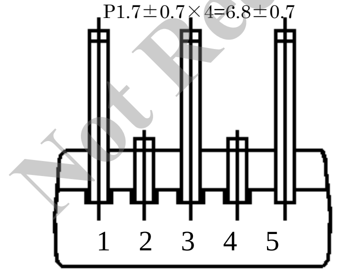
● 1-3 Type

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

2. Specification

● 2-1 Package Information





Pin Assignment

1. V_{IN}
2. SWOUT
3. GND
4. V_{OS}
5. SS

a. Type Number

b. Lot Number

1st letter The last digit of year

2nd letter Month

January to September by Arabic number

October to December by O (October), N (November) and D (December)

3rd & 4th letter Day

01 – 31: Arabic Numerical

<Notes> * shows the dimensions measured at the top of lead.

*2 In the SI-8000SS, the mark “S” is stamped on the right side of SK mark.

In the SI-8000S, the mark “S” may be stamped on the right side of SK mark.

Unit: mm DWG. NO.: TG3A-1102

● 2-2 Ratings

2-2-1 Lineup

Product Name	Vout(V)
SI-8033S	3.3
SI-8050S	5
SI-8090S	9
SI-8120S	12
SI-8150S	15

2-2-2 Absolute Maximum Ratings

Parameter	Symbol	Rating	Unit
Input Voltage	V_{IN}	43 *1	V
Allowable Power Dissipation in Infinite Radiation	Pd1	18	W
Allowable Power Dissipation without Heat sink	Pd2	1.5	W
Junction Temperature	Tj	125	°C
Storage Temperature	Tstg	-40 - +125	°C
SW Terminal Applied Reverse Voltage	Vsw	-1	V

*1: 35V for SI-8033S and SI-8033SS.

2-2-3 Recommended Conditions

Parameter	Symbol	SI-8033S,SS	SI-8050S,SS	SI-8090S,SS	SI-8120S	SI-8150S	Unit
DC Input Voltage	V_{IN}	5.5 - 28	7 - 40	12 - 40	15 - 40	18 - 40	V
Output Current	I_O	0 - 3					A
Junction Temperature in Operation	Tjop	-30 - +125					°C

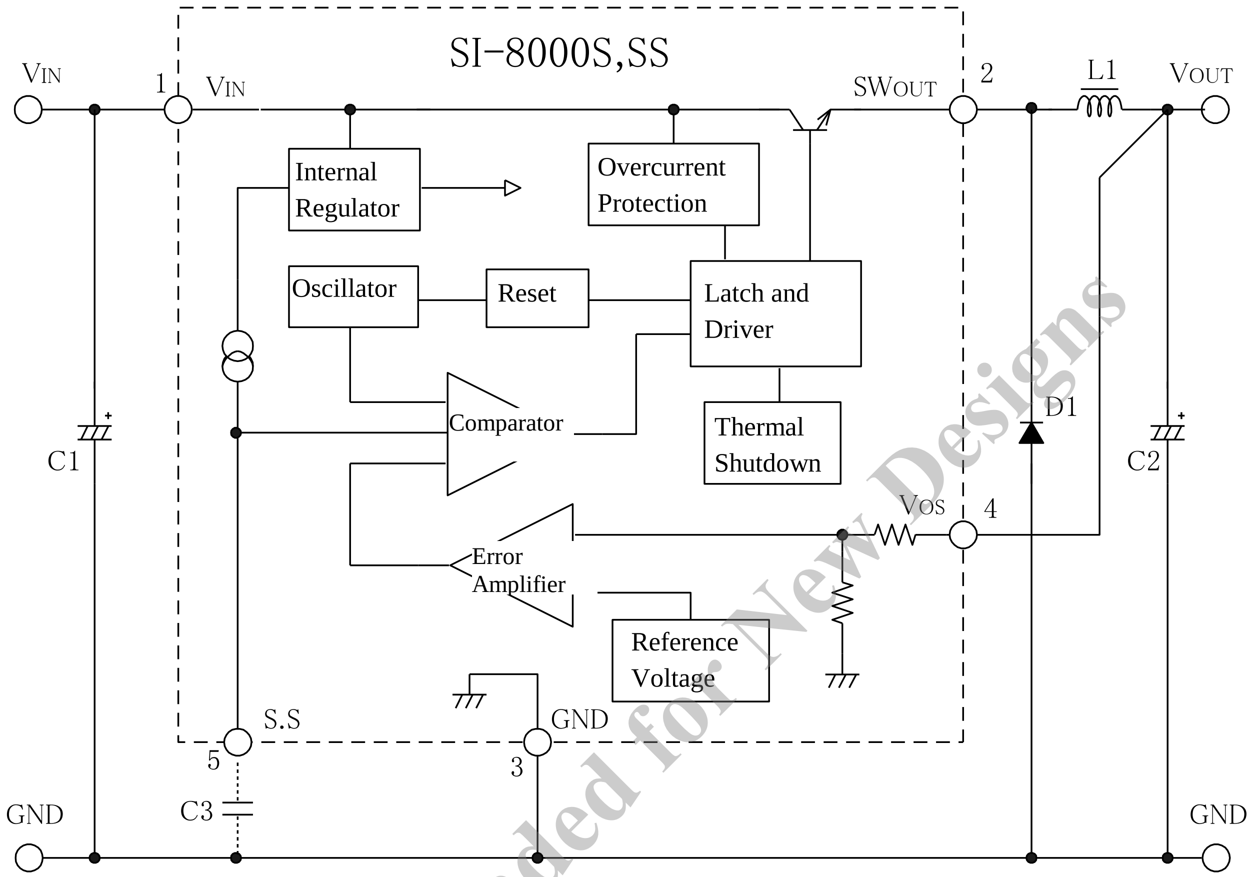
2-2-4 Electrical Characteristics

(Ta=25°C)

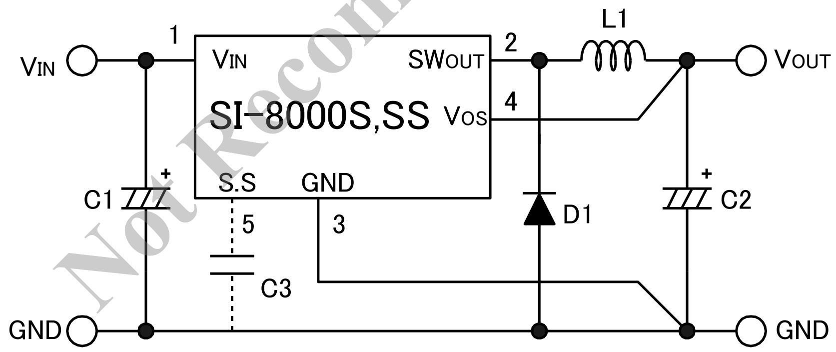
Parameter	Symbol	SI-8033S			SI-8050S			SI-8090S			SI-8120S			SI-8150S			Unit
		min	typ	max	min	typ	max	min	typ	max	min	typ	max	min	typ	max	
Set Output Voltage	Vo S	3.17	3.30	3.43	4.80	5.00	5.20	8.55	9.00	9.45	11.5	12.0	12.5	14.25	15.0	15.75	V
	Vo SS	3.234	3.30	3.366	4.90	5.00	5.10	8.73	9.00	9.27	—			—			
	Conditions	V_{IN}=15V/Io=1A			V_{IN}=20V/Io=1A			V_{IN}=21V/Io=1A			V_{IN}=24V/Io=1A			V_{IN}=25V/Io=1A			
Efficiency	η		79			84			88			90			91		%
	Conditions	V_{IN}=15V/Io=1A			V_{IN}=20V/Io=1A			V_{IN}=21V/Io=1A			V_{IN}=24V/Io=1A			V_{IN}=25V/Io=1A			
Switching Frequency	f		60			60			60			60			60		kHz
	Conditions	V_{IN}=15V/Io=1A			V_{IN}=20V/Io=1A			V_{IN}=21V/Io=1A			V_{IN}=24V/Io=1A			V_{IN}=25V/Io=1A			
Input Voltage – Output Voltage (Iout=1A)	⊿Voline		25	80		40	100		50	120		60	130		60	130	mV
	Conditions	V_{IN}=8 - 28V			V_{IN}=10 - 30V			V_{IN}=15 - 30V			V_{IN}=18 - 30V			V_{IN}=21 - 30V			
Output Current – Output Voltage (Iout=0.5 - 1.5A)	⊿Voload		10	30		10	40		10	40		10	40		10	40	mV
	Conditions	V_{IN}=15V			V_{IN}=20V			V_{IN}=21V			V_{IN}=24V			V_{IN}=25V			
Overcurrent Protection Start Current	Is	3.1			3.1			3.1			3.1			3.1			A
	Conditions	V_{IN}=15V			V_{IN}=20V			V_{IN}=21V			V_{IN}=24V			V_{IN}=25V			
Output Voltage Temperature Variation	Kt		±0.5			±0.5			±1.0			±1.0			±1.0		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

(only when the soft start function is used)

L1 : 150μH

D1 : RK46 (Sanken Product)

3. Operational Description

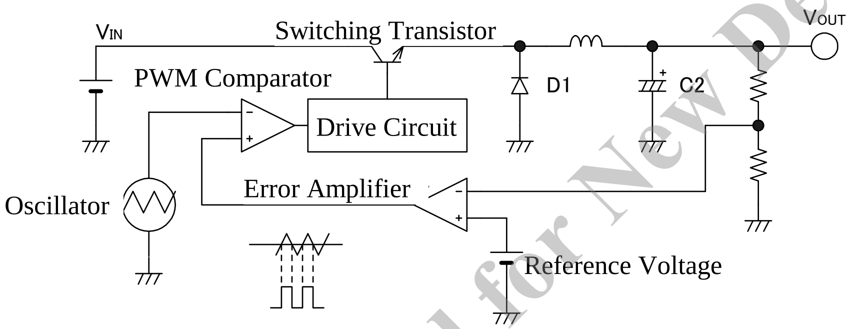
● 3-1 PWM Output Voltage Control

In the SI-8000S, SS series, the output voltage is controlled by the PWM system and the IC integrates 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 Configuration

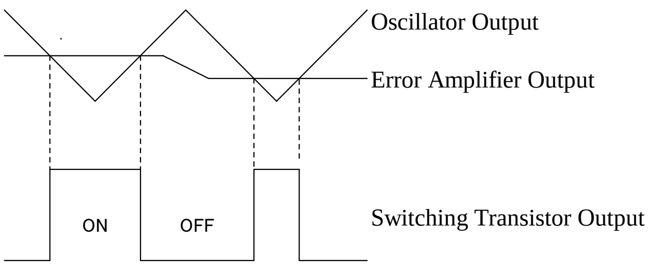


The error amplifier output and the oscillator output are compared by the PWM comparator to generate the drive signal of rectangular wave and to drive the switching transistor.

On the assumption that the output voltage attempts to rise, the output of the error amplifier is lowered, because the error amplifier is of inverting type. As the output of the error amplifier is lowered, the time period where 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 constant.

As described above, the output voltage is controlled by varying the ON time of the switching transistor with the switching frequency fixed (the higher is V_{IN}, the shorter is the ON time of the switching transistor.)

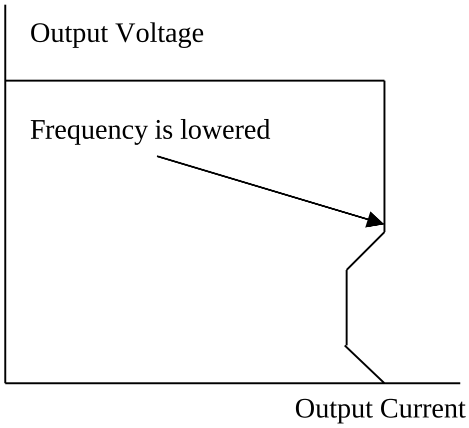
PWM Comparator Operation



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

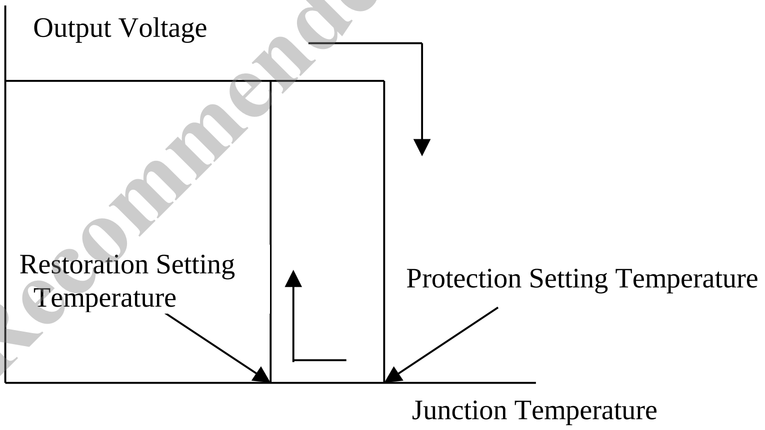
● 3-2 Overcurrent Protection / Thermal Shutdown

Output Voltage Characteristics in Overcurrent



The SI-8000S, SS series integrates 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. When the output voltage further drops to about 50% of the rated value, the switching frequency is lowered to about 30KHz to prevent the current increase at low output voltage. When the overcurrent condition is released, the output voltage will be automatically restored.

Output Voltage Characteristics in Thermal Shutdown



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 from the set value for overheat protection by around 15°C, 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 it should be noted that this function does not assure the operation including reliability in the state that overheat continues due to long time short circuit.

4. Cautions

● 4-1 External Components

4-1-1 Choke coil L1

The choke coil L1 is one of the most important components in the 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.

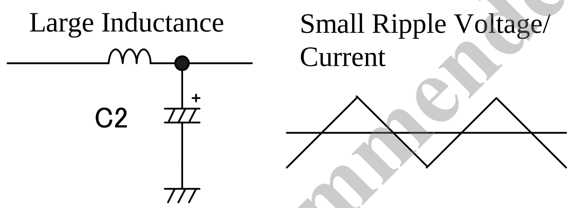
a) The choke coil should be fit for the switching regulator.

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

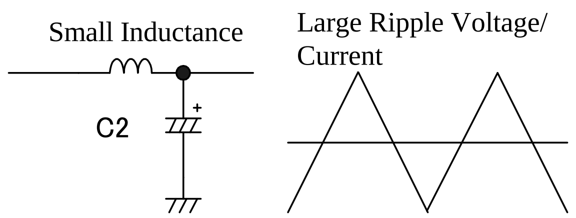
b) The inductance value should be appropriate.

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

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



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



The smaller is the inductance, the larger will be the ripple current/voltage.
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 calculated by the equation (1).

ΔIL shows the ripple current value of the choke coil and the lower limit of inductance are 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-8000S, SS: 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, the peak current detection system is adopted for overcurrent detection and 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 which is of drum shape, since magnetic flux passes outside the coil, the peripheral circuit may be damaged 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 connected as close as to the regulator IC.

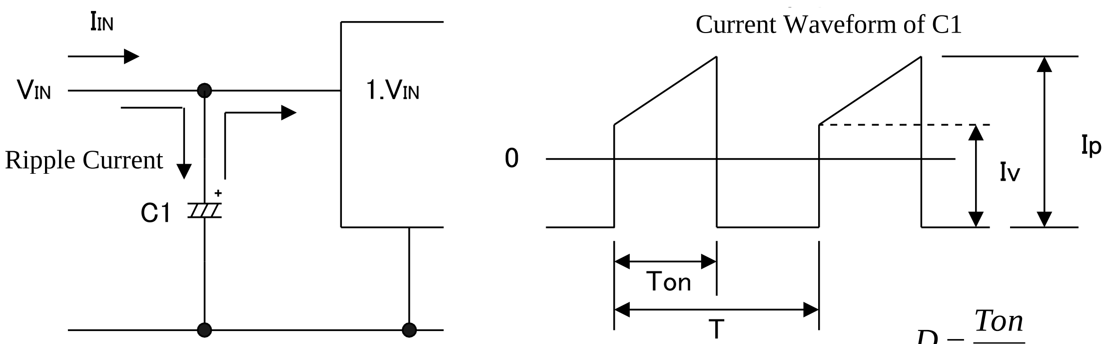
In addition, in the case that the smoothing capacitor of the AC rectifier circuit is located in the input circuit, the input capacitor may be also used as a smoothing capacitor, but similar attention should be paid.

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 voltage shall be met.

Current Flow of C1



$$D = \frac{Ton}{T}$$

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

If the withstanding voltages or allowable ripple voltages 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 calculated by the following equation (2):

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

For instance, where VIN = 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.

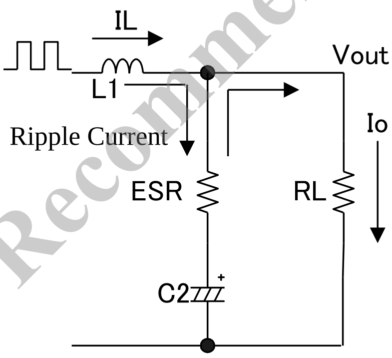
4-1-3 Output Capacitor C2

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

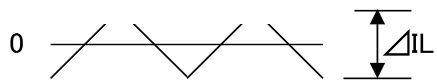
The current equivalent to the pulse current ΔIL of the choke coil current is charged and discharged in the output capacitor.

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).

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

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.

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

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.

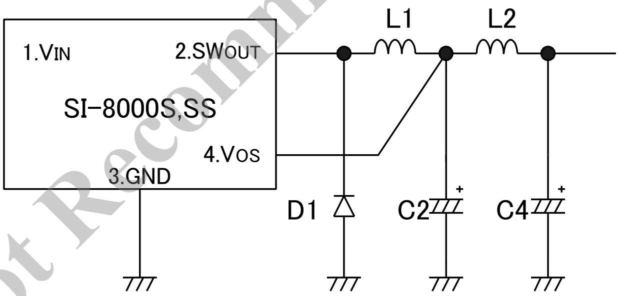
When ΔIL = 0.5A, Vrip = 40mV,

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

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 the 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.



L2: 20uH

C4: 200uF

The abnormal oscillation can be caused unless the output voltage detection point (wiring to the Vos terminal) is placed before the second stage filter if the second stage filter is added. Therefore, the care should be taken.

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 Flywheel Diode D1

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

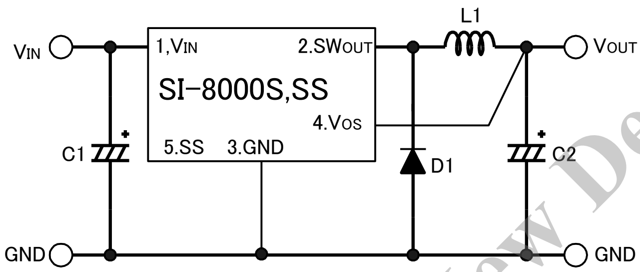
For the flywheel diode, the Schottky barrier diode must be used. If a general rectifying diode or fast recovery diode is used, the IC may be damaged by applying reverse voltage due to the recovery and ON voltage.

In addition, since the output voltage from the SWOUT terminal (pin 2) of the SI-8000S, SS 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.

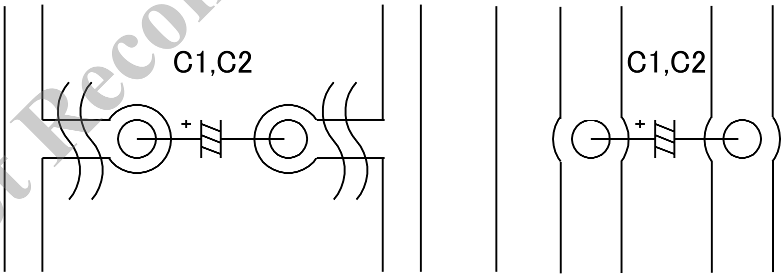


4-2-2 Input / Output Capacitor

The input capacitor C1 and the output capacitor C2 should be connected 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.



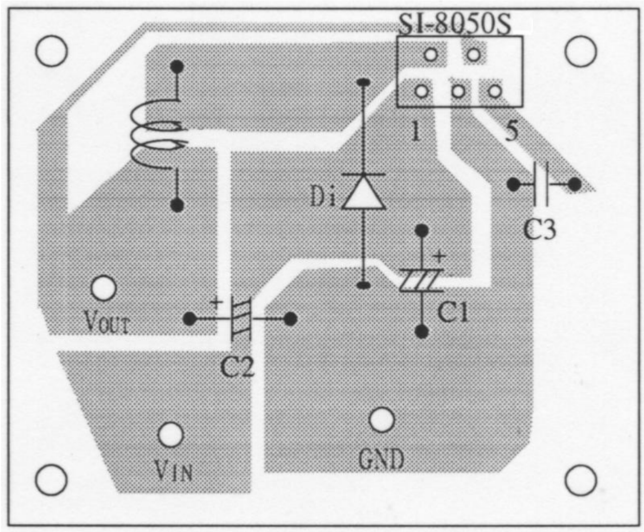
Improper Pattern Example   Proper Pattern Example

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.

Board Pattern Example (Top View)

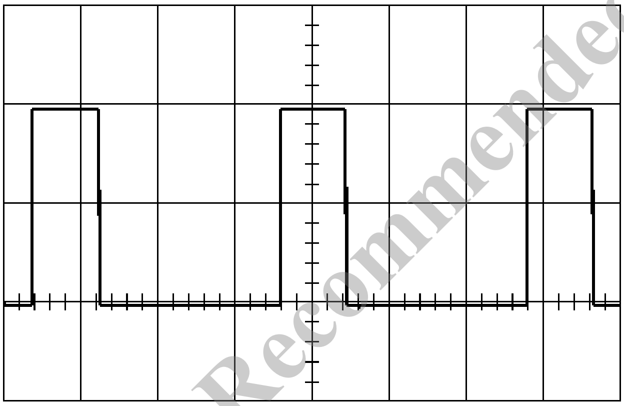


● 4-3 Operation Waveform Check

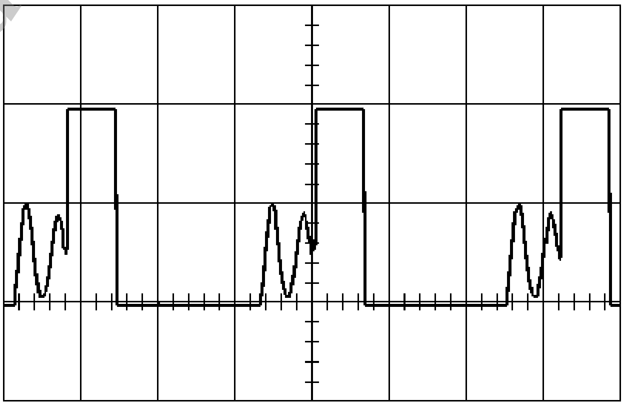
It can be checked by the waveform between the pin 2 and 3 (SW_{OUT}-GND waveform) of the SI-8000S, SS whether the switching operation is normal or not.

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

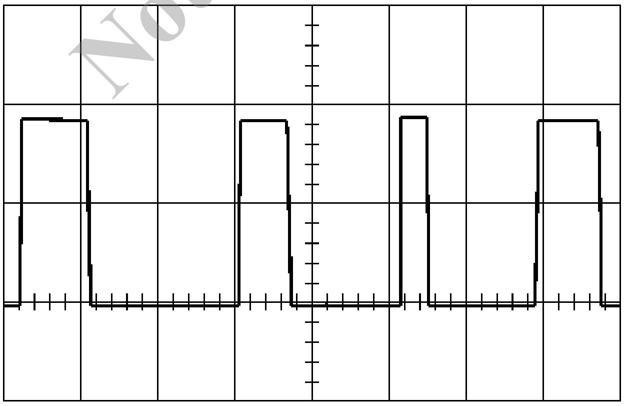
1. Normal Operation (continuous area)



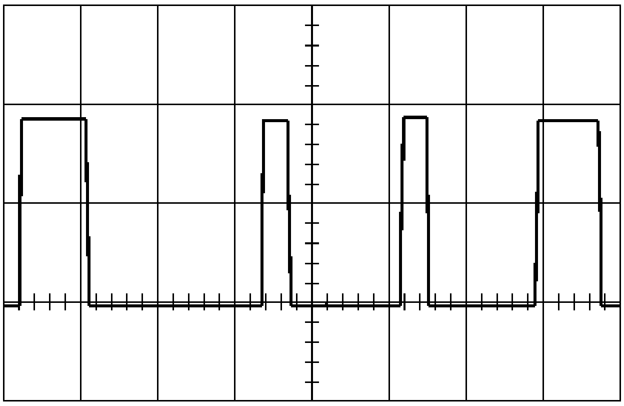
2. Normal Operation (discontinuous area)



3. When C1 is distant from IC



4. When C2 is distant from IC



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.

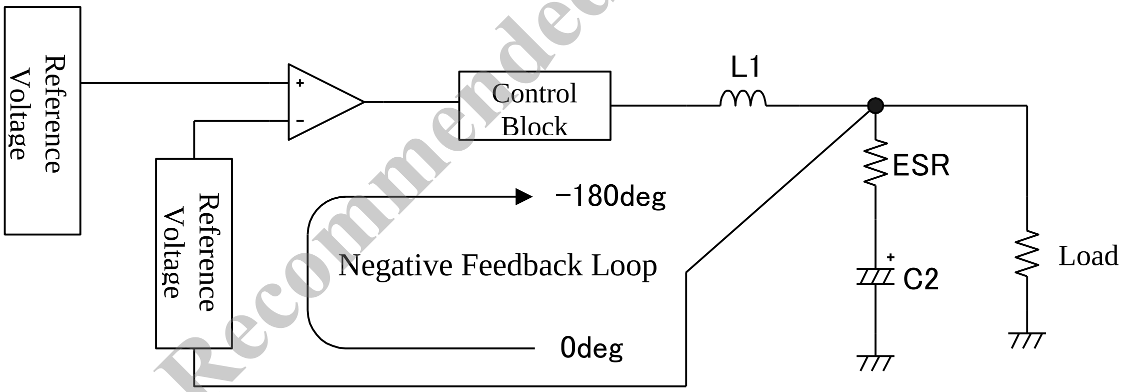
In the continuous area, the switching waveform is formed in the normal rectangular waveform (waveform 1) and in the discontinuous area, damped oscillation is caused in the switching waveform (waveform 2), but this is a normal operation without any problem.

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

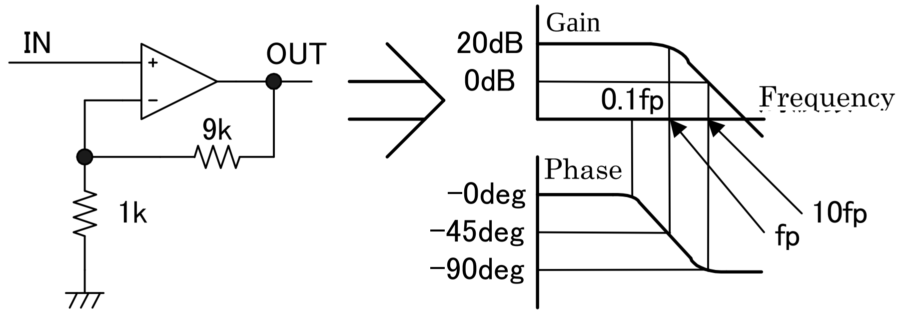
This block diagram shows that the chopper type regulator is a negative feedback amplifier which controls the output voltage by constantly comparing with the output voltage and the reference voltage which is set in advance. Therefore, it has a negative feedback loop to control the output by detecting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

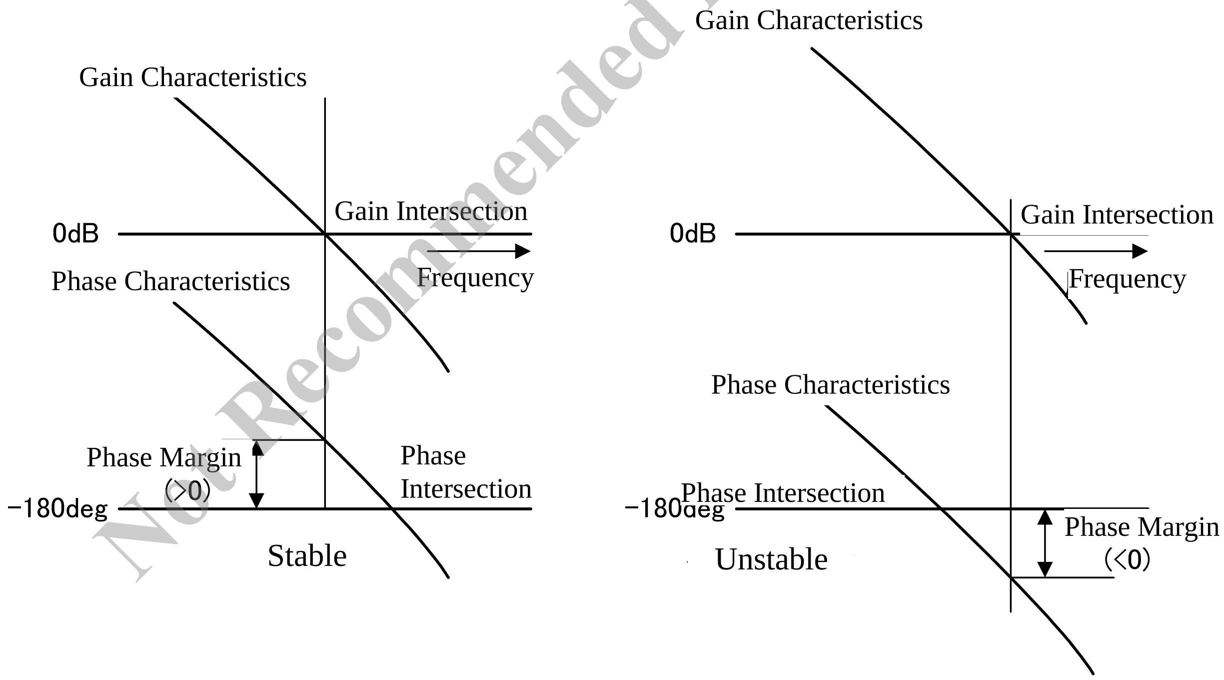
1-step Differential Amplifier   Bode Diagram Example



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, 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):

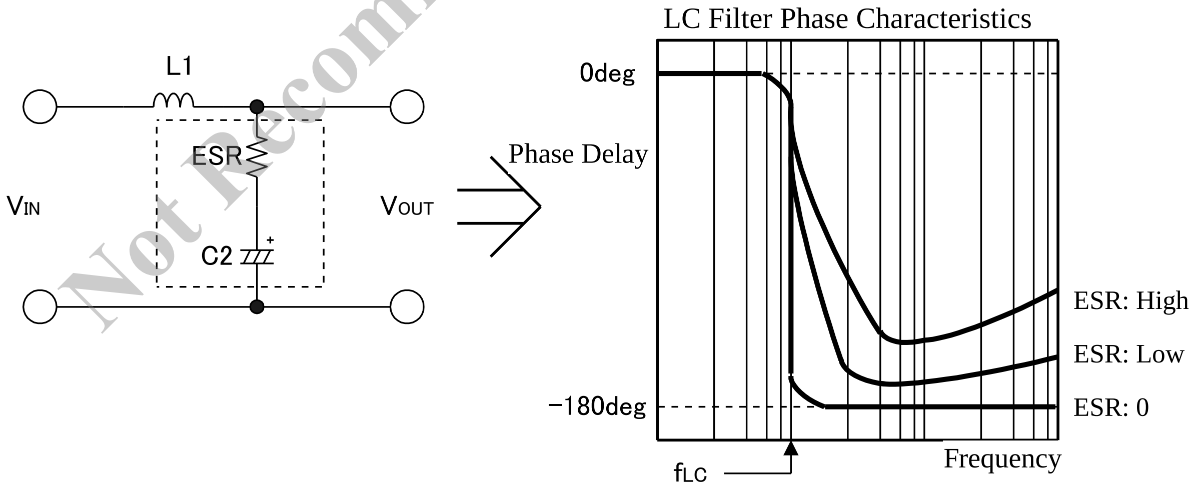
$$f_{LC} = \frac{1}{2\pi\sqrt{LC}} \qquad ---(5)$$

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 view point of securing the phase margin, use of the electrolytic capacitor is preferable.

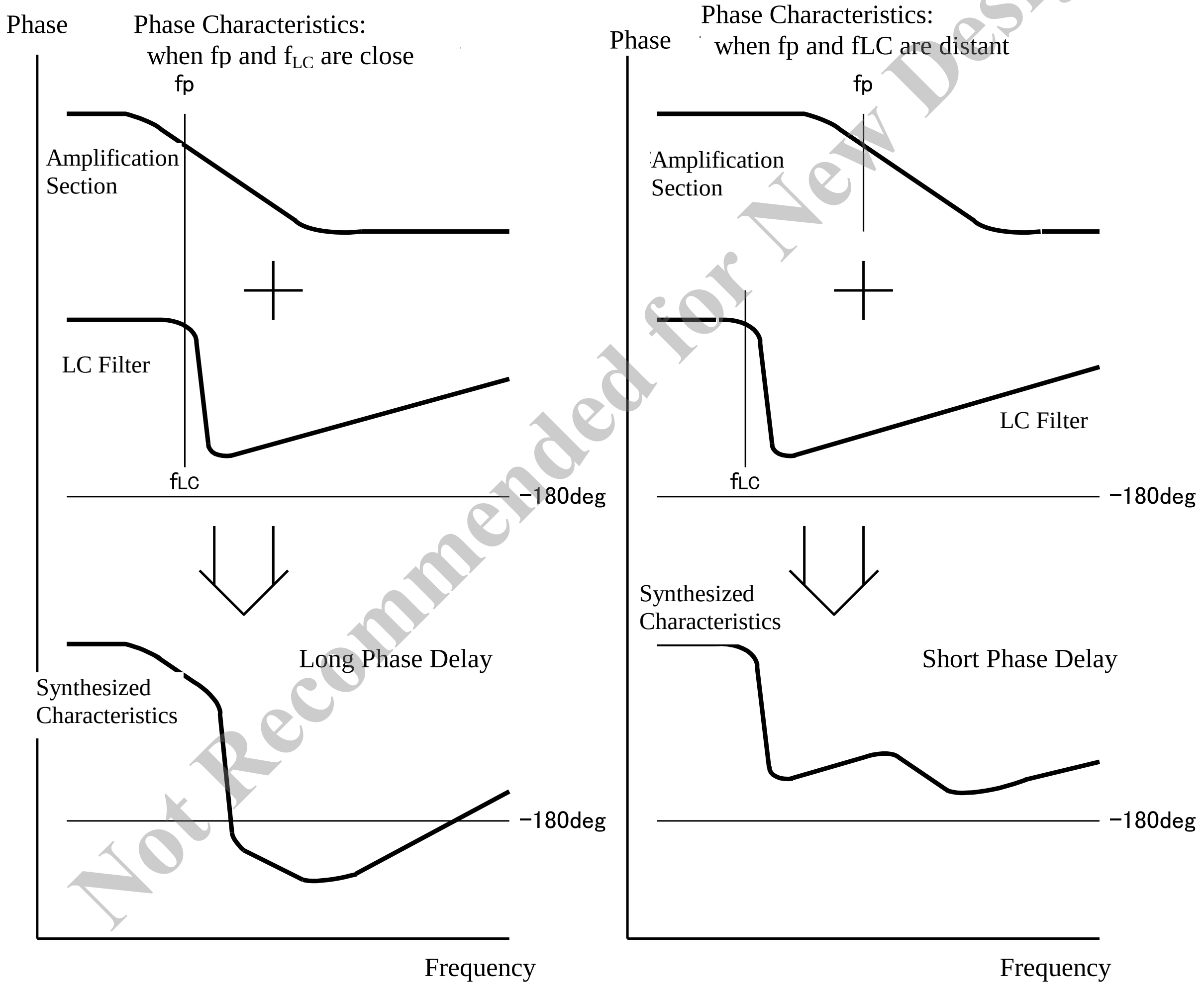
4-4-4 Relation of Phase Characteristics of Internal IC and LC Filter

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.

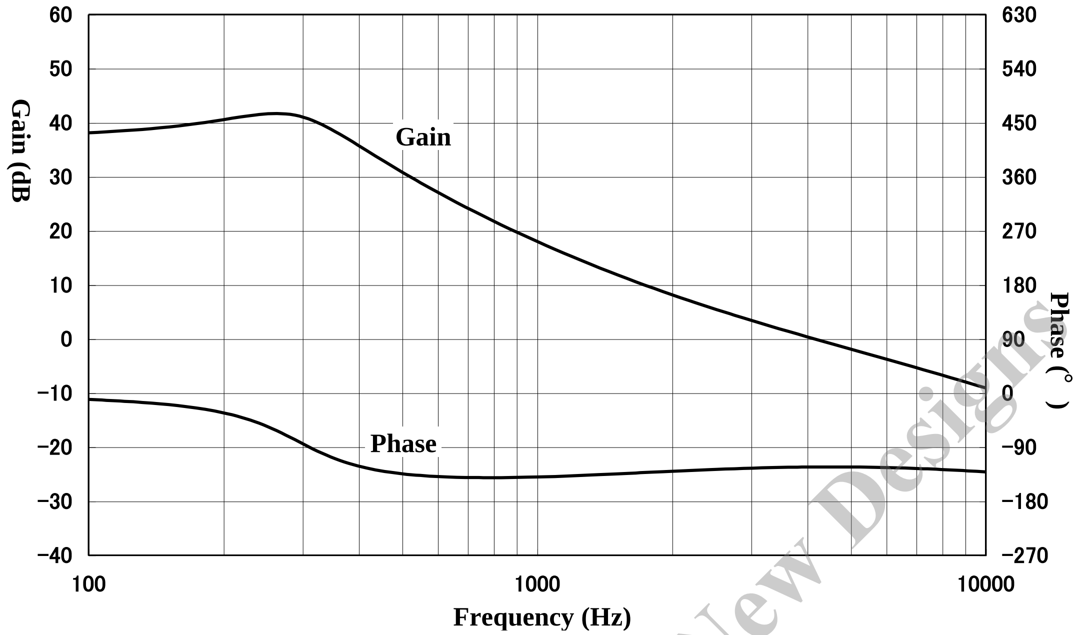


Generally, the frequency fp of the chopper type regulator IC is set from several KHz to higher than ten KHz.

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.

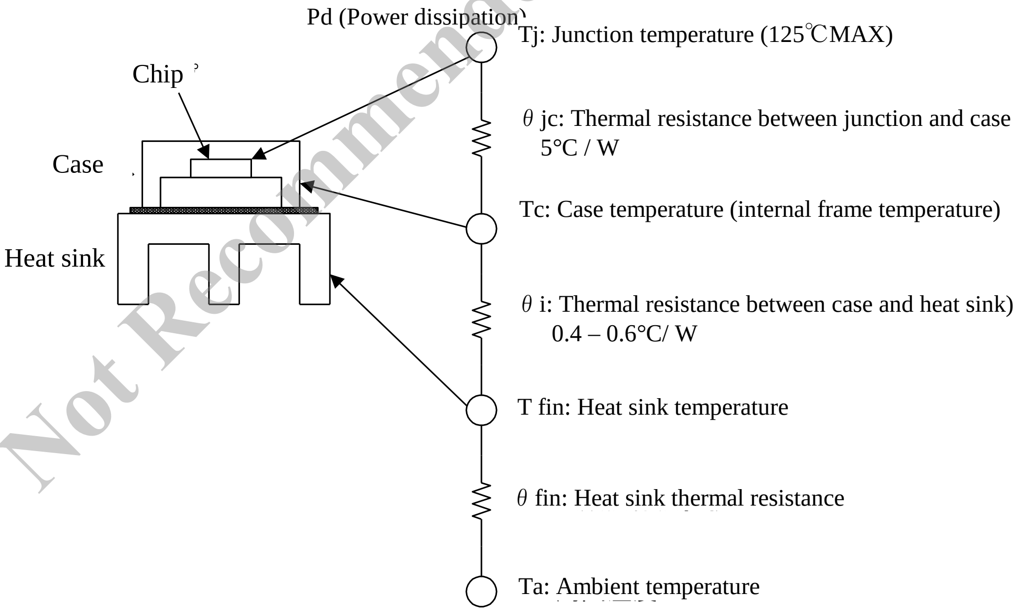
Typical Characteristics of Gain and Phase



● **4-5 Thermal Design**

4-5-1 Calculation of Heat Dissipation

The relation among the power dissipation Pd of regulator, junction temperature Tj, case temperature Tc, heat sink temperature Tfin and ambient temperature Ta is as follows:



$$Pd = \frac{Tj - Tc}{\theta jc} \quad ---(6)$$

$$Pd = \frac{Tj - Tfin}{\theta jc + \theta i} \quad ---(7)$$

$$Pd = \frac{Tj - Ta}{\theta jc + \theta i + \theta fin} \quad ---(8)$$

The TjMAX is an inherent value for each product, therefore it must be strictly observed.
For this purpose, it is required to design the heat sink in compliance with PdMAX, TaMAX (determination of θfin).
The heat derating graphically describes this relation.
The designing of the heat sink is carried out by the following procedure:

1) The maximum ambient temperature Ta MAX in the set is obtained.

2) The maximum power dissipation PdMAX is obtained.

$$Pd = VOUT \cdot Io\left(\frac{100}{\eta x} - 1\right) - Vf \cdot Io\left(1 - \frac{VOUT}{VIN}\right) \qquad ---(9)$$

* ηx= efficiency (%), Vf= diode forward voltage

3) The size of heat sink is determined from the intersection of the heat derating.
The required thermal resistance of the heat sink can be also calculated. The thermal resistance required for the heat sink is obtained by the following equation:

$$\theta i + \theta fin = \frac{Tj - Ta}{Pd} - \theta jc \qquad ---(10)$$

An example of heat calculation for using SI-8050S under the conditions of V_{IN} = 10V, Io = 3A and Ta = 85°C is shown below. Where efficiency η = 77% , Vf = 0.5V from the typical characteristics,

$$Pd = 5 \times 3 \times \left(\frac{100}{77} - 1\right) - 0.5 \times 3 \times \left(1 - \frac{5}{10}\right) \fallingdotseq 3.73W$$

$$\theta i + \theta fin = \frac{125 - 85}{3.73} - 5.5 \fallingdotseq 5.22^{\circ} C / W$$

As a result, the heat sink with the thermal resistance of 5°C /W or less is required. As described above, the heat sink is determined, but the derating of 10 – 20% or more is used. Actually, heat dissipation effect significantly changes depending on the difference in component mounting. Therefore, heat sink temperature or case temperature should be checked with the heat sink mounted.

4-5-2 Installation to Heat sink

Selection of silicon grease

When the SI-8000S, SS is installed to the heat sink, silicon grease should be thinly and evenly coated between the IC and heat sink. Without coating, thermal resistance θi is significantly increased because of contact failure due to micro concavity/convexity between the backside of the IC and the surface of the heat sink to accelerate the heating of the IC, resulting in shorter life of the IC.
In some kind of silicon grease to be used, oil component may be separated to penetrate into the IC, resulting in the deformation of packages or the adverse effect on built-in elements.
Any other silicon grease than one based on the modified silicon oil shall not be used.
The recommended silicon greases are as follows:

Sanken's recommended silicon greases:

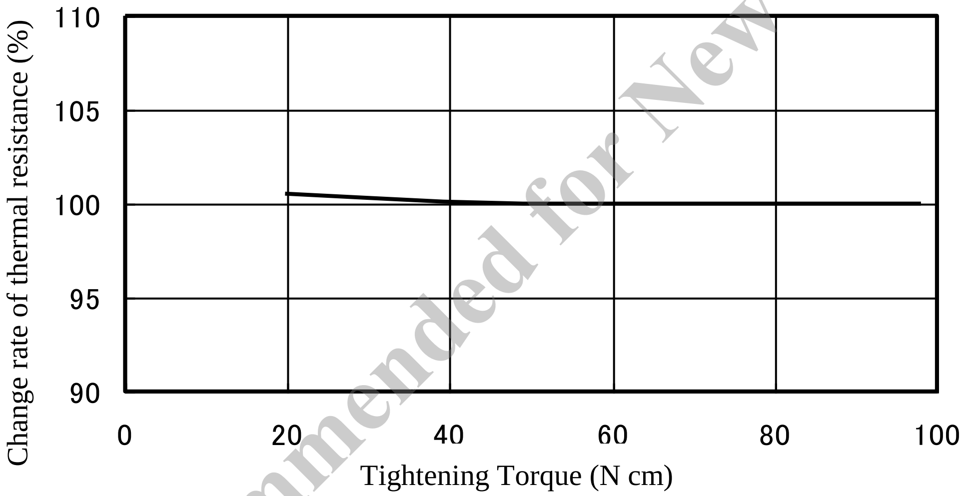
Types	Suppliers
G746	Shin-Etsu Chemical Co., Ltd.
SC102	Toray Silicone Co., Ltd.
YG6260	Momentive Performance Materials Inc.

Tightening torque of fixing screws

In order to keep the thermal resistance between the IC and the heat sink at low level without damaging the IC package, it is necessary to control the torque of fixing screws in a proper way.

Even if silicon grease is coated, the thermal resistance θi increases if the tightening torque is not enough.

For the SI-8000S, SS, 58.8 – 68.6N cm (6.0 – 7.0 kg cm) are recommended.



* 1. The change rate of thermal resistance in the case that 58.8N cm (6kg cm) is expressed as 100% is shown above.

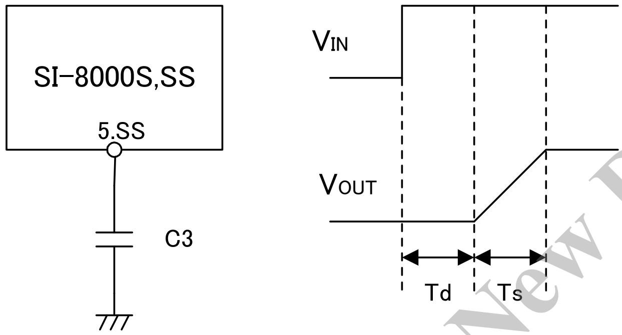
* 2. The silicon grease G746 shall be used.

5. Applications

5-1 Soft Start

When a capacitor is connected to terminal 5, the soft start is activated when the input voltage is applied. The capacitor C3 controls the OFF period of PWM control to control the start -up time, and the delay time Td and the start-up time Ts are obtained by the following equation.

It should be, however, noted that in the actual equipment, slight fluctuation may happen due to the effects from input power supplies, load start-up etc. The terminal 5 should be open, when the soft start is not used.



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

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

For example, when V_{IN} = 20V, Vo = 5V and C3 = 1μF, Td and Ts are obtained as follows:

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

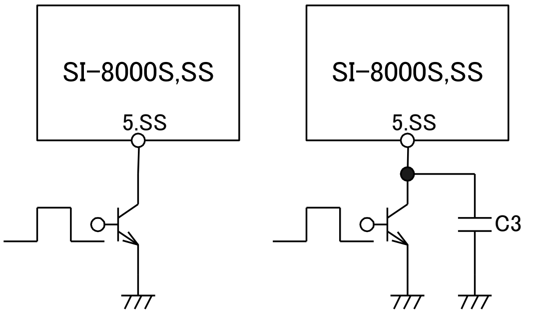
$$Td + Ts \fallingdotseq 47(ms)$$

As shown above, it takes 47 ms from power-on to output voltage start-up. However, when C3 is made larger, it takes longer time for discharging the C3 after VinOFF. It is recommended to use C3 at the value of 10μF or less. Under the load condition of discontinuous mode (light load), Ts may be shorter than the above-calculated value.

5-2 Output ON / OFF Control

The output ON-Off control is possible using the soft start (No.5) terminal. The output is turned OFF when the terminal 5 voltage falls to low by such as open collector. It is possible to use the soft start together.

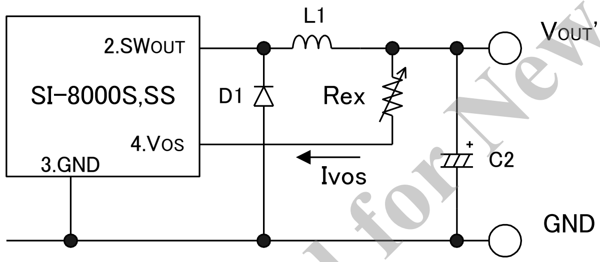
Since the soft start terminal has been already pulled up, no voltage shall be applied from the external side.



● <u>5-3 Controllable Output Voltage</u>

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 calculated by the following equation.

$$Rex = \frac{Vout' - Vos}{Ivos} \quad ---(13)$$

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)

$$VOUT\ MAX = VosMAX + RexMAX \times IvosMAX \quad ---(14)$$

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

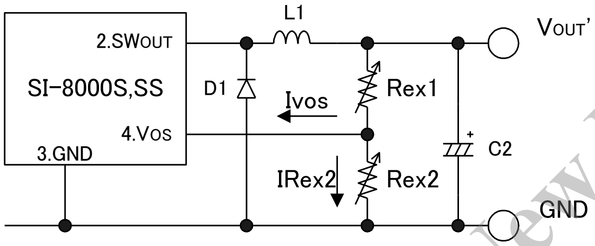
$$Vout'\,MIN = VosMIN + RexMIN \times IvosMIN \quad ---(15)$$

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

RexMAX: 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 is S, the more is the variation of temperature characteristic and output voltage 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 of the specifications in page 6.

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

Rex2 MIN: 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)

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

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 of the specifications in page 6.

Rex1 MIN: 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.

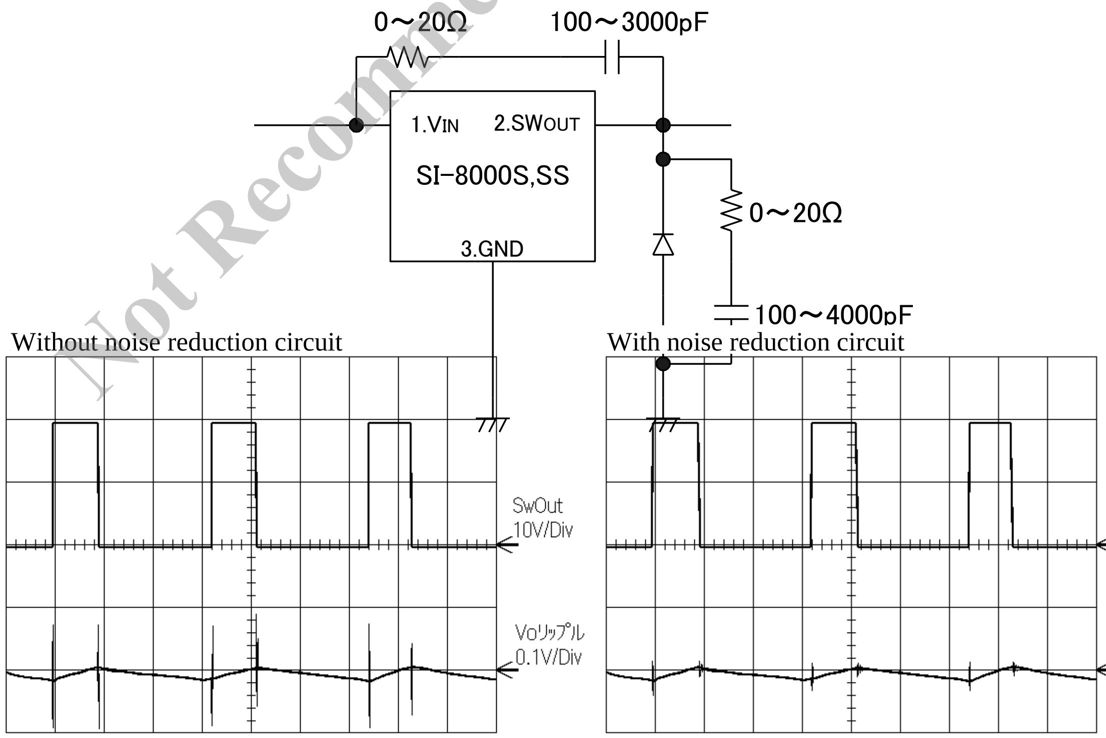
If it is varied drastically, the increase of coil capacitance value may be required since the overcurrent protection current is assumed to be lowered due to the increase in coil current.

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-8000S, SS and the recovery time of the diode by a capacitor, but it should be noted that the efficiency is also slightly reduced.

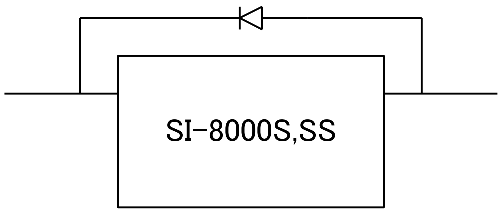


A resistor of 10Ω and a capacitor of 2200pF
are connected to external resistor

* 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 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.



● 5-6 Buck-boost converter

5-6-1 Choke coil L1, diode D1 current rating

Since the circuitry of the buck-boost converter is different from that of the buck converter, current flowing across the choke coil L1 and the diode D1 is large. The peak current can be calculated by the equation 20. As seen in this equation, the lower is the input voltage, the larger is the peak current, therefore the choke coil and diode which can meet the peak current at the lowest input voltage should be selected.

$$Ip \approx \frac{Io\max(Vin\min + |Vo|)}{Vin\min} + \frac{Vin\min|Vo|}{Vin\min + |Vo|} \times \frac{1}{2L1fosc} \quad ---(20)$$

fosc: 60kHz, L1: Choke coil inductance, It should be calculated by the equation 24.

5-6-2 Ripple current of input/output capacitor C1 and C2

In comparison with the buck converter, large ripple current flows across the output capacitor C2, therefore care should be taken of the allowable ripple current. The ripple current (Colrms) of the output capacitor can be calculated by the equation 22.

Since the ripple current is large in the buck-boost converter in comparison with the boost converter, it is recommended to use products with low ESR.

The ripple current (CinIrms) of the input capacitor is obtained by the equation 21.

$$CinIrms = \sqrt{\frac{|Vo|}{|Vo| + Vin}\left\{\frac{1}{3}\left(Ip^2 + IpIv + Iv^2\right) - \frac{|Vo|}{4Vin|Vo|}\left(Ip + Iv\right)^2\right\}} \quad ---(21)$$

$$CoIrms = \sqrt{\frac{Vin}{|Vo| + Vin}\left\{\frac{1}{3}\left(Ip^2 + IpIv + Iv^2\right) - \frac{Vin}{4Vin|Vo|}\left(Ip + Iv\right)^2\right\}} \quad ---(22)$$

$$Iv = \frac{Iload\left(Vin + |Vo|\right)}{Vin} - \frac{Vin|Vo|}{Vin + |Vo|} \times \frac{1}{2L1fosc} \quad ---(23)$$

Ip: Maximum value of peak current, Iv: Minimum value of peak current, Iload: Continuous current

5-6-3 Choke coil L1 capacitance

Since the circuitry of the buck-boost converter is different from that of the buck converter, the choke coil capacitance is unable to be calculated by the same design procedure as that of the buck converter.

In the case of the buck converter, as the energy stored in the coil becomes the output power, the inductance L1 of the choke coil can be calculated by the equations 24 and 25.

$$L1 = \frac{Vin^2 \times ton^2 \times fosc}{2 \times |Vo| \times Io\max} \quad ---(24)$$

$$ton = \frac{|Vo|}{(|Vo| + Vin\min) \times fosc} \quad ---(25)$$

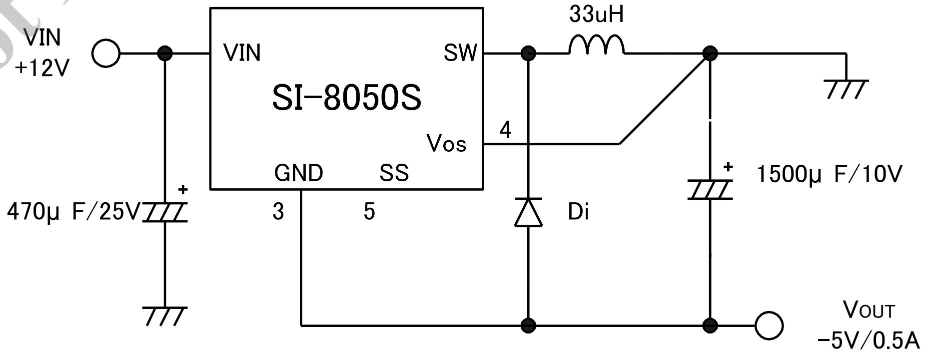
5-6-4 Input voltage and output current ranges

Input voltage, output current and peak current ranges in the case that the SI-8000S and SS series are used as a buck-boost converter are shown below, but the actual operational values should be evaluated sufficiently.

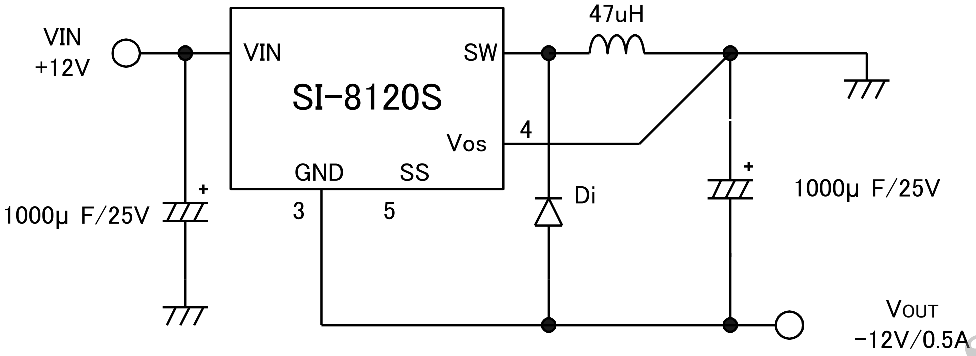
- Input voltage: The sum of input voltage and output voltage is applied between the emitter and collector of the switching transistor; therefore the maximum input voltage is 40V - Vo. As the peak current increases rapidly, the input voltage range is 10 - 40Vo (V).
- Output current: The maximum output current is around 0.8A subject to the inductance of the choke coil.
- Peak current: In the case that the peak current is large, as the overcurrent protection is likely to be operated, the peak current should be 3A or lower. Although the peak current can be calculated by the equation 20, it should be checked in the actual operation.

5-6-5 Circuit Example

-5V/0.5A

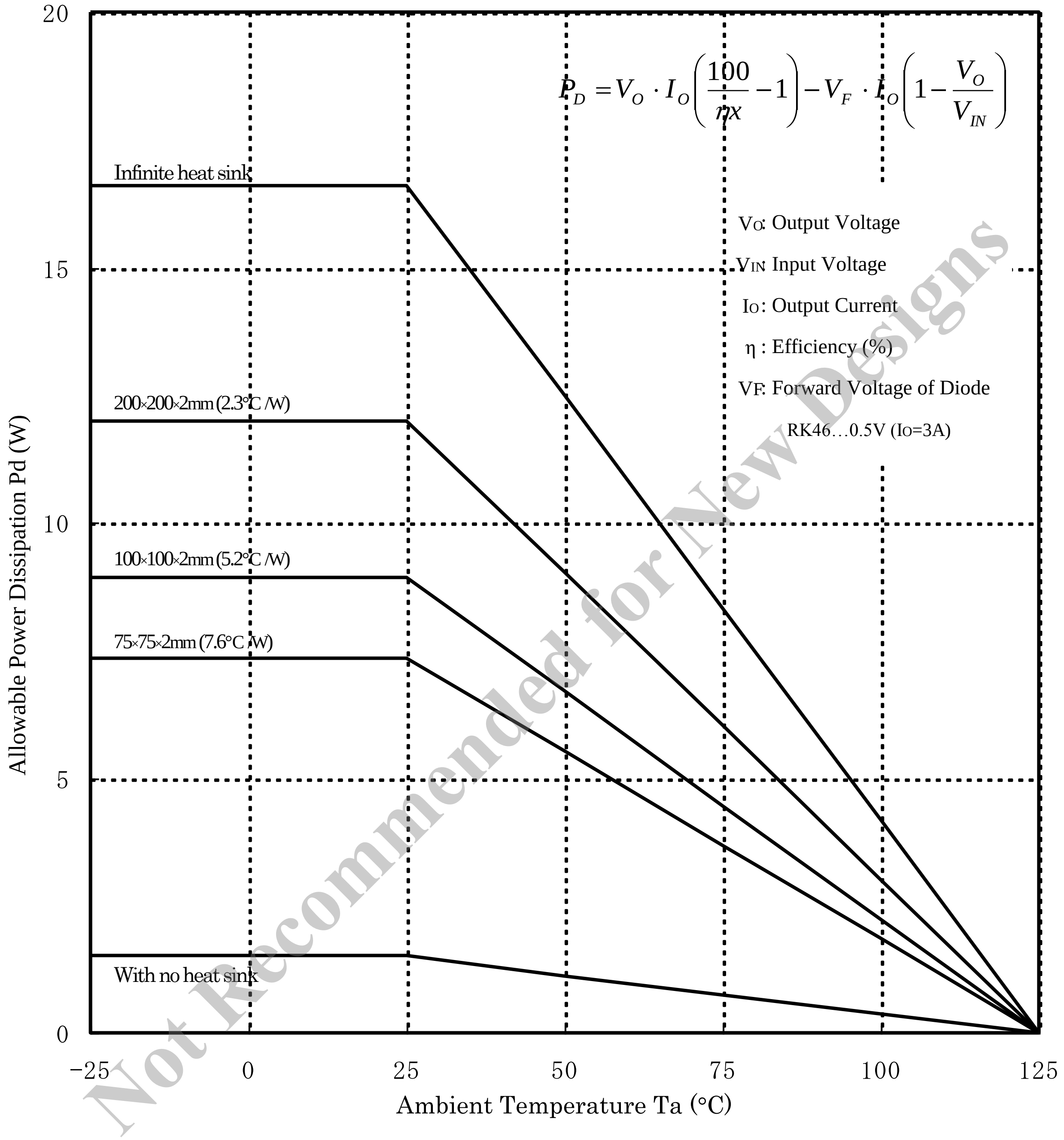


-12V/0.5A



* Care should be taken for GND of the output side.

6. Heat Derating



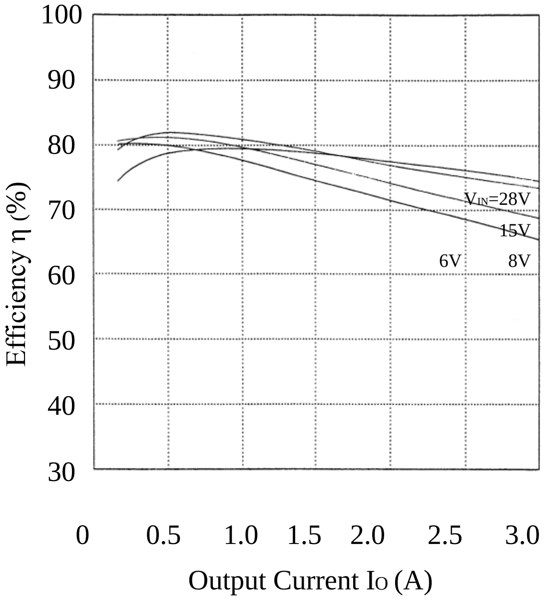
Note1. Since the efficiency is subject to change depending on the input voltage and output current,it should be obtained from the efficiency curve of Fig. 4-2, and be substituted in percent.

Note2. The thermal design of Di should be made separately.

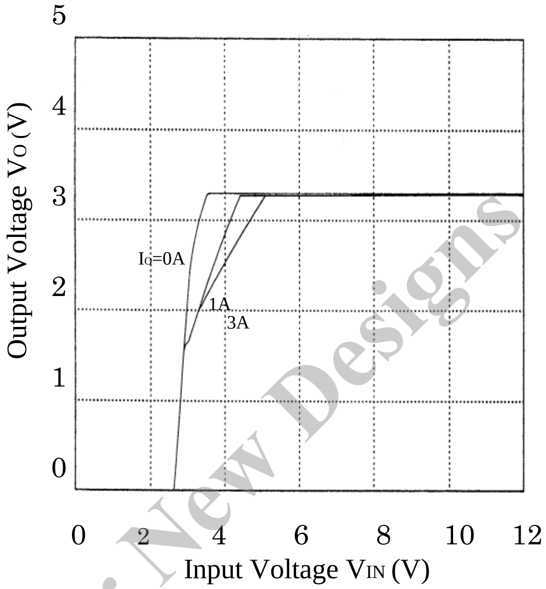
7. Typical Characteristics

- SI-8033S, SS

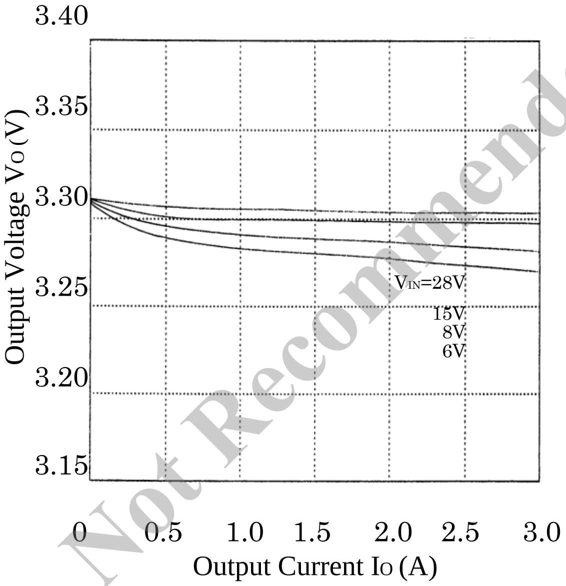
(1) Efficiency



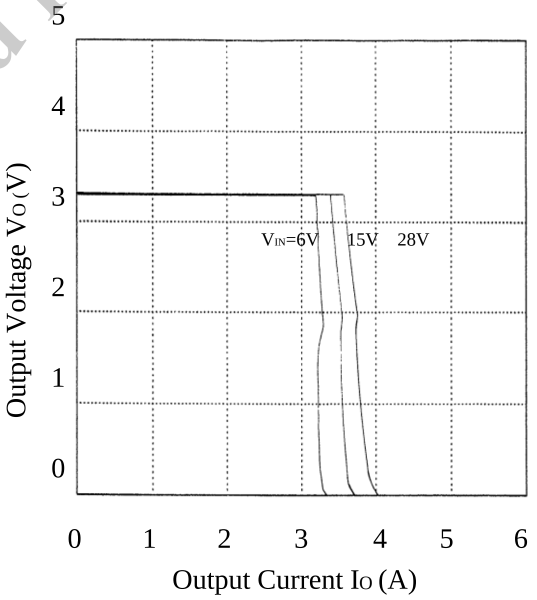
(2) Output Voltage Rising *Load=C.C



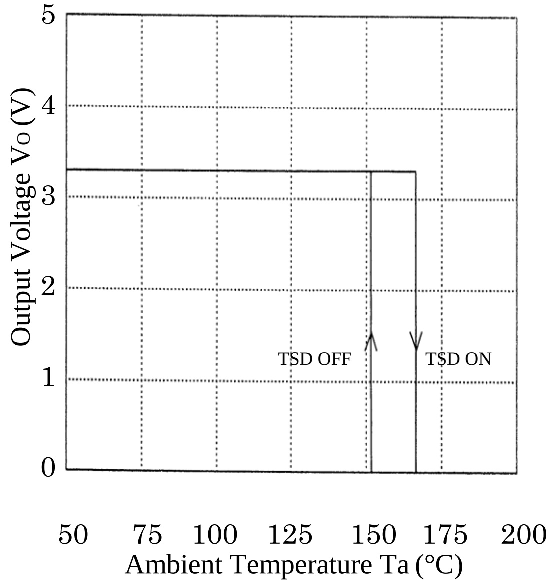
(3) Output Voltage Variation



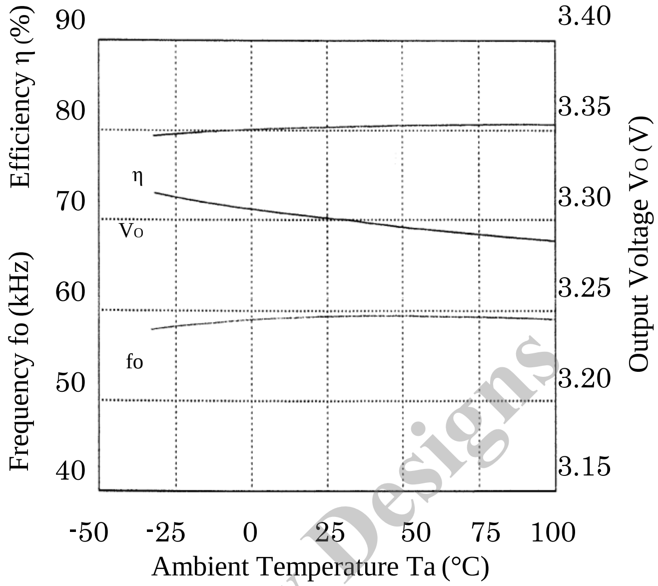
(4) Overcurrent Protection Characteristics



(5) Thermal Shutdown V_{IN}=15V, I_O=0A

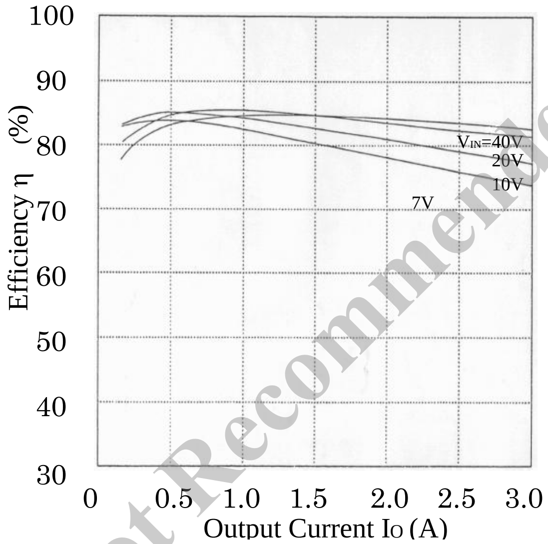


(6) Temperature Characteristics V_{IN}=15V, I_O=1A

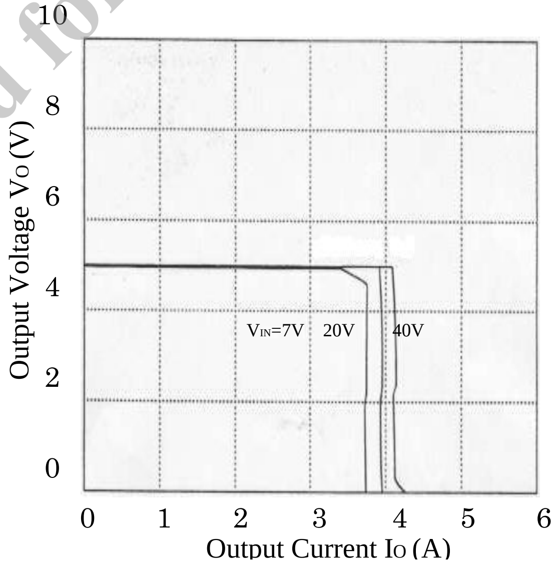


- SI-8050S, SS

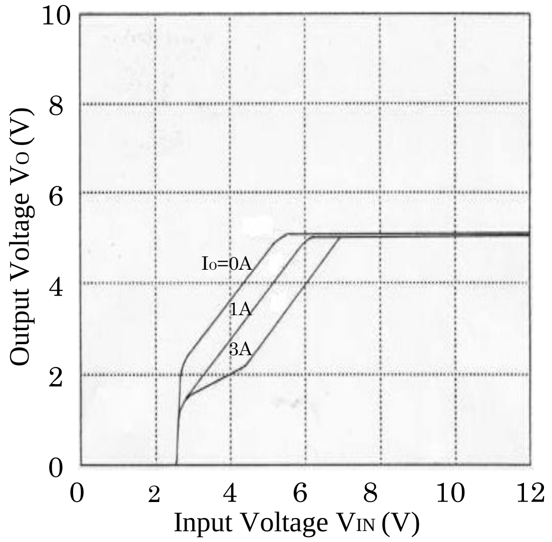
(1) Efficiency



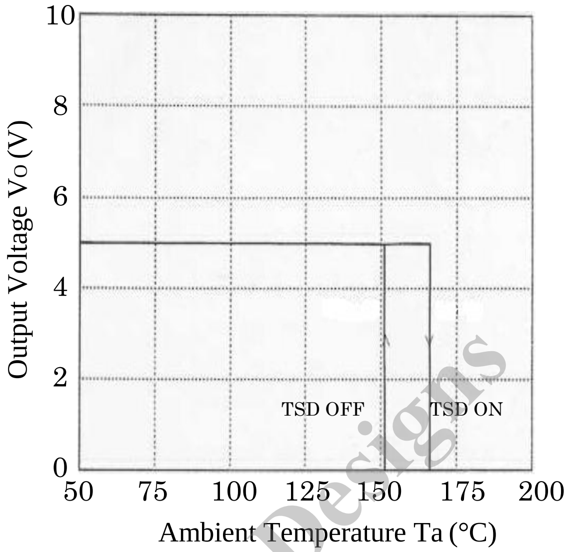
(2) Output Voltage Rising * Load=C.C



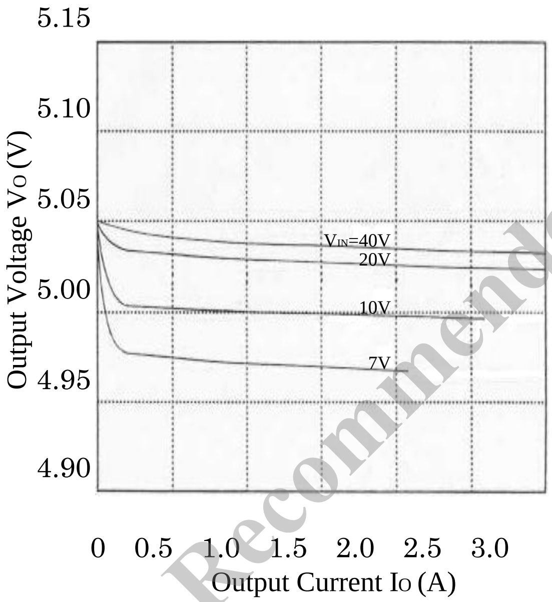
(3) Output Voltage Variation



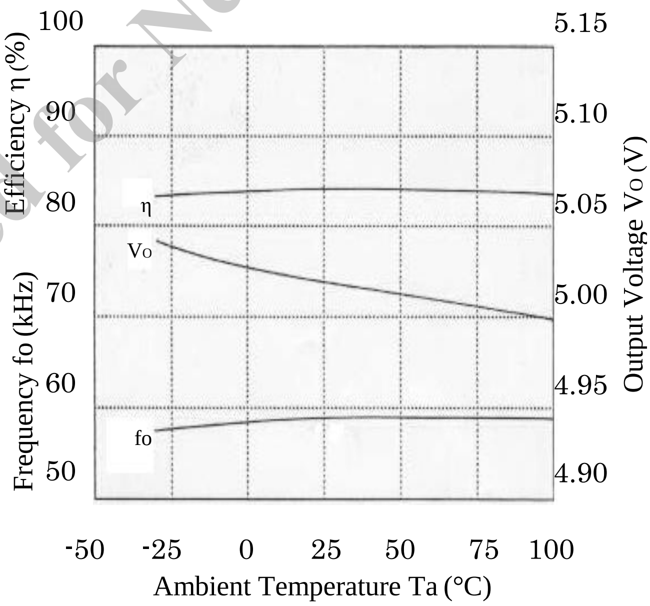
(4) Overcurrent Protection Characteristics



(5) Thermal Shutdown VIN=20V, IO=0A

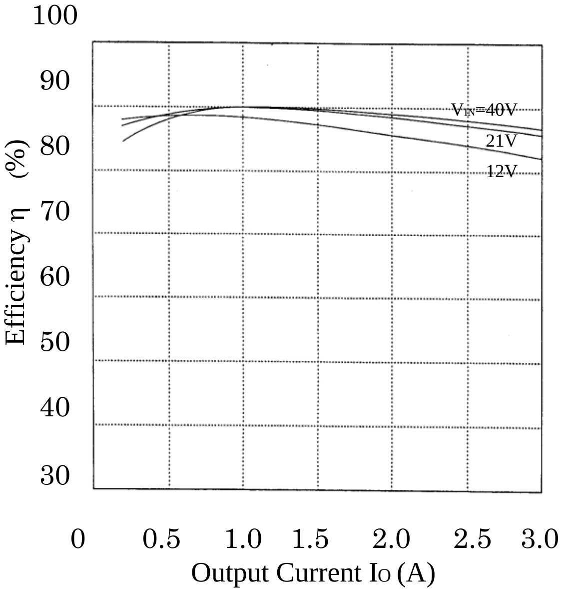


(6) Temperature Characteristics VIN=20V, IO=1A

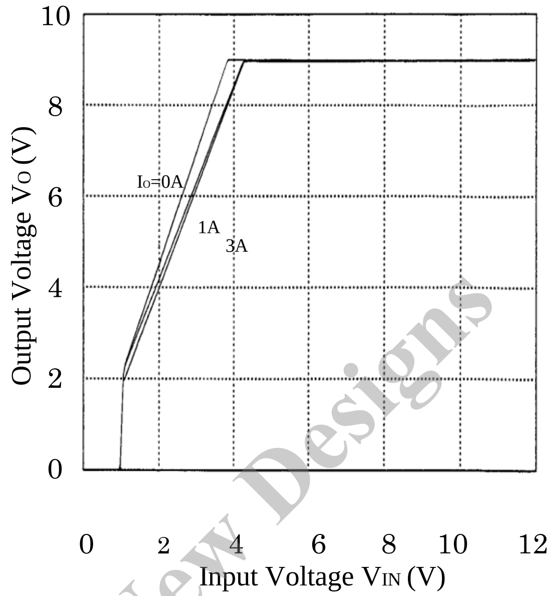


- SI-8090S, SS

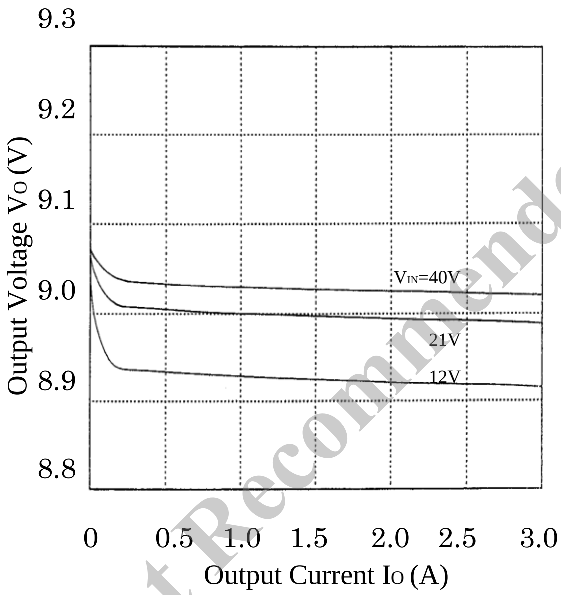
(1) Efficiency



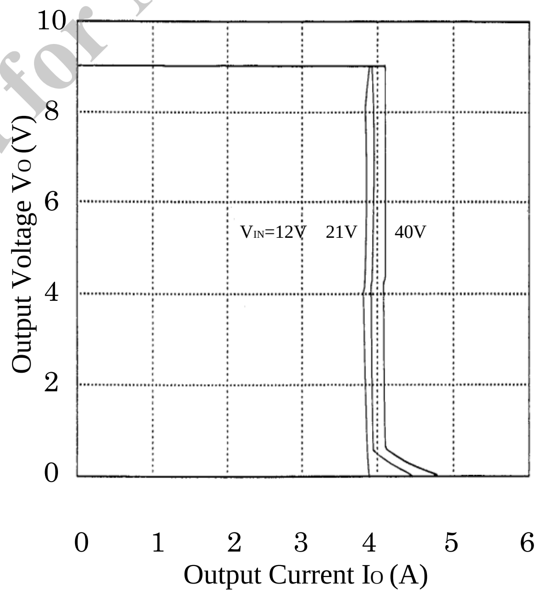
(2) Output Voltage Rising *Load=C.C



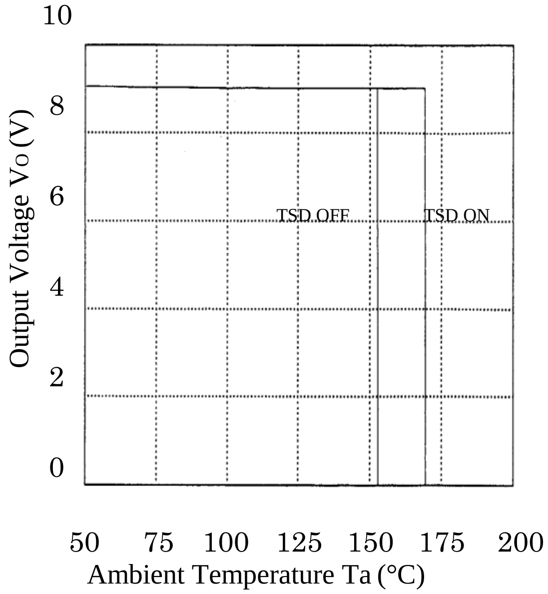
(3) Output Voltage Variation



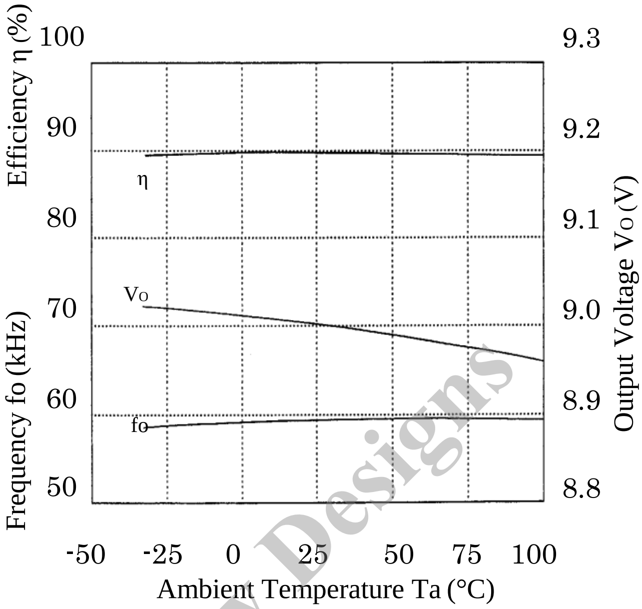
(4) Overcurrent Protection Characteristics



(5) Thermal Shutdown V_{IN}=21V, I_O=0A

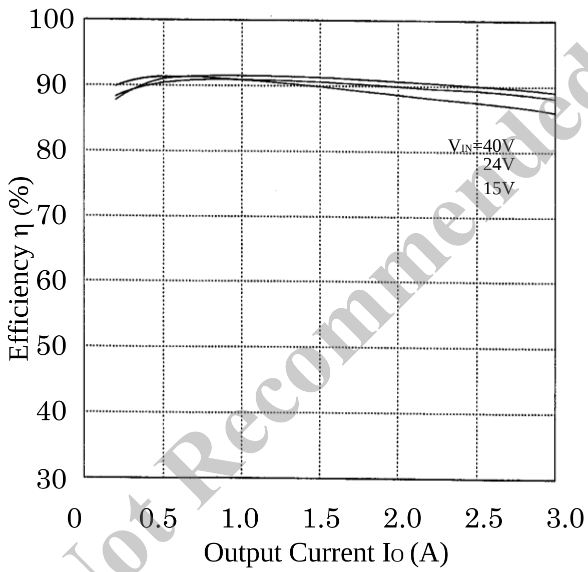


(6) Temperature Characteristics V_{IN}=21V, I_O=1A

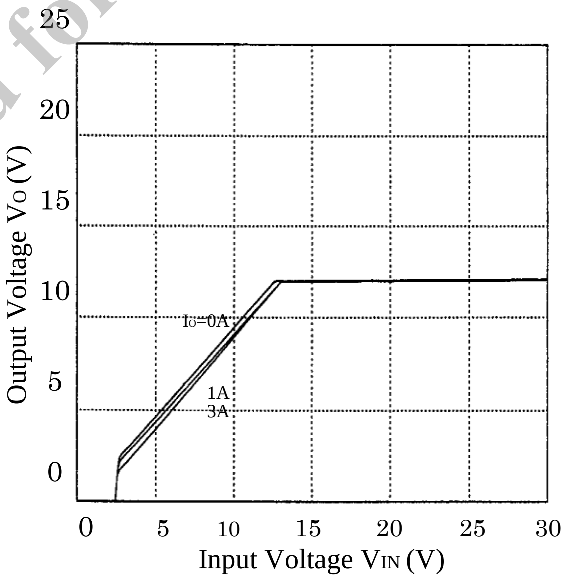


- SI-8120S

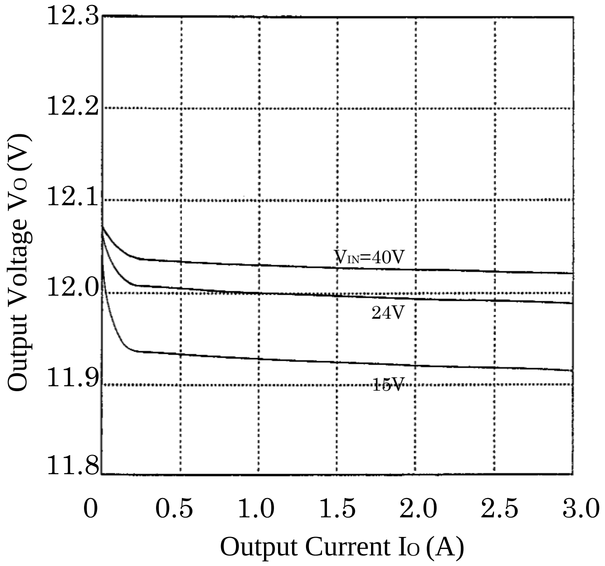
(1) Efficiency



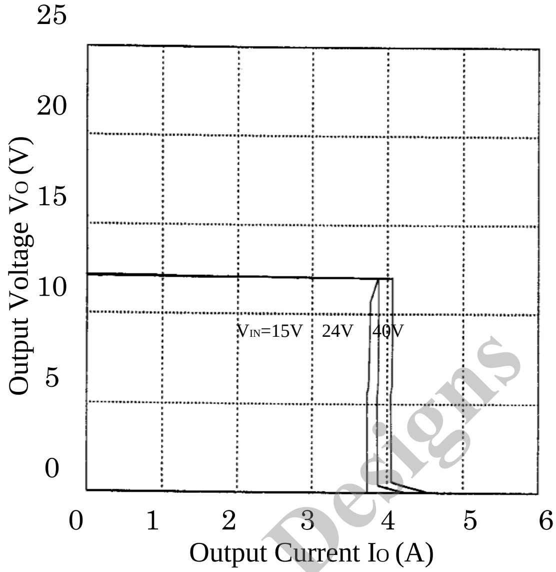
(2) Output Voltage Rising * Load=C.C



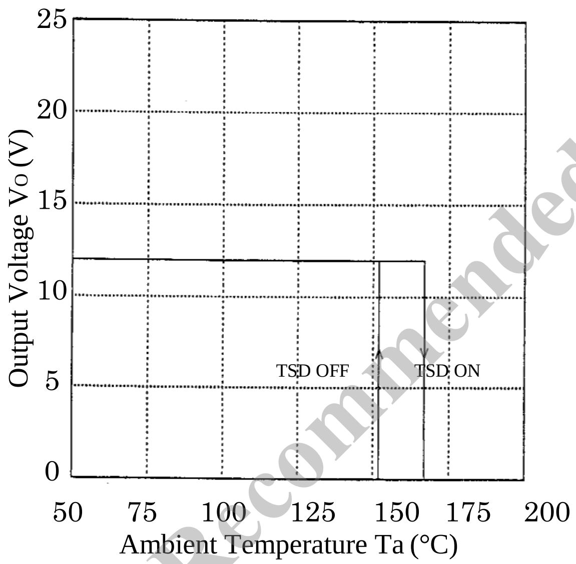
(3) Output Voltage Variation



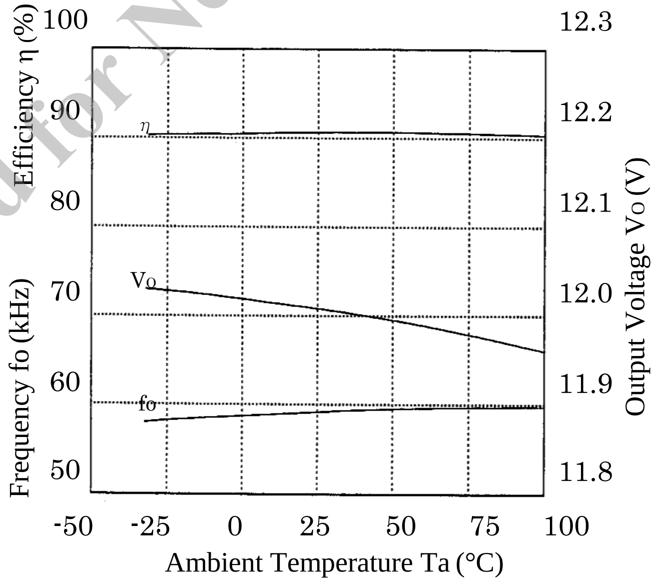
(4) Overcurrent Protection Characteristics



(5) Thermal Shutdown VIN=24V, IO=0A

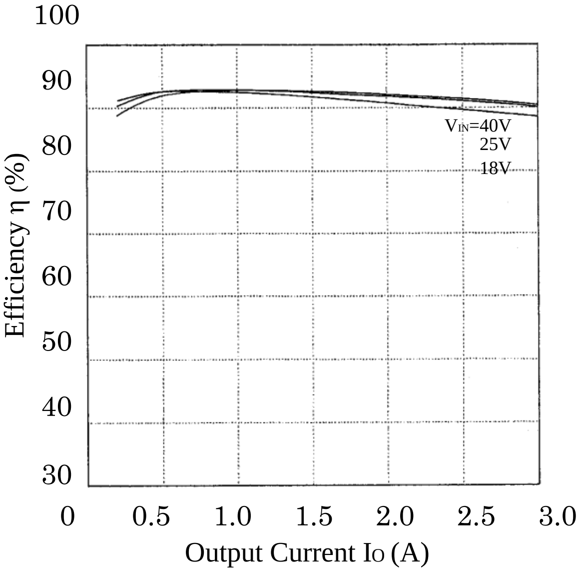


(6) Temperature Characteristics VIN=24V, IO=1A

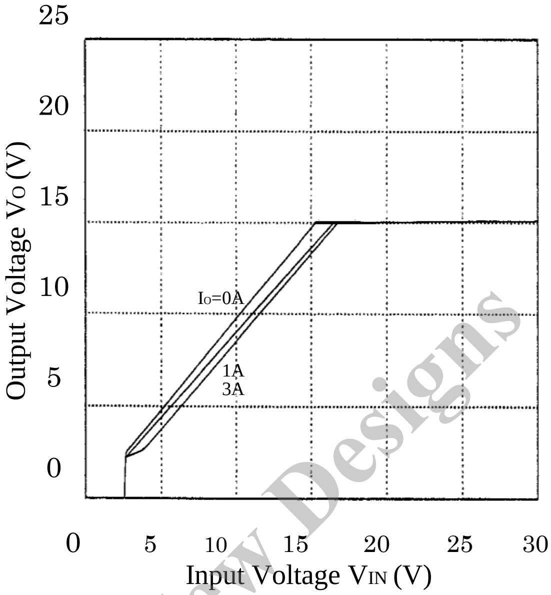


- SI-8150S

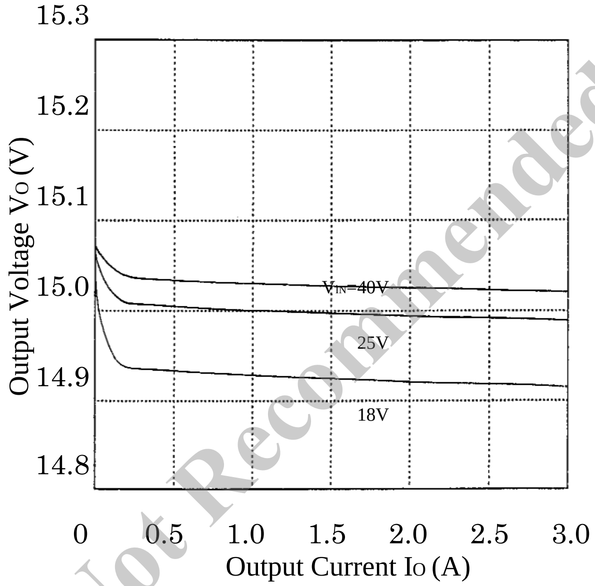
(1) Efficiency



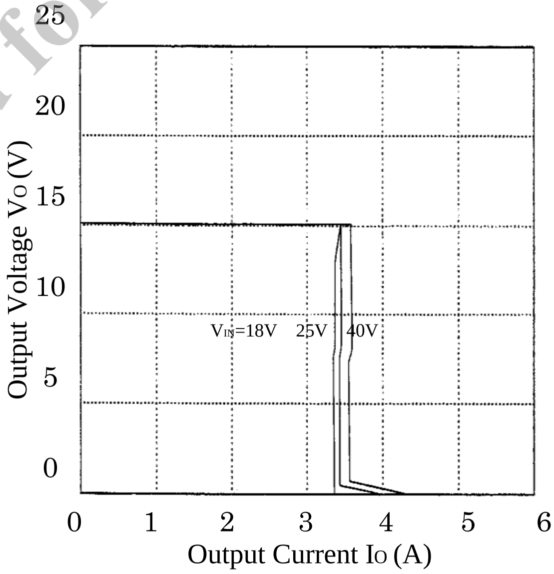
(2) Output Voltage Rising * Load=C.C



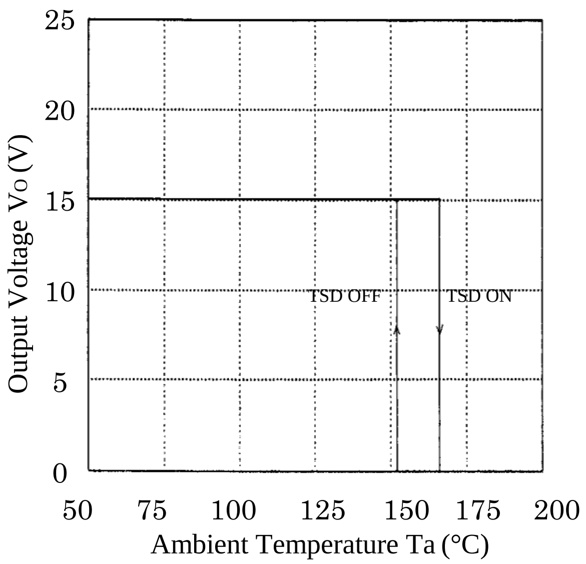
(3) Output Voltage Variation



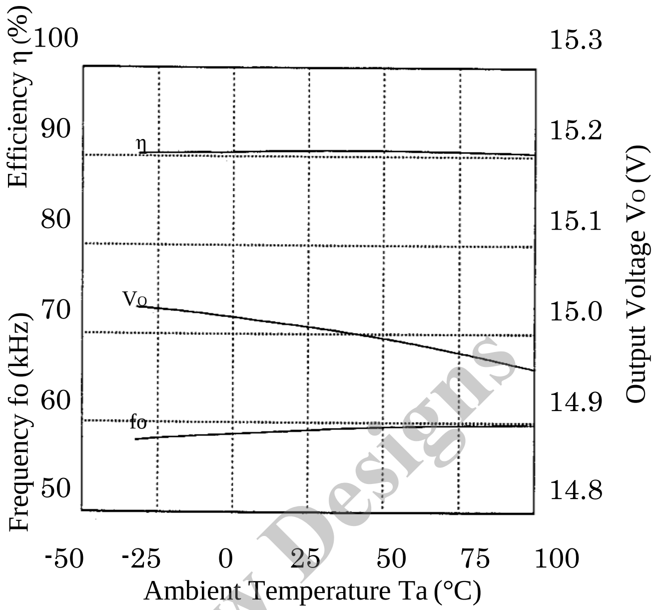
(4) Overcurrent Protection Characteristics



(5) Thermal Shutdown V_{IN}=25V, I_O=0A



(6) Temperature Characteristics V_{IN}=25V, I_O=1A



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 / 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 specified value for a moment during instantaneous or normal operation.

- Electrical Characteristics

  It is the specified characteristic values 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.

・The contents of this brochure shall not be transcribed nor copied without our written consent.