Application Note

Chopper Type Switching Regulator IC

SI-8050HFE

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SANKEN ELECTRIC CO., LTD.

――― Contents ―――

1. General Description

The SI-8050HFE is a chopper type switching regulator IC which is provided with various functions required for the buck switching regulator and protection functions. The output is fixed at Vo = 5V, but the voltage may be variable only for rising-up by adding two external resistors.
By using five external components, a highly efficient switching regulator can be composed.

● 1-1 Features

- Compact size and large output current of 5.5 A
  The maximum output current of 5.5 A for the outline of TO220F class
- High efficiency of 83% (VIN = 15V/IO = 3A)
  Heat dissipation is small due to high efficiency to allow for the downsizing of a heat sink.
- Five 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 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)

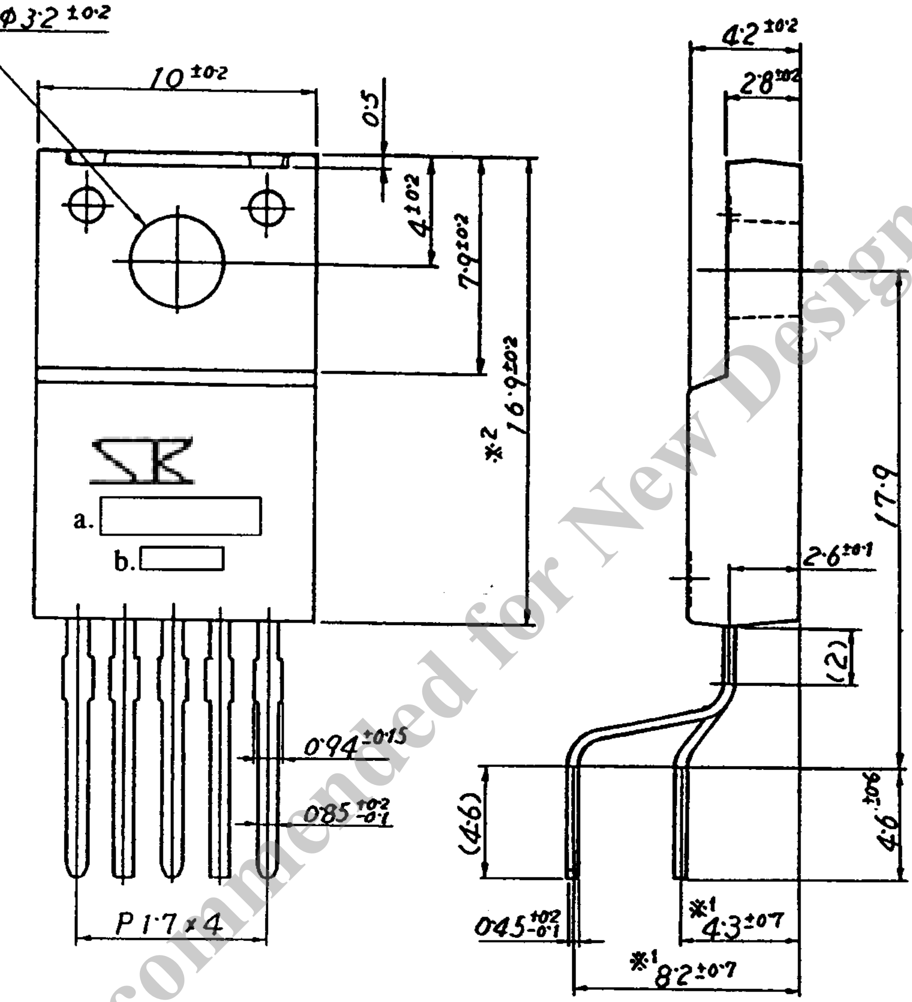
2. Specification

● **2-1 Package Information**

Unit: mm

Outline drawing of lead forming No.1113

Dimensions in mm



Pin Assignment

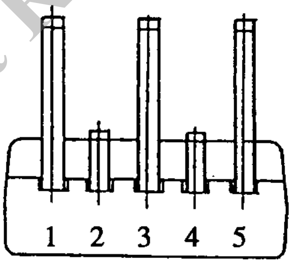
1: IN

2: SW

3: GND

4: Vos

5: SS



a. Type Number

b. Lot Number

1st letter: Last digit of year

2nd letter: Month

January to September by Arabic number

October by O

November by N

December by D

3rd and 4th letter: Day

01-31 by Arabic number

External Terminal Processing: Sn-3Ag-0.5Cu dip

The dimensions don’t include the gate burr.

____ shows the dimensions measured at the top of lead.

2-2 Ratings

2-2-1 Absolute Maximum Ratings

Parameter	Symbol	Rating	Unit
Input Voltage	V_{IN}	43 *1	V
Allowable Power Dissipation in Infinite Radiation	Pd1	25	W
Allowable Power Dissipation without Heat sink	Pd2	1.72	W
Junction Temperature	Tjmax	150 *1	°C
Storage Temperature	Tstg	-40 - +150	°C

*1. Since the thermal shutdown is provided, it may be operated at Tj > 130°C. The design for operation below 125°C is recommended.

2-2-2 Recommended Conditions

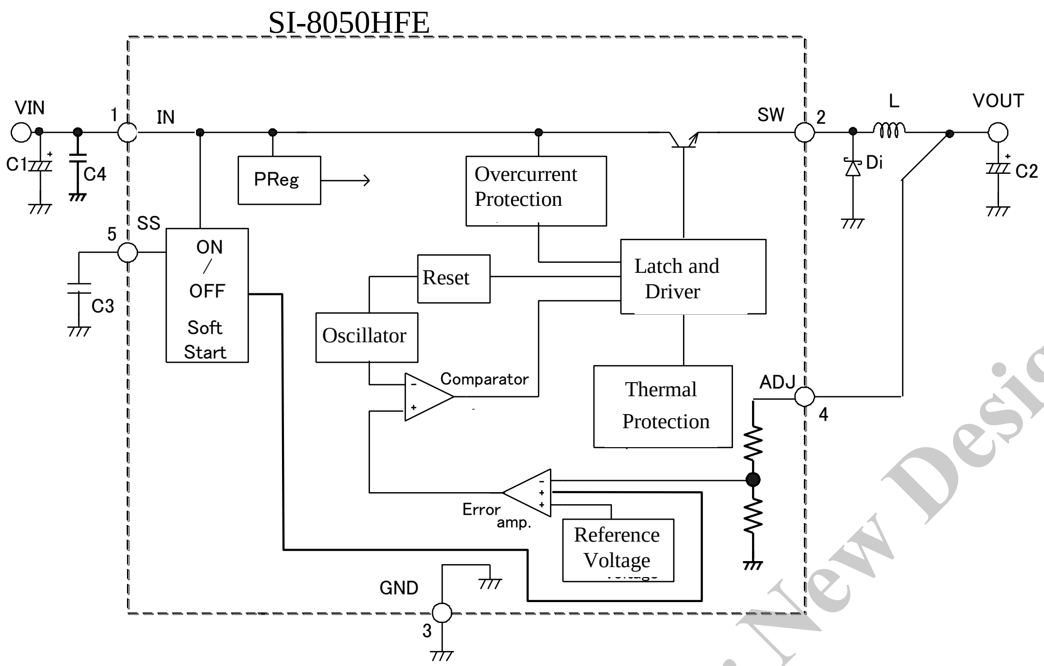
Parameter	Symbol	Ratings	Unit
DC Input Voltage	VIN	8 - 40	
Output Current	I_O	0 - 5.5	A
Junction Temperature in Operation	Tjop	-30 - ＋125	°C

2-2-3 Electrical Characteristics (Ta=25°C)

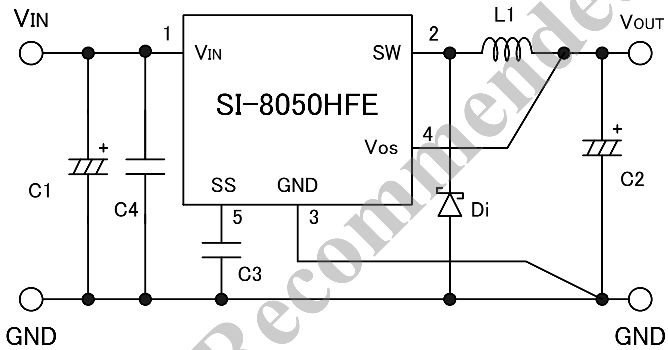
Parameter		Symbol	Ratings			Unit	Test Condition
			MIN	TYP	MAX		
Setting Reference Voltage		V_{OUT}	4.90	5.00	5.10	V	V_{IN}=15V, I_O=1A
Output Voltage Temperature Coefficient		$\Delta V_O/\Delta T$		±0.5		mV/°C	V_{IN}=15V , I_O=1A,Tc=0~100℃
Efficiency *3		η		83		%	V_{IN}=15V,I_O=3A
Operation Frequency		fo		150		kHz	V_{IN}=15V, I_O=3A
Line Regulation		VLine		60	80	mV	V_{IN}=10 - 30V, I_O=3A
Load Regulation		VLoad		20	50	mV	V_{IN}=15V, I_O=0.2 - 5.5A
Overcurrent Protection Start Current		I_S	5.6	6.5	7.5	A	V_{IN}=15V
On/ Off Terminal *4	Low Level Voltage	V_{SSL}			0.5	V	
	Flow-out Current at Low Level Voltage	I_{SSL}		10	30	μA	V_{IN}=15V, V_{SS}=0V
Circuit Current in Non-operation 1		Iq		6		mA	V_{IN}=15V, I_O=0A
Circuit Current in Non-operation 2		Iq(off)		200	400	μA	V_{IN}=15V V_{SS}=0V

● 2-3 Circuit Diagram

2-3-1 Internal Equivalent Circuit



2-3-2 Typical Connection Diagram



C1: 1500µF

C2: 1000µF

C3: around 0.1µF

(only in use of soft start function)

L1: 100µH

Di: FMB-G16L (Sanken products)

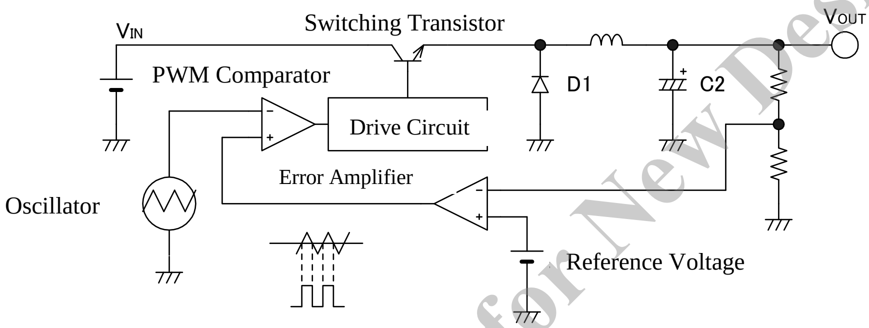
3. Operational Description

● 3-1 PWM Output Voltage Control

The SI-8050HF controls the output voltage by the PWM system and comprises PWM comparator, oscillator, error amplifier, reference voltage, output transistor drive circuit etc. For the input of the PWM comparator, the triangular wave output (≈150KHz) from the oscillator and the output of the error amplifier are given.

The PWM comparator compares the oscillator output with the error amplifier output to control to turn on the switching transistor at the time when the error amplifier exceeds the error amplifier output.

PWM Control Chopper Type Regulator Basic Configuration



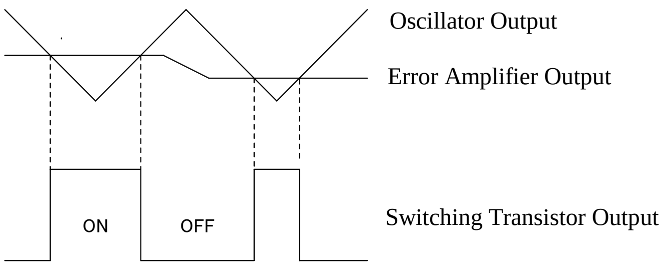
The error amplifier output and oscillator output are compared by the PWM comparator to generate the rectangular wave signal and this signal is inputted into the drive circuit to drive the switching transistor.

On the assumption that the output voltage commences to rise, the output of the error amplifier will drop, because the error amplifier is of inverting type.

As the output of the error amplifier 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 is Vin, the larger is the ON time of the switching transistor.)

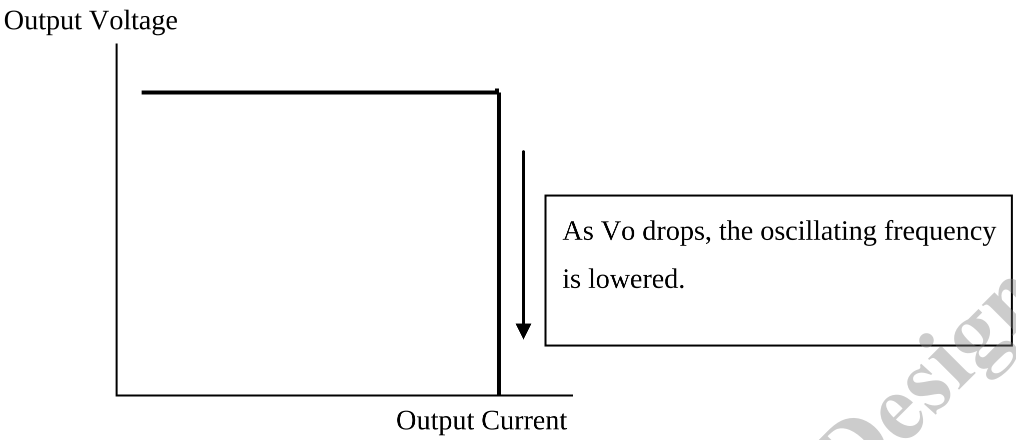
PWM Comparator Operation Diagram



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

● 3-2 Overcurrent Protection / Thermal Shutdown

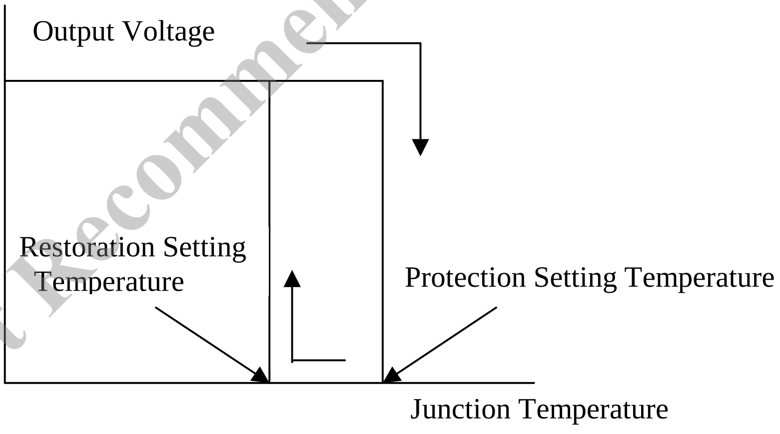
Output Voltage Characteristics in Overcurrent



The SI-8050HFE 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.

In addition, when the output voltage is lowered, the increase of current at low output voltage is prevented by dropping linearly the switching frequency to about 30 KHz. 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 (around 150°C), 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.

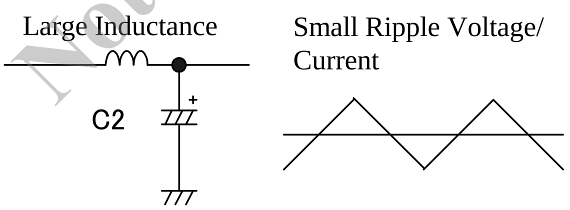
On the other hand, if the inductance is small, the peak current flowing across the switching transistor and diode is increased to make the ripple voltage higher and this operation state is not favorable for maintaining the stable operation.

When the ripple voltage of the output voltage becomes too high, the operation is likely to be unstable and waveform skipping or jitter may be generated.

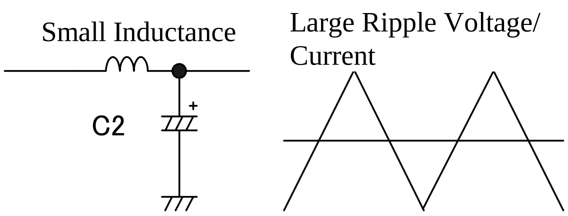
It is recommended that the ripple voltage of the output voltage should be 1% or less of the set output voltage.

The ripple voltage of the output voltage is determined as the product of ΔIL and ESR (equivalent series resistance) of the output capacitor, therefore when the ESR is too large, a problem may happen. The ESR should also be taken into account as well as the selection of the output capacitor.

Vout ripple = ΔIL x ESR of output capacitor



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 obtained by the equation (1).

However, it should be noted that the ripple value should also be adjusted to be appropriate.

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

- In the case that the output current to be used is nearly equal to the maximum rating (5.5A) of the SI-8050H: output current × 0. 1 or so
- In the case that the output current to be used is approximately 3A 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 = 150 KHz,

$$L1 = \frac{(25-5)\times 5}{0.5\times 25\times 150\times 10^3} \fallingdotseq 53.3uH$$

As shown above, the coil of about 54μH 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 CapacitorC1, C4

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.

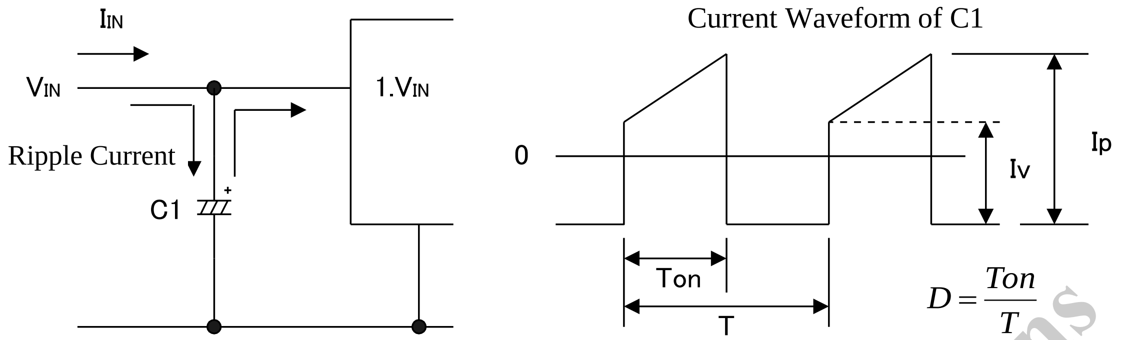
Even in the case that the rectifying capacitor of the AC rectifier circuit is located in the input circuit, the input capacitor cannot play a role of the rectifying capacitor unless it is placed near the SI-8050HF.

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



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 V_{IN} = 20V, Io = 3A and 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.

In addition to the electrolytic capacitor C1, either a ceramic capacitor with the high frequency characteristic or a film capacitor C4 is required.

For the film capacitor, 0.47μF is recommended, while 4.7μF is recommended for the ceramic capacitor in which the capacitance is likely to be lowered due to applied voltage.

It is important to lay out C4 nearer to the IC than C1.

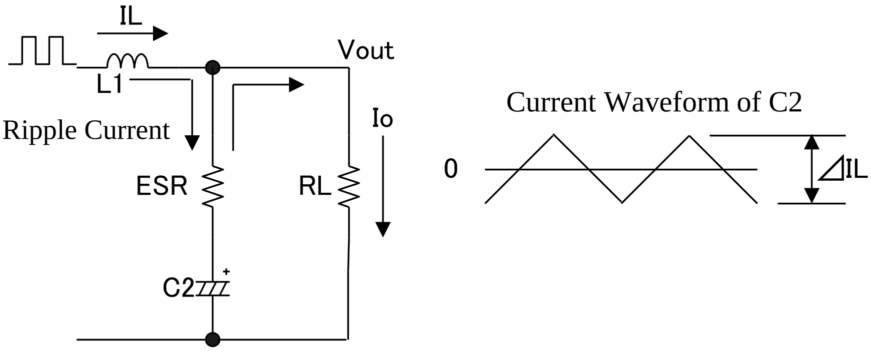
4-1-3 Output Capacitor C2

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



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 calculated 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.

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

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.

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

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).

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.

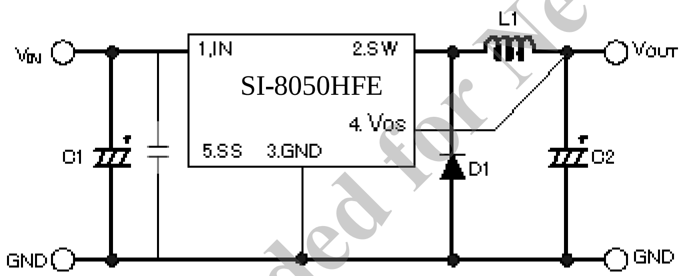
In addition, since the output voltage from the SW terminal (pin 2) of the SI-8050HFE series is almost equivalent to the input voltage, the flywheel diode with the reverse withstand voltage of the input voltage or higher should be used.

It is recommended not use the ferrite beads for the flywheel diode.

● 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.

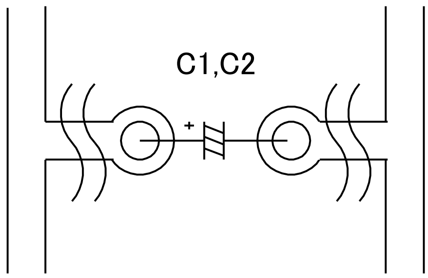


4-2-2 Input / Output Capacitor

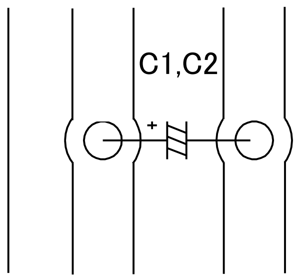
The input capacitor C1 and the output capacitor C2 should be placed to the IC as close as possible. If the rectifying capacitor for AC rectifier circuit is on the input side, it can be used as an input capacitor. However, if it is not close to the IC, the input capacitor should be connected in addition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

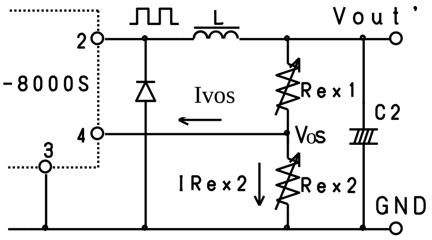
4-2-3 Vos Terminal (Output Voltage Set-up)

The Vos terminal is a feedback detection terminal for controlling the output voltage.

It is recommended to connect it as close as possible to the output capacitor C2.

When they are not close, the abnormal oscillation may be caused due to the poor regulation and increase of switching ripple.

The output voltage can be variable only for rising-up by connecting the Rex1 and Rex2.



The output voltage adjustment resistance Rex 1 and 2 are calculated by the following equations:

$$\mathrm{Re}\,x1 = \frac{Vout' - Vos}{S \cdot IVos} \qquad --- (3)$$

$$\mathrm{Re}\,x2 = \frac{Vos}{(S-1) \cdot IVos} \qquad --- (4)$$

S: Stability coefficient

The stability coefficient S indicates the ratio of IRex2 to the Vos terminal in-flow current Ivos. As S is increased, the variation of temperature characteristic and output voltage is improved. (normally 5 - 10)

Ivos of SI-8050HFE should be deemed as 1mA + 66% - 44%.

The variation range of output voltage is shown as follows, taking into account the variation of Rex1, Rex2, IVos and Vos.

- Maximum output voltage (Vout Max)

$$\mathrm{Vout'\,MAX} = \mathrm{VosMAX} + \mathrm{Rex1MAX}\left(\frac{\mathrm{VosMAX}}{\mathrm{Rex2MIN}} + \mathrm{IvosMAX}\right)$$

VosMAX : The maximum value of set output voltage. The maximum value of set output voltage shown in the electric characteristics of the specifications should be put.

Rex1MAX : The maximum value of Rex1. It can be obtained from the allowable tolerance of resistance.

Rex2MIN : The minimum value of Rex2. It can be obtained from the tolerance of resistance.

IvosMAX : The maximum in-flow current of Vos terminal. 1. 66mA

- Minimum output voltage (Vout Min)

$$\mathrm{Vout'\,MIN} = \mathrm{VosMIN} + \mathrm{Rex1MIN}\left(\frac{\mathrm{VosMIN}}{\mathrm{Rex2MAX}} + \mathrm{IvosMIN}\right)$$

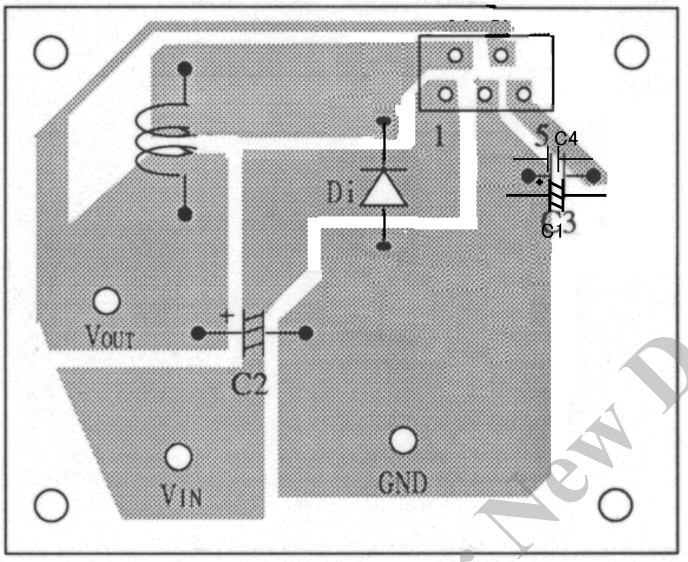
VosMIN: The minimum value of set output voltage. The minimum value of set output voltage indicated in the electric characteristics of specifications should be put.

Rex1MIN: The minimum value of Rex1. It can be obtained from the tolerance of resistance.

Rex2MAX: The maximum value of Rex2. It can be obtained from the tolerance of resistance.

IvosMIN: The minimum in-flow current of Vos terminal. 0.6mA

Mounting Board Pattern Example Component Insertion Type (SI-8050HFE)



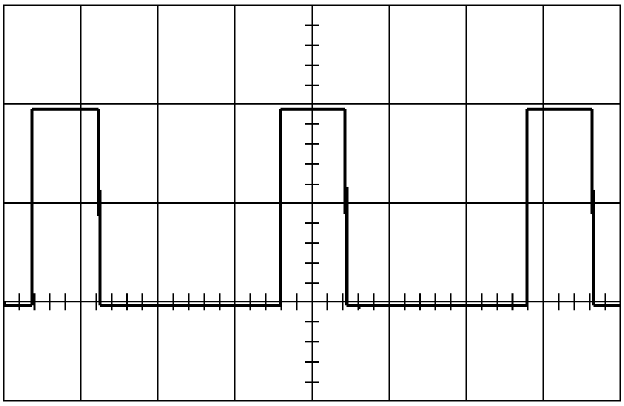
Top View: Silk Print Side

● 4-3 Operation Waveform Check

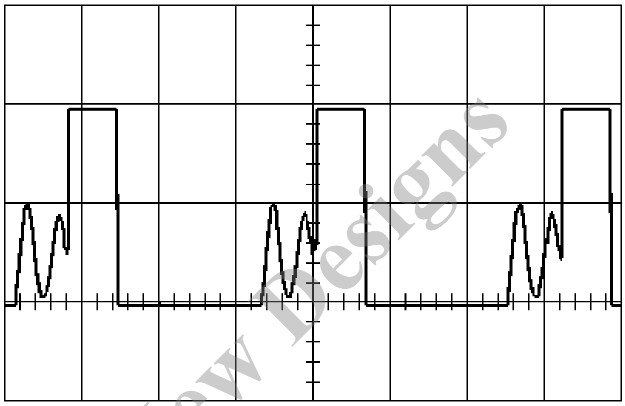
It can be checked by the waveform between the pin 2 and 3 (SW - GND) of the SI-8000 H whether the switching operation is normal or not.

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

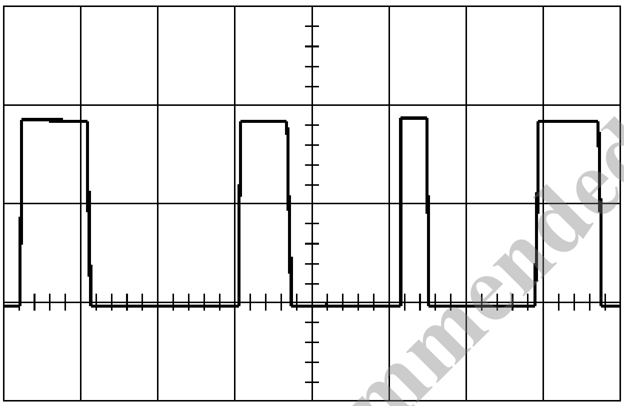
1. Normal Operation (continuous area)



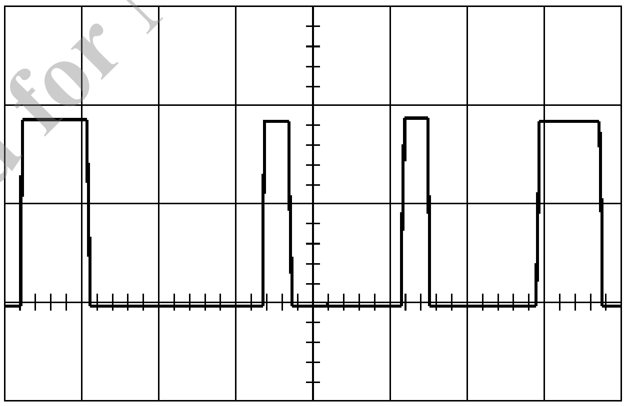
2. Normal Operation (discontinuous area)



3. When C1 and C4 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.

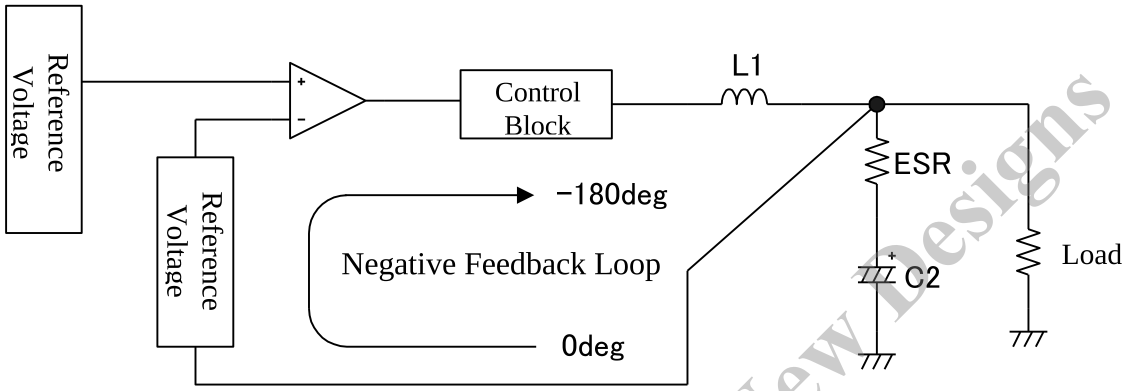
In the continuous area, the switching waveform is formed in the normal rectangular waveform (waveform 1) and in the discontinuous area, damped oscillation is caused in the switching waveform (waveform 2), but this is a normal operation without any problem.

In the meantime, when the IC is far from C1 and C4, jitter which disturbs the ON – OFF time of switching will happen, as shown in the waveforms (3, 4). As described above, C1 and C4 should be connected close to the IC.

● 4-4 Power Supply Stability

4-4-1 Phase Margin

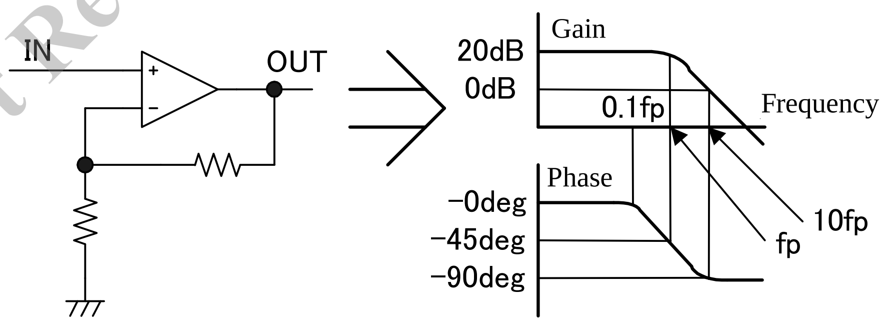
This block diagram shows that the chopper type regulator is a negative feedback amplifier which controls the output voltage by constantly comparing with the output voltage and the reference voltage which is set in advance. Therefore, it has a negative feedback loop to control the output by detecting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

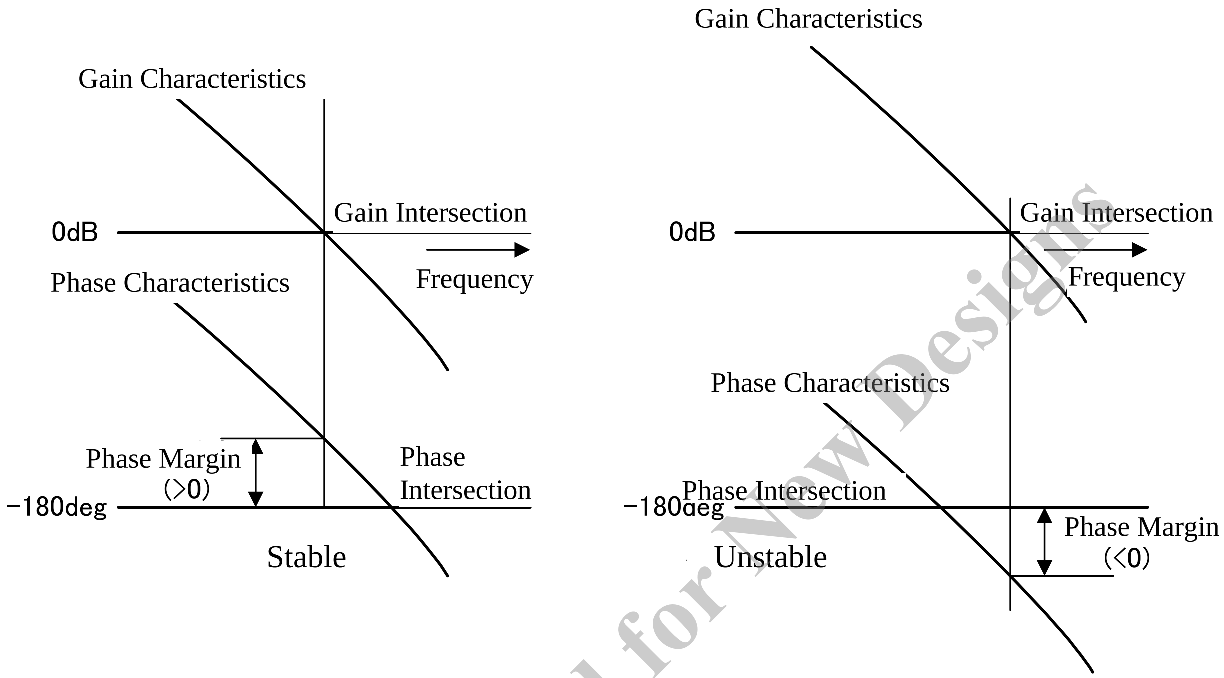


In the Bode diagram, the frequency at which the gain is 1 (0 dB) is called gain intersection and the frequency at which the phase of feedback loop is -180° is called phase intersection.

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 characteristic 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 connected 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):

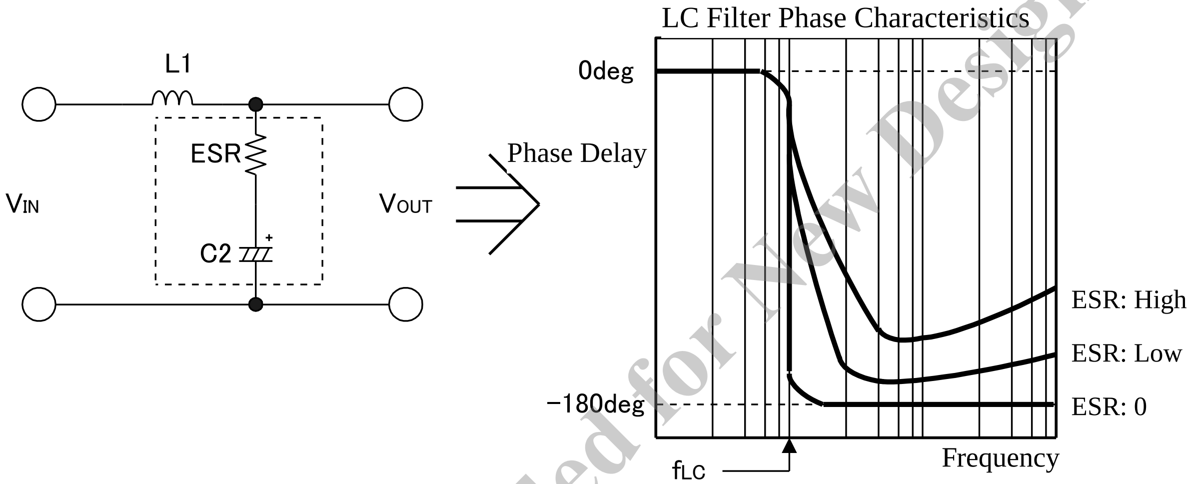
$$f\,LC = \frac{1}{2\pi\sqrt{LC}} \qquad ---(5)$$

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.

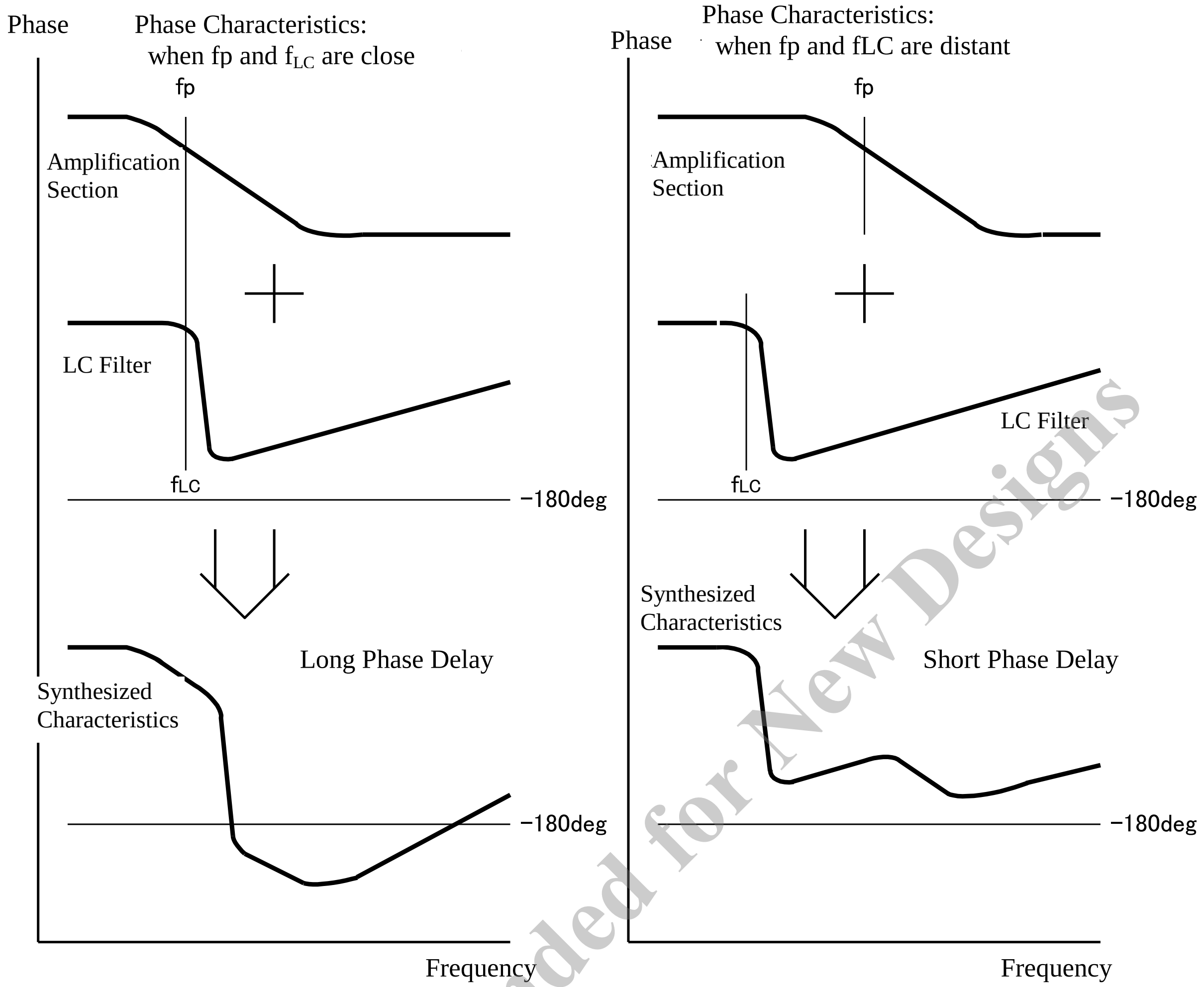
4-4-4 Relation of phase characteristic of regulator IC and that of LC filter

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.

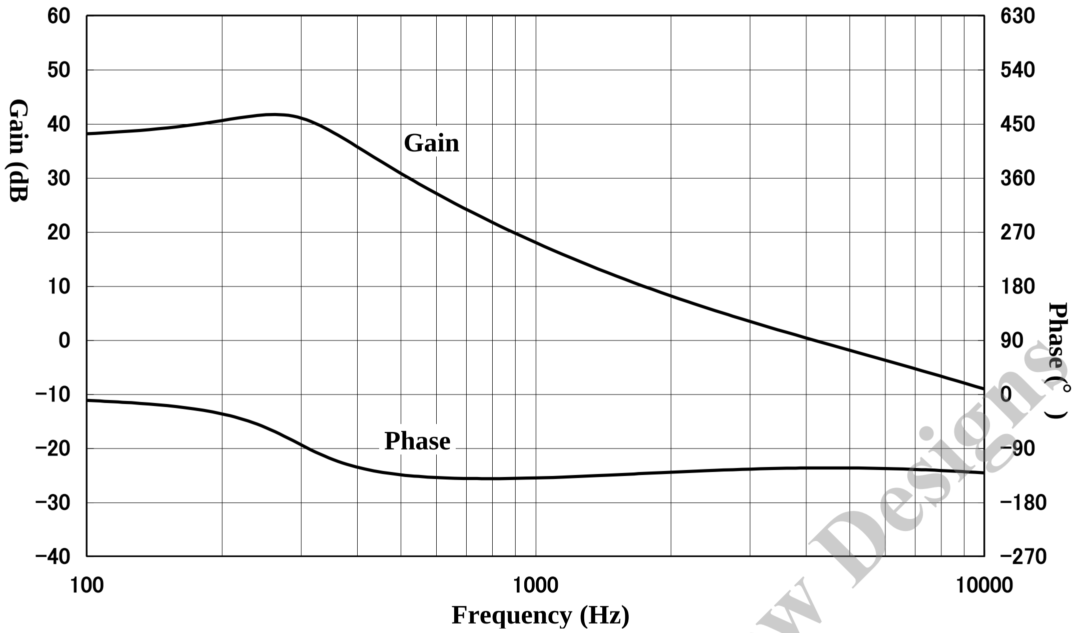


Generally, the frequency fp of the chopper type regulator IC is set from several KHz to higher than ten KHz.

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 I.C.

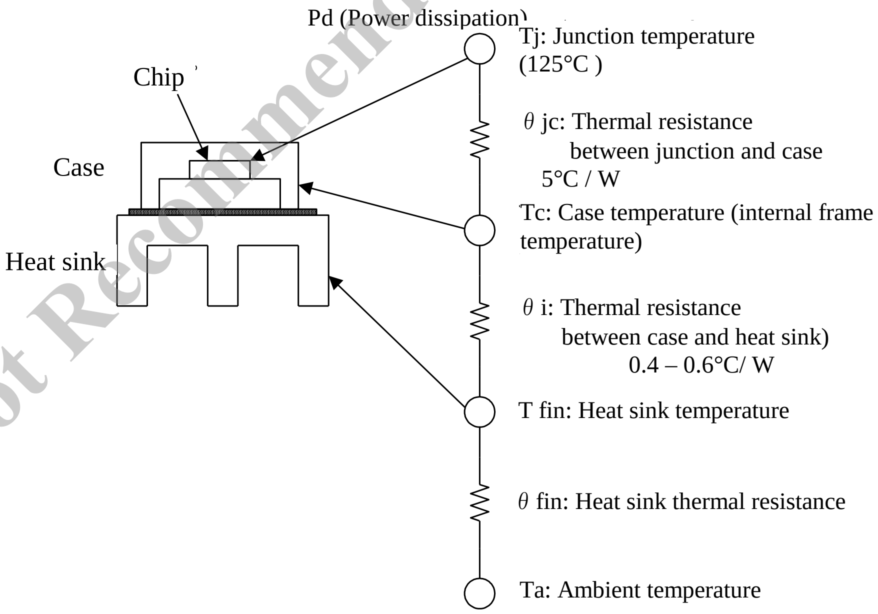
Typical Characteristics of Gain and Phase



● <u>4-5 Thermal Design</u>

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:



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

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

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

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 calculated.

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

* 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 calculated by the following equation:

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

An example of heat calculation for using SI-8050HFE under the conditions of VIN = 15V, Io = 4A and Ta = 85°C is shown below. Where efficiency η = 80% , Vf = 0.5V from the typical characteristics,

$$Pd = 5 \times 4 \times \left(\frac{100}{80} - 1\right) - 0.5 \times 4 \times \left(1 - \frac{5}{15}\right) \fallingdotseq 3.67W$$

$$\theta i + \theta fin = \frac{125 - 85}{2.75} - 5 \fallingdotseq 5.9^{\circ} C/W$$

As a result, the heat sink with the thermal resistance of 5.9°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.
The maximum rating Tjmax of the SI-8050HFE is 150°C, but it is recommended to design the heat sink at TjMAX < 125°C since the thermal shutdown circuit may be operated at 130°C or higher.

4-5-2 Installation to Heat sink

Selection of silicon grease

When the SI-8050HFE 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,

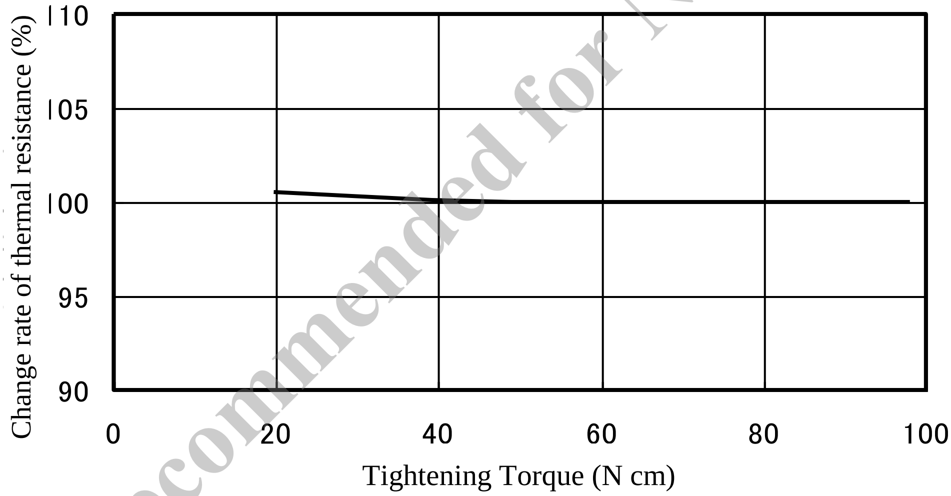
resulting in the deformation of packages or the adverse effect on built-in elements.
Any other silicon grease than one based on the modified silicon oil shall not be used.
The recommended silicon greases are as follows:

Sanken's recommended silicon greases:

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

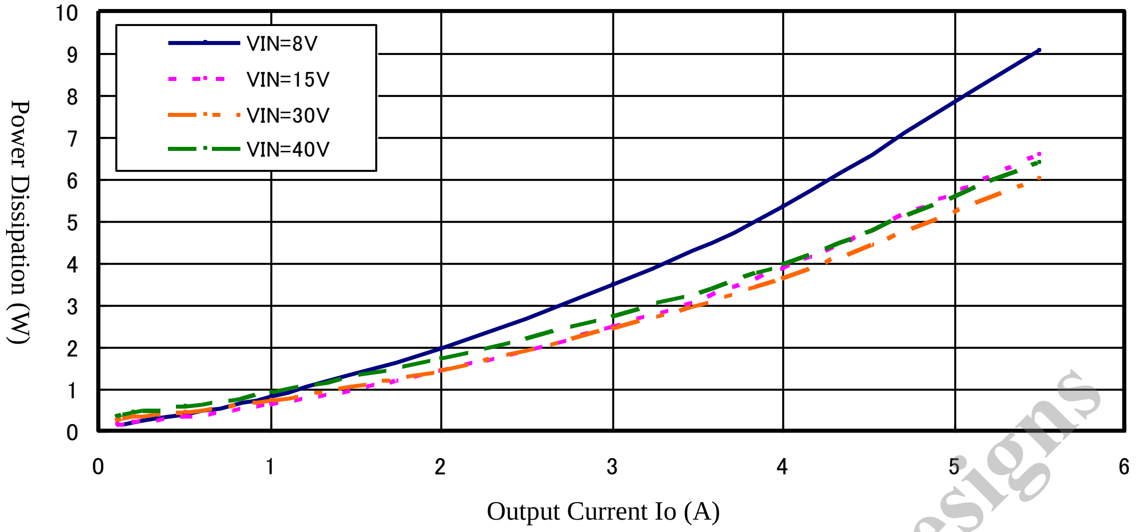
Tightening torque of fixing screws

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-8050HFE, 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.

SI-8000H Series I_O-P_D Characteristics
Output Current-Power Dissipation



Io – Pd reference data of the SI-8000H series is shown above.

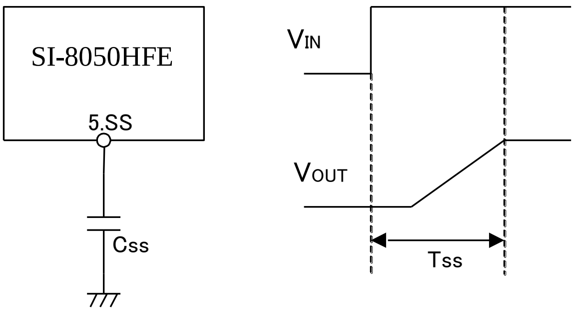
5. Applications

5-1 Soft Start

When a capacitor is connected to terminal 5, the soft start is activated when the input voltage is applied. Vout rises in relation with the charging voltage of Css. Therefore, the rough estimation is done by the time constant calculation of Css charging.

The capacitor Css controls the rise time by controlling the OFF period of PWM control. The rise time tss is obtained approximately by the following equation:

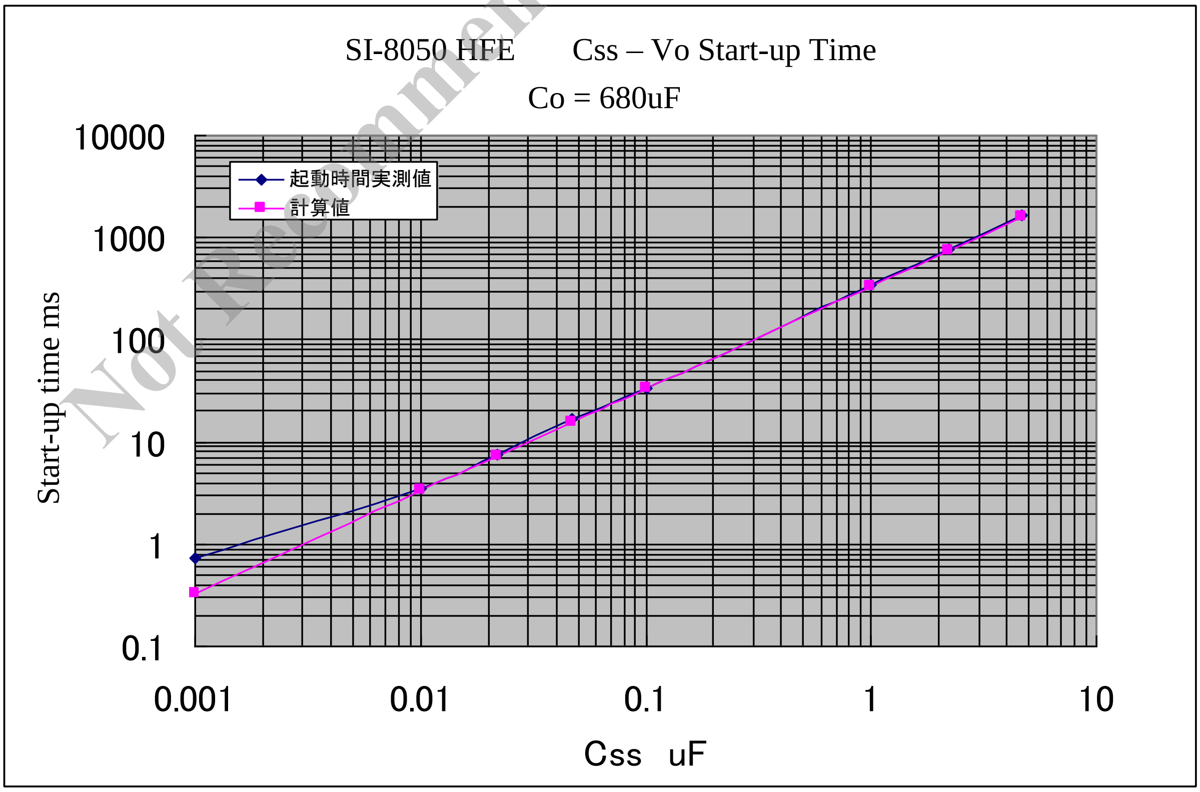
The terminal 5 should be open, when the soft start is not used.



$$Tss = (Css \times VssA) / IssL \text{ (sec)}$$

Since the SS terminal is pulled up (3.6V TYP) with the internal power supply of IC, the external voltage cannot be applied.

If Css is high, it takes time to discharge Css after Vin is turned OFF. It is recommended to use the Css with the value of 10µF or less. When Vin drops, the charges of Css are discharged from the Vin terminal.



The reference data of calculated value and actual value of start-up time of CSS are shown above.

If there is no Css or it is extremely low, Vout rises at the time constants charging the output capacitor with the output current restricted by the overcurrent protection Is.

At CSS = 0.001μF in the start-up time graph above, time constants charging output capacitors with output current restricted by overcurrent protection are predominant rather than time constants by Css.

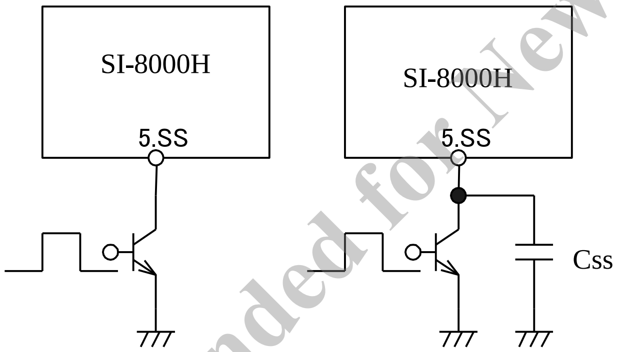
Time constants at output capacitor start-up t = (Co × Vo) / Is・・・・(at no load)

* The amount of load current ~~value~~ is deducted from the Is value at load.

● 5-2 Output ON/ OFF Control

The output ON-Off control is possible using the SS (No.5) terminal. The output is turned OFF when the terminal 5 voltage falls below VssL (0.5V) by such as open collector. It is possible to use the soft start together.

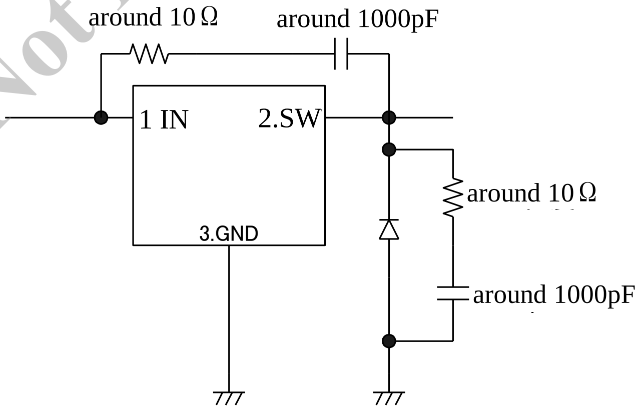
Since the soft start terminal has been already pulled up (3.7V TYP), no voltage shall be applied from the external side.



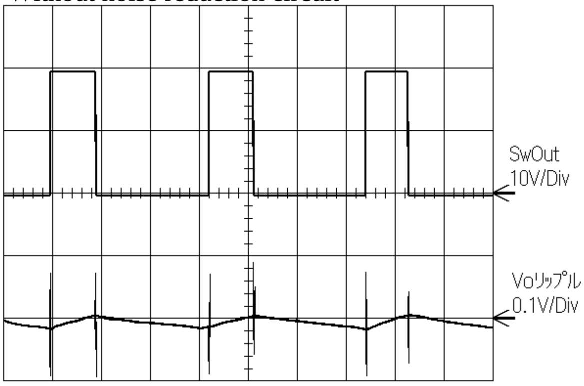
ON/OFF SS+ON/OFF

● 5-3 Spike Noise Reduction

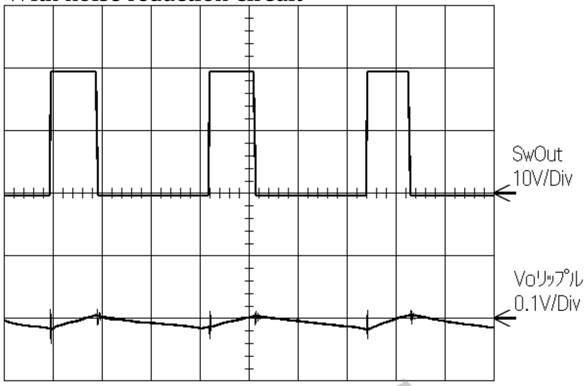
In order to reduce the spike noise, it is possible to compensate the output waveform of the SI-8000H and the recovery time of the diode by a capacitor, but it should be noted that the efficiency is also slightly reduced.



Without noise reduction circuit



With noise reduction circuit

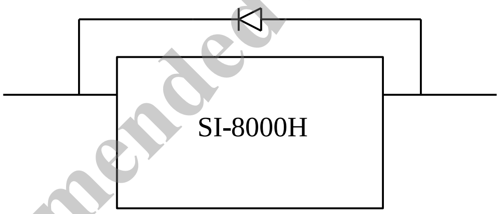


A resistor of 10Ω and a capacitor of 2200pF are connected to external resistor

* 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 as short as possible and be connected with the root of the output capacitor.

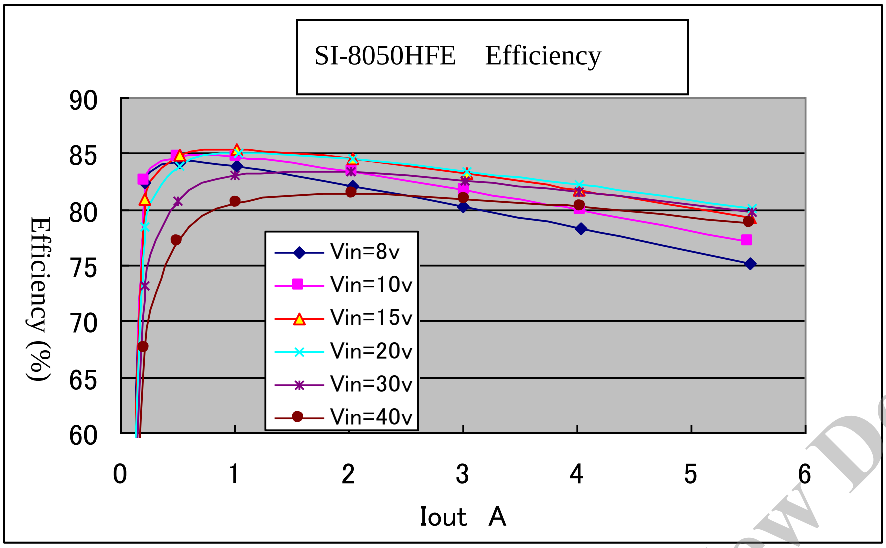
● 5-4 Reverse Bias Protection

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

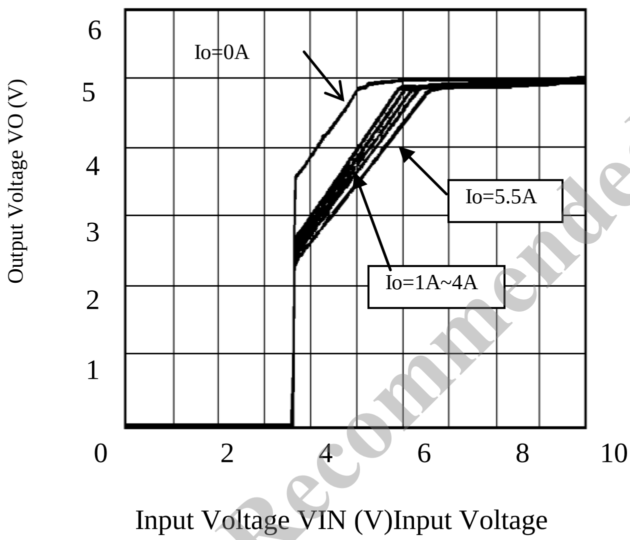


6. Typical Characteristics

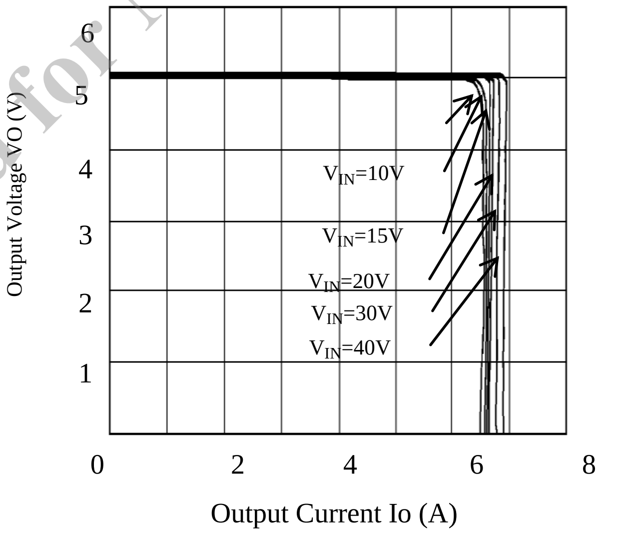
(1) Efficiency



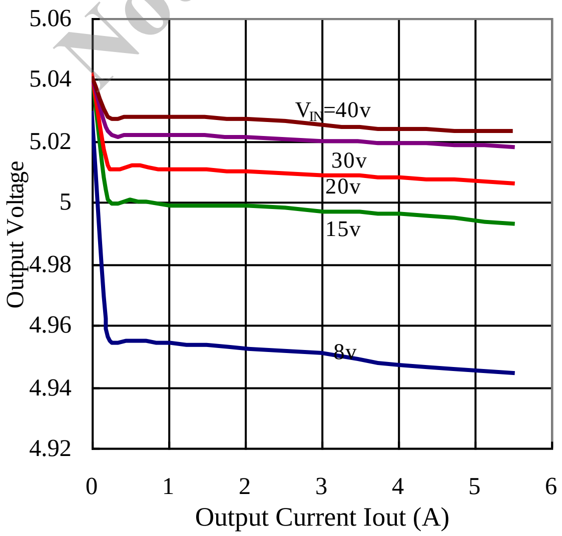
(2) Rising Characteristics



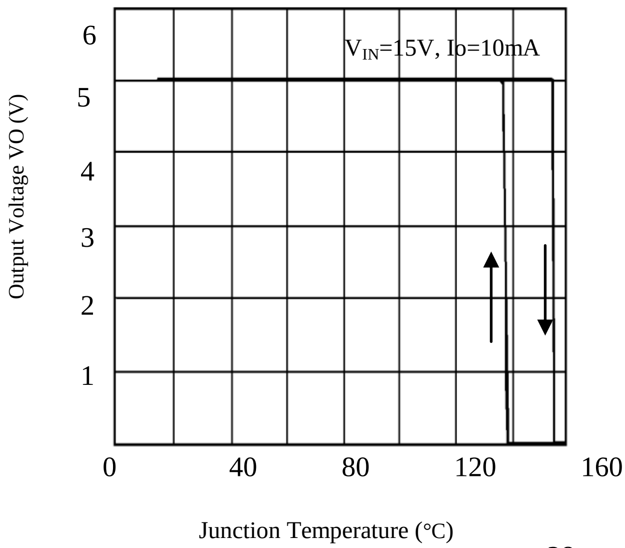
(4) Over Current Protection



(3) Load Regulation



(5) Thermal Protection



7. 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 specified 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.

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