Application Note

Full Mold Type Chopper Type Switching Regulator IC

SI-8000JF Series

5th Edition December 2005

SANKEN ELECTRIC CO., LTD.

――― Contents ―――

1. General Description

The SI-8000JF 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.

● 1-1 Features

- Compact size and large output current of 1.5A
  The maximum output current of 1.5A for the outline of TO220F class
- High efficiency of 82% (SI-8050JF Vin = 20V / Io = 0.5A)
  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
  The foldback type overcurrent protection and thermal shutdown circuit are built in.
  (automatic recovery type)
- Output ON / OFF function (rise time delay setting can be made.)
  The ON / OFF control function of output is also possible. Current consumption is decreased at OFF time. It is possible to delay the rising speed of output voltage at start-up by adding external capacitors.
- 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

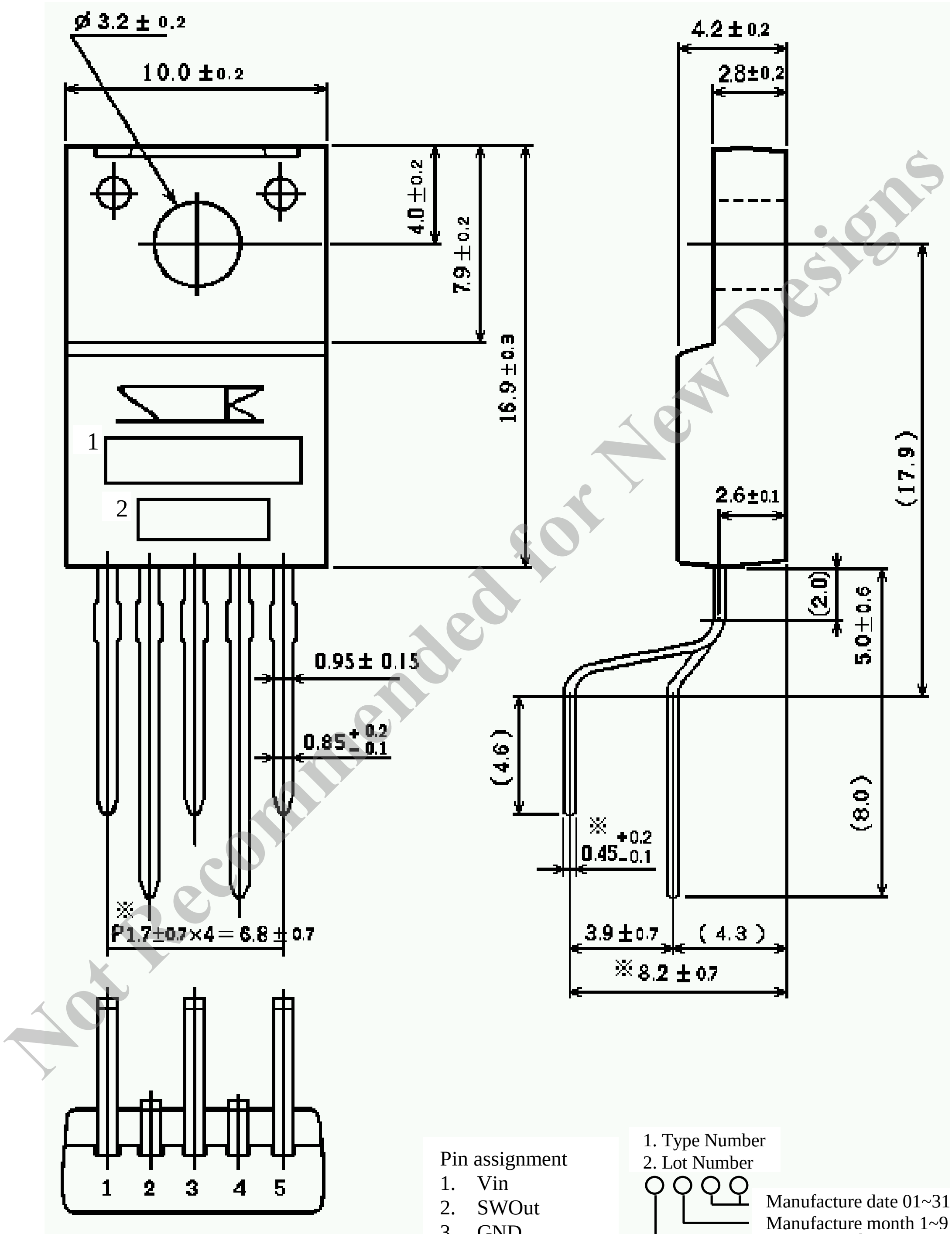
● 1-3 Type

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

2. Specification

● 2-1 Package Information (lead forming No.: LF1101)

Dimensions in mm



Pin assignment
1. Vin
2. SWOut
3. GND
4. Vos
5. ON/OFF

1. Type Number
2. Lot Number

○○○○

- Manufacture date 01~31
- Manufacture month 1~9
  - October O
  - November N
  - December D
- Manufacture year Last digit of year

2-2 Ratings

2-2-1 Lineup

Product Name	Vout(V)
SI-8015JF (variable type)	1.59 (reference voltage)
SI-8033JF	3.3
SI-8050JF	5
SI-8120JF	12

2-2-2 Absolute Maximum Ratings

Parameter	Symbol	Rating	Unit
Input Voltage	Vin	43	V
Allowable Power Dissipation in Infinite Radiation	Pd1	16.6	W
Allowable Power Dissipation without Heat sink	Pd2	1.5	W
Junction Temperature	Tj	125	°C
Storage Temperature	Tstg	-40 - +125	°C

2-2-3 Recommended Conditions

Parameter	Symbol	SI-8015JF	SI-8033JF	SI-8050JF	SI-8120JF	Unit	Conditions
DC Input Voltage	Vin1	Vo+2V	5.3 - 6.3	7 - 8	14 - 15	V	Io=0 - 1A
	Vin2	Vo+3V	6.3 - 40	8 - 40	15 - 40	V	Io=0 - 1.5A
Output Current	Io	0 - 1.5				A	Vin≧Vo+3V
Junction Temperature in Operation	Tjop	-30 - +125				°C	

Note: The variable output voltage range of the SI – 8015JF is 2.5 – 24V.

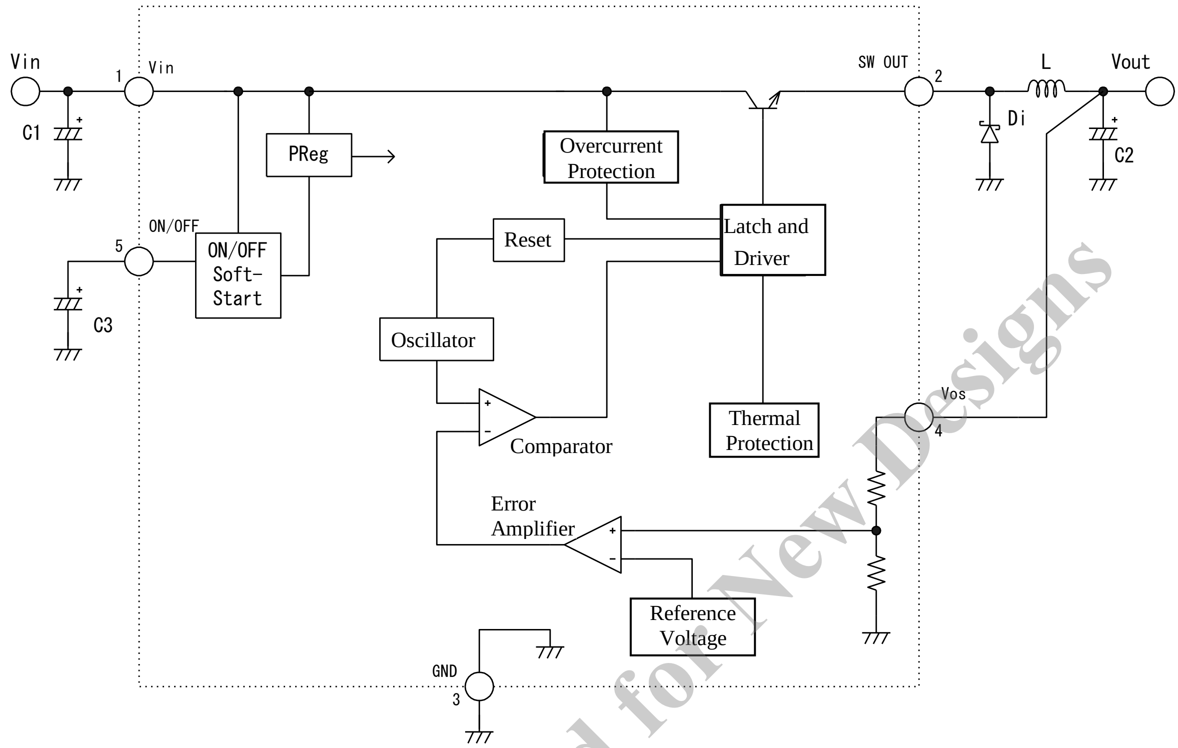
2-2-4 Electrical Characteristics (Ta=25°C)

Parameter	Symbol	SI-8015JF			SI-8033JF			SI-8050JF			SI-8120JF			Unit
		min	typ	max	min	typ	max	min	typ	max	min	typ	max	
Set Output Voltage	Vin	1.558	1.59	1.622	3.17	3.30	3.43	4.90	5.00	5.10	11.76	12.0	12.24	V
	Conditions	Vin=15V/Io=0.5A			Vin=15V/Io=0.5A			Vin=20V/Io=0.5A			Vin=24V/Io=0.5A			
Efficiency	η		67			77			82			88		%
	Conditions	Vin=15V/Io=0.5A			Vin=15V/Io=0.5A			Vin=20V/Io=0.5A			Vin=24V/Io=0.5A			
Operation Frequency	f		125			125			125			125		kHz
	Conditions	Vin=15V/Io=0.5A			Vin=15V/Io=0.5A			Vin=20V/Io=0.5A			Vin=24V/Io=0.5A			
Input Voltage – Output Voltage (Iout=0.5A)	⊿VLi		25	80		25	80		40	100		60	130	mV
	Conditions	Vin=8 - 30V			Vin=8 - 30V			Vin=10 - 30V			Vin=18 - 30V			
Output Current - Output Voltage (Iout=0.2 - 0.8A)	⊿VLo		10	30		10	30		10	40		10	40	mV
	Conditions	Vin=12V			Vin=15V			Vin=20V			Vin=24V			
Overcurrent Protection Start Current	Is	1.6			1.6			1.6			1.6			A
	Conditions	Vin=12V			Vin=15V			Vin=20V			Vin=24V			
Output Voltage Temperature Variation	Kt		±0.5			±0.5			±0.5			±1.0		mV/°C

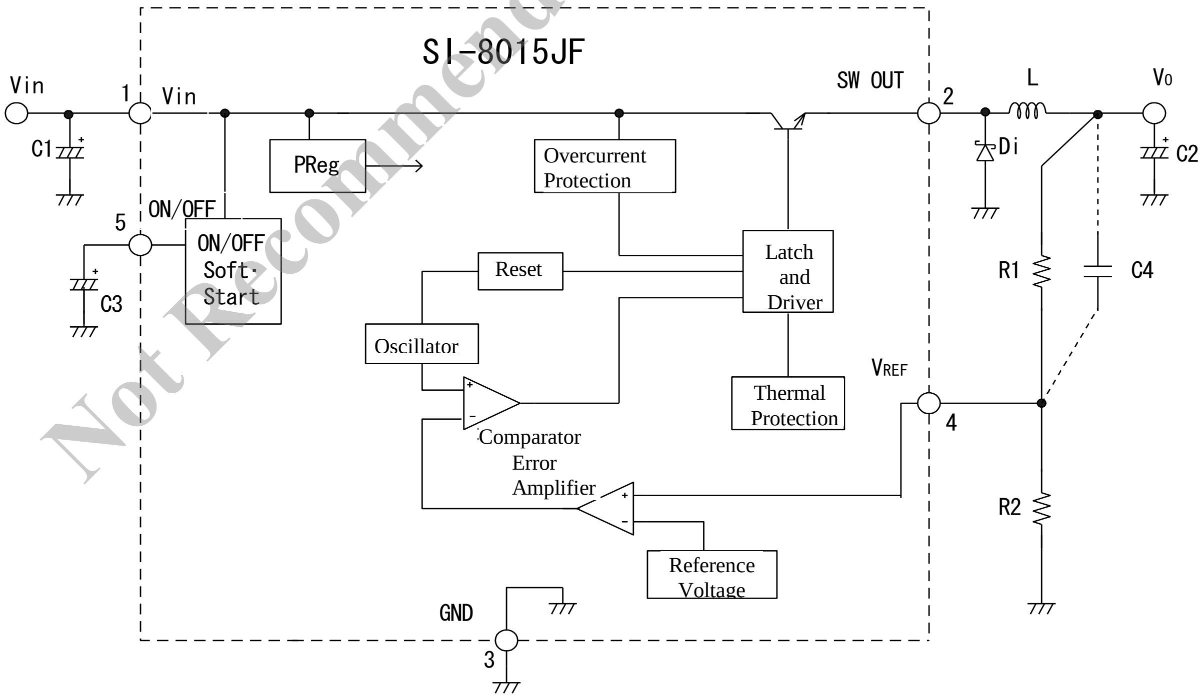
● 2-3 Circuit Diagram

2-3-1 Internal Equivalent Circuit

- SI-8033JF, SI-8050JF, SI-8120JF

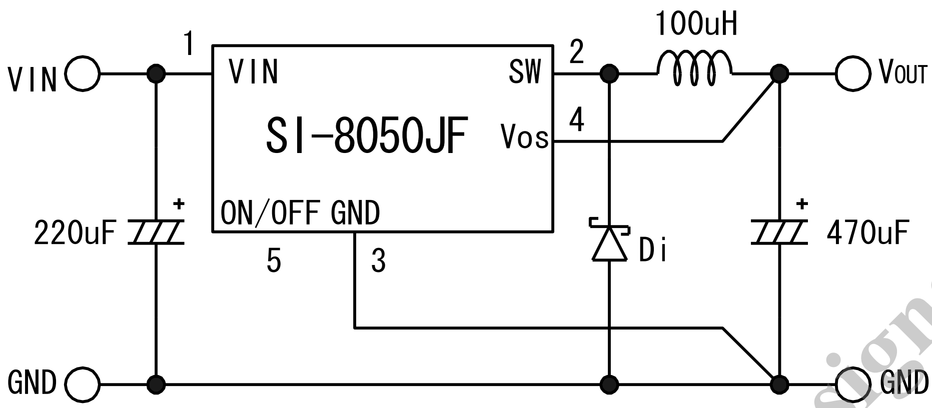


- SI-8015JF

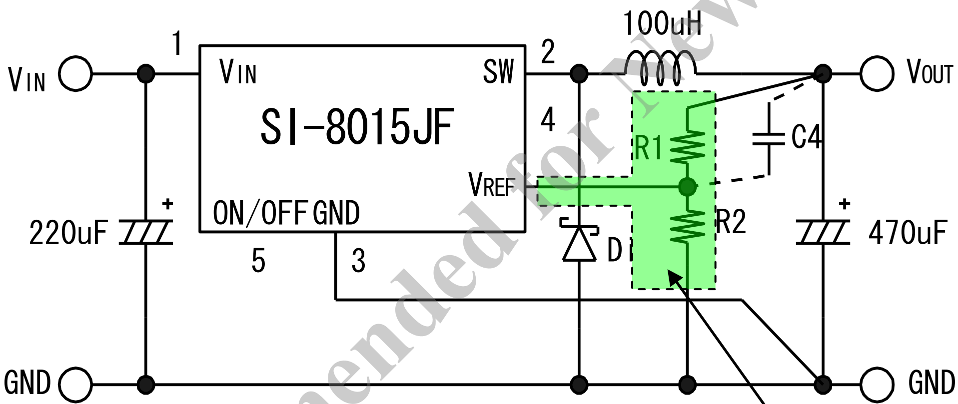


2-3-2 Typical Connection Diagram

- SI-8033JF, SI-8050JF, SI-8120JF



- SI-8015JF



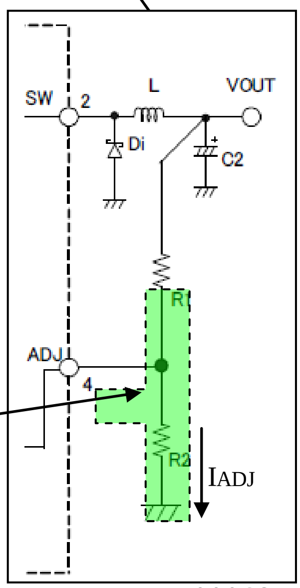
Resistors R1, R2

R1 and R2 are resistors for setting the output voltage. The output voltage should be set in a way that IADJ may be 2mA or so (approx. ±20% is recommended, but there is no restriction toward a larger value.)

The equation to obtain R1 and R2 values is as follows:

$$R1 = \frac{(V_{OUT} - V_{REF})}{I_{REF}} = \frac{(V_{OUT} - 1.59)}{2 \times 10^{-3}} (\Omega), \quad R2 = \frac{V_{REF}}{I_{REF}} = \frac{1.59}{2 \times 10^{-3}} \fallingdotseq 800(\Omega)$$

In order not to be affected by the switching noise for stable operation, the voltage detection line should be designed in a simple way.

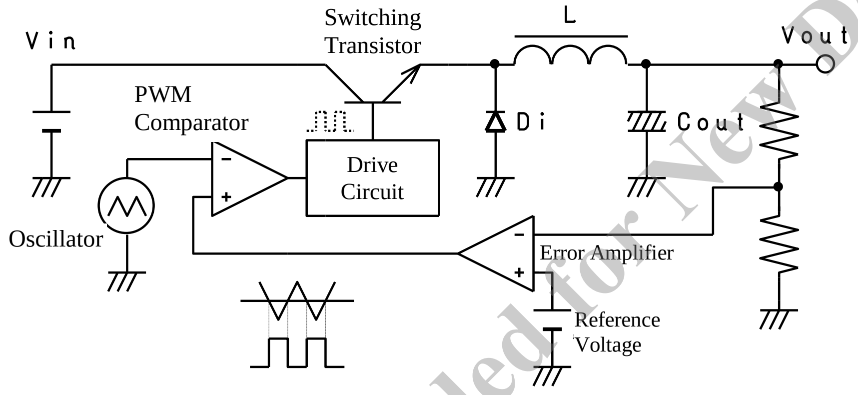


3. Operational Description

● 3-1 PWM Output Voltage Control

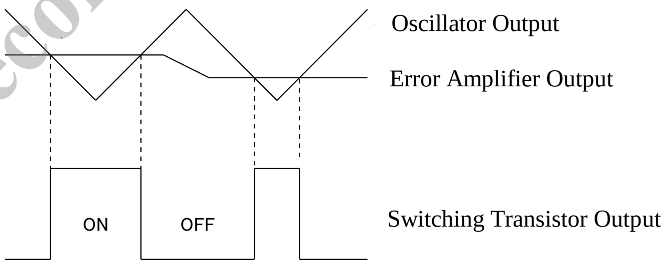
In the SI-8000JF series, the output voltage is controlled by the PWM system and the IC integrates the PWM comparator, oscillator, error amplifier, reference voltage, output transistor drive circuit etc. The triangular wave output (≈ 125KHz) from the oscillator and the output of the error amplifier are 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.

PWM Comparator Operation Diagram

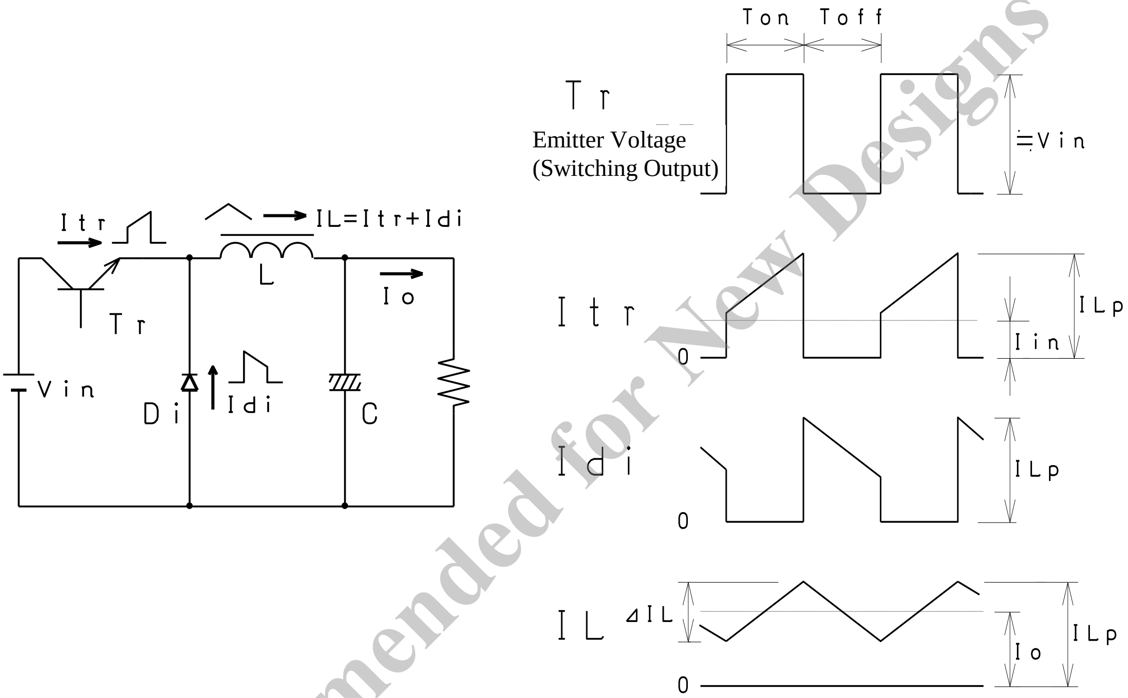


On the assumption that the output voltage attempts to rise, the output of the error amplifier is lowered, because the error amplifier is of inverting type. As the output of the error amplifier is lowered, the time period where it falls below the triangular wave level of the oscillator is increased to 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.)

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 Input / Output Current and Choke Coil Current

The rectangular output which is produced by the switching transistor of the SI-8000JF is converted into DC output voltage by being smoothed by the LC filter composed of a choke coil and an output capacitor. The operation of this LC filter significantly affects the stable operation of the chopper type regulator. The relation between the choke coil and the current and the relation between the current and the ripple voltage are shown below.

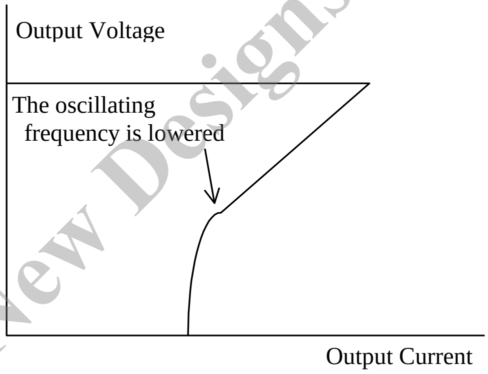


The current IL flowing across the choke coil is of triangular wave shape. This triangular wave is composed of two kinds of current components, Itr and Idi. The current Itr is supplied from the input side through the transistor when the transistor is ON and its average value is input current Iin. The current Idi is the current that the energy stored in the choke coil is commutated via the flywheel diode Di when the transistor is OFF. The total of Itr and Idi is the current IL of choke coil. In addition, the average value of IL is the DC output current Io since the triangular wave component superimposed on the IL is smoothed by charging and discharging of the capacitor C.

● 3-3 Overcurrent Protection / Thermal Shutdown

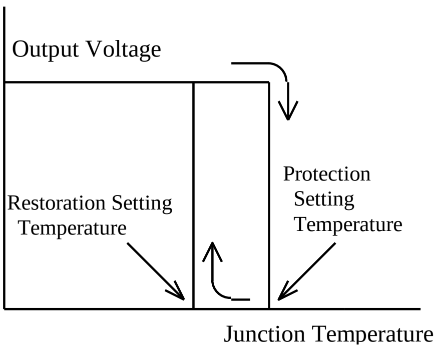
3-3-1 Output Voltage Characteristics in Overcurrent Protection

The SI-8000JF includes the foldback type overcurrent protection circuit. The overcurrent protection circuit detects the peak current of a switching transistor and when the peak current exceeds the set value, the ON time of the transistor is compulsorily shortened to limit the current by lowering the output voltage. In addition, when the output voltage is lowered up to the 50% of the rated value, the increase of current at low output voltage is prevented by dropping linearly the switching frequency to about 40kHz. When the overcurrent condition is released, the output voltage will be automatically restored.



3-3-2 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℃, the output transistor is automatically restored.



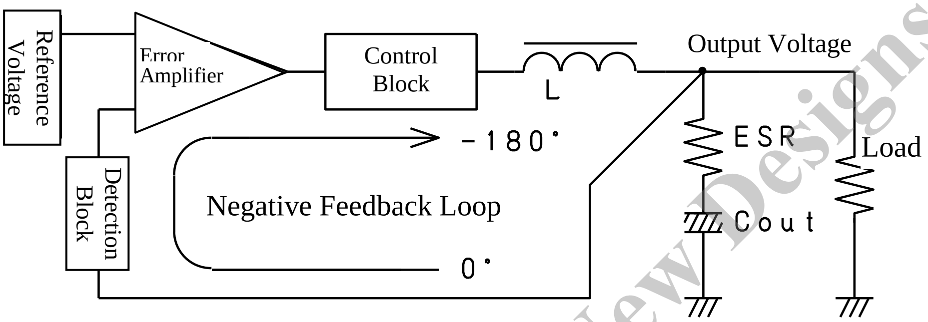
* Note for thermal shutdown characteristic

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. Power Supply Stability

● 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.

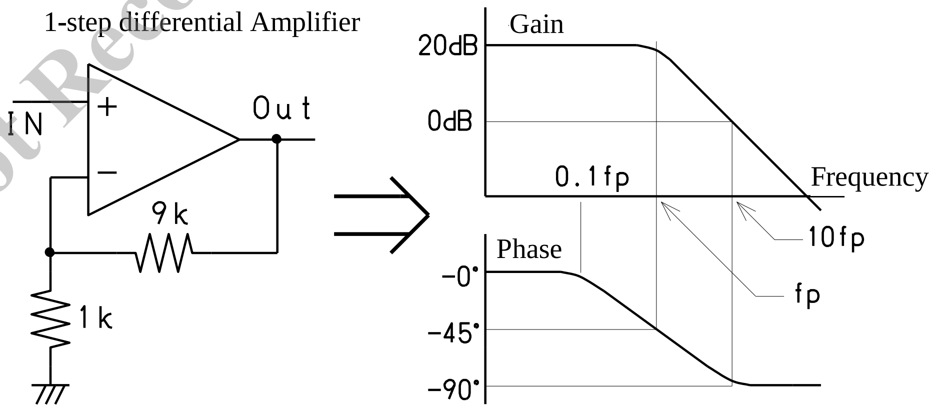


The phase within the negative feedback loop is displaced by 180° to negate the variation of the output voltage, but in the event that the phase is further delayed by 180° in the state that the amplification degree (gain) is 1 or more, the total phase delay amounts to 360° to deviate from the stable operation 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

1-step differential Amplifier

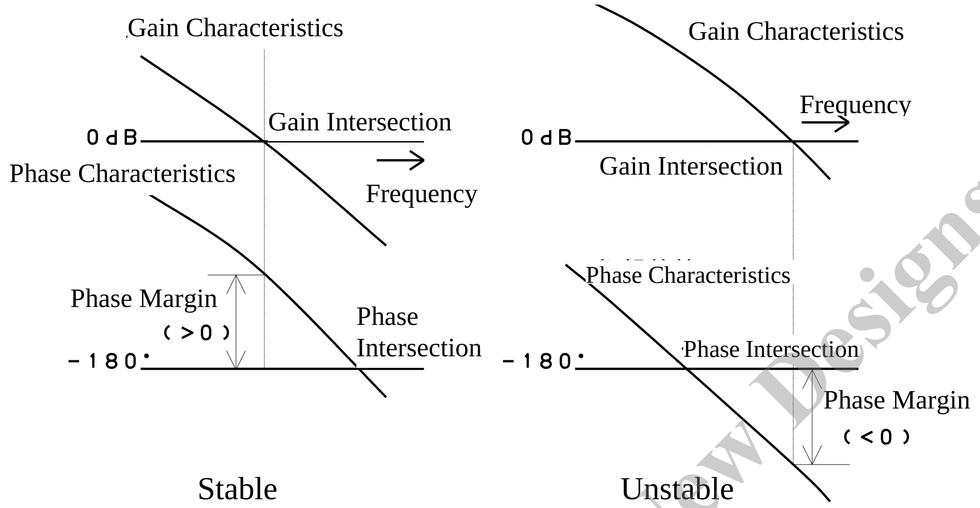


In the Bode diagram, the frequency at which the gain is 1 (0 dB) is called gain intersection and the frequency at which the phase of feedback loop is -180° is called phase intersection.

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



● 4-2 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 L of coil and of capacitance C of the capacitor and at frequency higher than the resonance point, the phase is delayed by 180°at a maximum.

The resonance frequency fLC is expressed as shown in the equation:

$$f\,LC = \frac{1}{2\pi\sqrt{LC}}$$

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

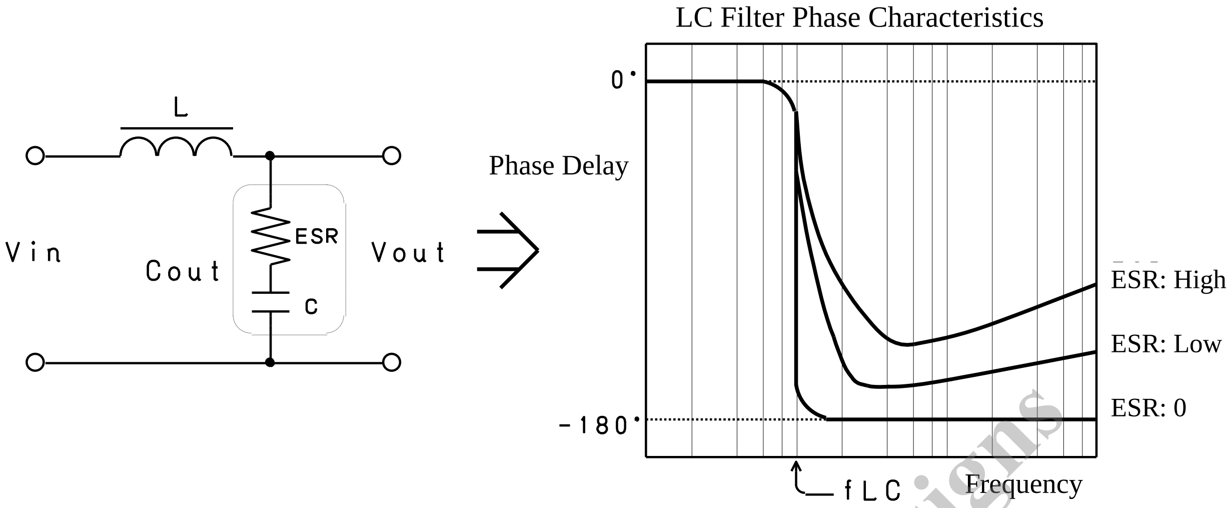
The phase characteristics are 180° if they are higher than the resonance frequency fLC.

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).

If the ESR is large, the phase delay of the LC filter becomes shorter.

However, the phase margin may be lowered due to the rising gain resulting from the lowered attenuation rate of the LC filter, and abnormal oscillation may occur due to increased output ripple voltage, therefore care should be taken of these two events.



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.

● 4-3 Relation of phase characteristics of regulator IC and IC filter

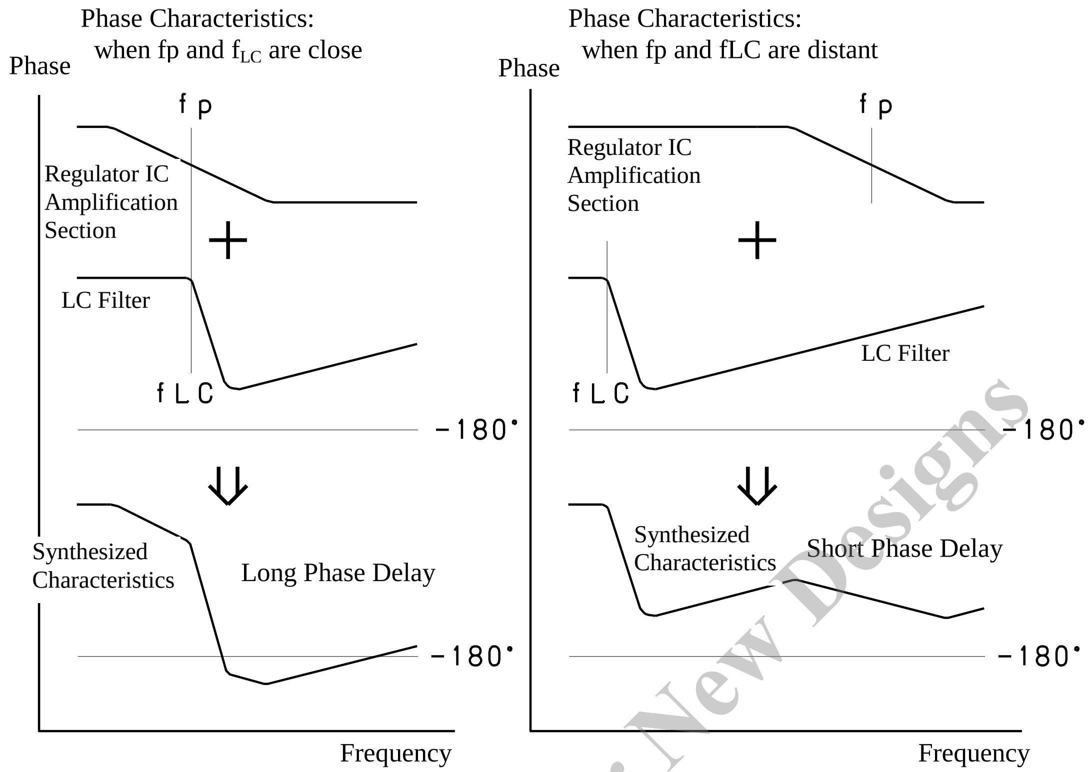
The phase characteristic of the chopper type regulator IC is determined by the phase of the regulator IC and the phase characteristic of the LC filter. In this respect, the relationship between these two characteristics is important. The cause of phase delay of the regulator is generally regarded as the delay of the output stage or the error amplifier, and the higher is the frequency, the longer is the delay time.

In the meantime, in the case of the LC filter, above the resonant frequency fLC of the LC filter, the higher is the frequency, the shorter is the phase delay.

Therefore, when the gain lowering start frequency fp and the resonant frequency fLC of the LC filter are close each other, the phase margin of the regulator is decreased, because both phase delays are concentrated. Generally, as the fLC is lower, the phase margin tends to be increased.

In order to lower the fLC, it is required to increase the capacitance of a coil or capacitor as shown in the following equation:

Resonant frequency $fLC = \dfrac{1}{2\pi\sqrt{\mathrm{LC}}}$



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 rises to decrease the phase margin. Care should be taken for this phenomenon.

5. Cautions

● 5-1 External Component s

5-1-1 Choke coil L

The choke coil L supplies current to the load side when the switching transistor is OFF. And the choke coil 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.

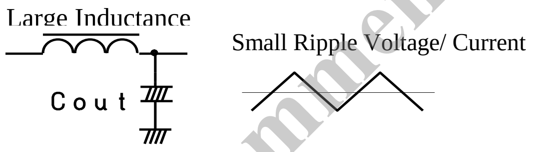
a) The choke coil should be fit for the switching regulator.

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

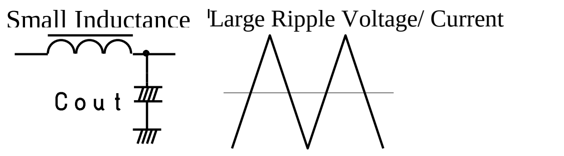
b) The inductance value should be appropriate.

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 curtent/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 following equation.

ΔIL shows the ripple current value of the choke coil and 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 (1.5A) of the SI-8050JF: output current × 0.2- 0.3
- In the case that the output current to be used is approximately 0.5A or less: output current × 0.5 - 0.6

$$L = \frac{(Vin - Vout) \cdot Vout}{\Delta IL \cdot Vin \cdot f} \qquad ---(1)$$

For example, where V_{IN} = 25V, V_{Out} = 5V, ΔIL = 0.3A, frequency = 125KHz,

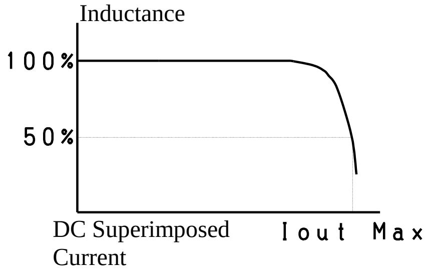
$$L = \frac{(25-5)\times 5}{0.3\times 25\times 125\times 10^3} \fallingdotseq 106uH$$

As shown above, the coil of about 100μH may be selected.

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) Excellent DC superimposition characteristic



The current waveform that flows across the choke coil is a waveform that the triangular wave is superimposed to the DC current equivalent to the load current. The inductance of a coil tends to be decreased in accordance with the increase of superimposed current. The coil may be used until the inductance of the coil is decreased up to 50% of the rated value. This information is useful for the selection of coils.

e) 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.

5-1-2 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.

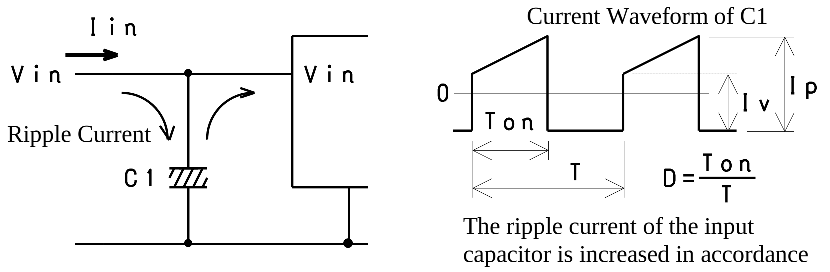
In addition, in the case that the smoothing capacitor of the AC rectifier circuit is located in the input circuit, the input capacitor may be also used as a smoothing capacitor, but similar attention should be paid.

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



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 obtained by the following equation:

$$Irms \approx 1.2 \times \frac{Vo}{Vin} \times Iout \qquad --(2)$$

For instance, where Io=1.5A, V_{IN}=20V, Vo=5V,

$$Irms \approx 1.2 \times \frac{5}{20} \times 1.5 = 0.45A$$

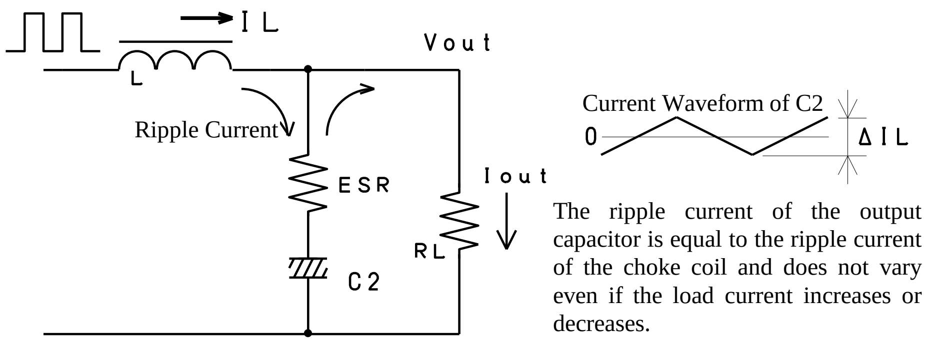
Therefore, it is necessary to select the capacitor with the allowable ripple current of 0.45A or higher.

5-1-3 Output Capacitor C2

The output capacitor C2 composes a LC low pass filter together with a choke coil L 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. Additional points to be checked are DC equivalent series resistance (ESR) and capacitance.

The following points should be taken into consideration.

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.

- Allowable Ripple Current

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

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

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.

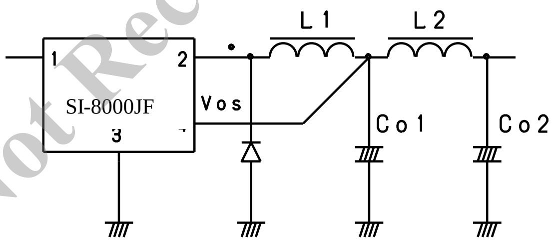
- DC equivalent series resistance (ESR)

It is necessary for the stable operation to select the ESR properly. When the ESR is too large or too small, abnormal oscillation due to increase of ripple voltage or insufficient phase margin occurs respectively.
The output ripple voltage is determined by a product of the pulse current ΔIL (=C2 discharge and charge current) of the choke coil current and the ESR, and the output ripple voltage which is 0.5 % - 1% of the output voltage (for example, where 0.5% at Vout = 5V, 25mV) is good for the stable operation. Please refer to the equations (4) and (5) to obtain the output ripple voltage. It should be noted that the ESR is changeable subject to temperature and it is especially lowered at high temperature.

$$Vrip \approx \frac{(Vin - Vout)Vout}{L \cdot Vin \cdot f} ESR \quad ---(4)$$

$$Vrip \approx \Delta IL \cdot ESR \quad ---(5)$$

When the ESR is too low (approx. 10 - 20Ω or lower), the phase delay becomes larger, resulting in abnormal oscillation.
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
Co2 : 200uF

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.
With respect to the layout of the output capacitor, if it is located far from the IC, it will give same effect as the increase of ESR due to wiring resistance etc., therefore it is recommended to place it near the IC.

5-1-4 LC Filter Constants Selection Example

Based on the above description, the calculation methods of the inductance of choke coil, the capacitance of output capacitor and the ESR are shown below. The following values are deemed as a target and in many cases, the larger are the inductance and capacitance of output capacitor, the more stable operation will be achieved.

Samples: SI-8050JF, conditions: input voltage V_{IN}: 20V, output voltage Vo: 5V, output current Io: 0.5A

- Inductance L of choke coil L

Choke coil ripple current ΔIL = Io × 0.5 – 0.6 = 0.3A

$$L = \frac{(Vin - Vo)Vo}{\Delta IL \cdot Vin \cdot f} = \frac{(24-5)5}{0.3 \cdot 25 \cdot 125000} \approx 101\mu H \qquad \mathrm{L}:100\mu H$$

- Output capacitor ESR

The output ripple voltage Vrip shall be: 5V × 0.5% = 25 mV.

$$Vrip = \Delta IL \cdot ESR \qquad ESR = \frac{Vrip}{\Delta IL} = 83.3m\Omega$$

5-1-5 Flywheel Diode Di

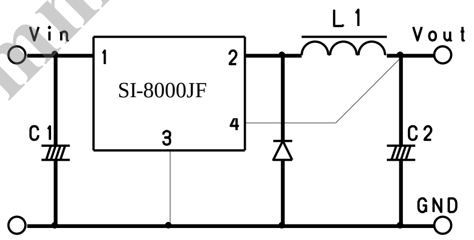
The flywheel diode Di is to discharge the energy which is stored in the choke coil at switching OFF.

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.

● **5-2 Pattern Design Notes**

5-2-1 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.

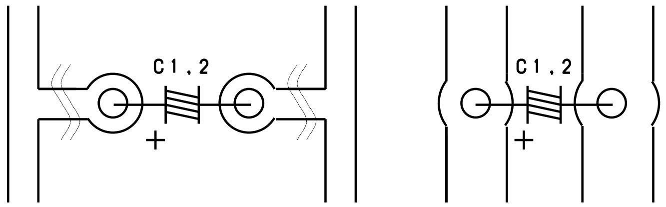


5-2-2 Input/ Output Capacitor

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.



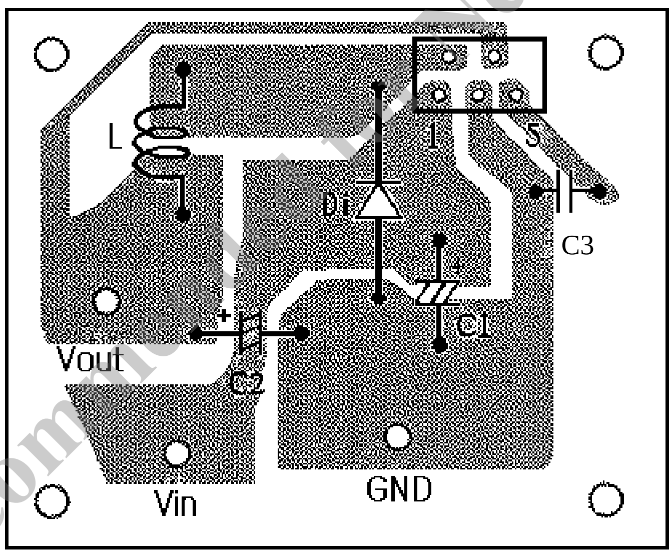
Improper Pattern Example Proper Pattern Example

5-2-3 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. 0.5mA.)

Boad Pattern Example (Top view)

SI-8000JF



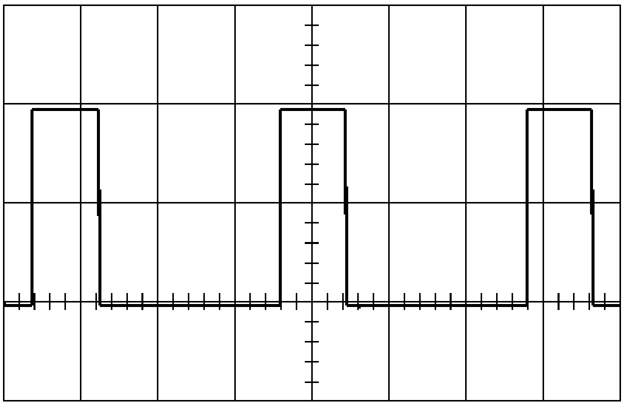
If it is connected far from C2, it should be noted that abnormal oscillation may happen due to the low regulation and increased switching ripple.

● 5-3 Operation Waveform Check

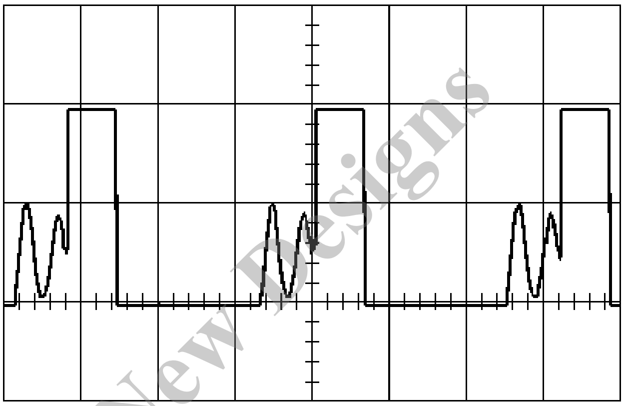
It can be checked by the waveform between the pin 2 and 3 (SWOut waveform) of the SI-8000JF whether the switching operation is normal or not.

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

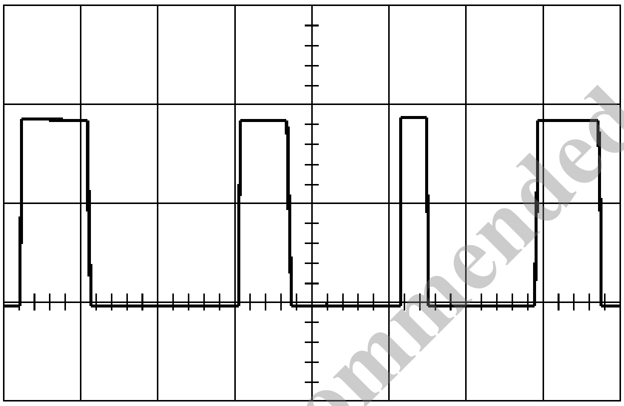
1. Normal Operation (continuous area)



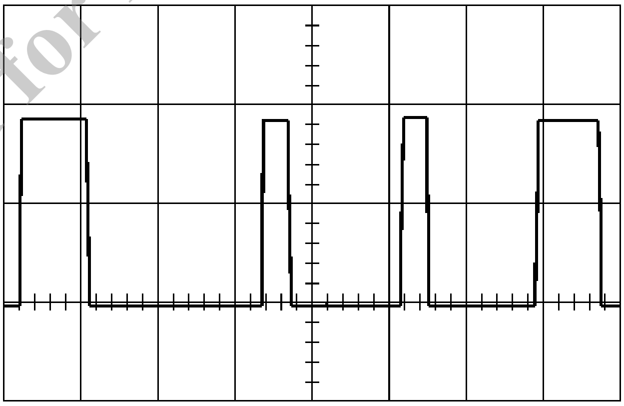
2. Normal Operation (discontinuous area)



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.

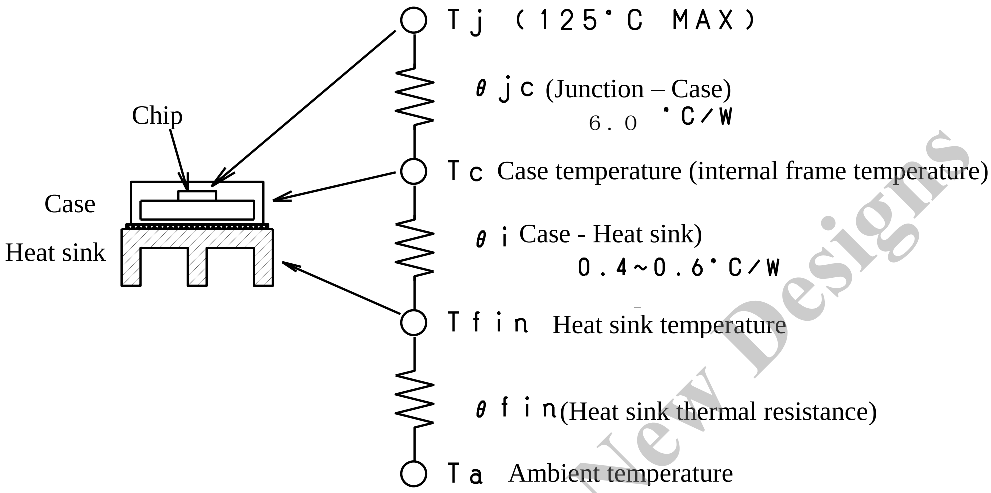
In the continuous area, the switching waveform is formed in the normal rectangular waveform (waveform 1) and in the discontinuous area, damped oscillation is caused in the switching waveform (waveform 2), but this is a normal operation without any problem.

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.

● 5-4 Thermal Design

5-4-1 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.

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

* 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 obtained by the following equation:

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

An example of heat calculation for using SI-8050JF under the conditions of V_{IN} = 20V, Iout = 1.5A and Ta =

85°C is shown below. Where efficiency η = 82% , Vf = 0.4V from the typical characteristics,

$$Pd = 5 \times 1.5 \times \left(\frac{100}{82} - 1 \right) - 0.4 \times 1.5 \times \left(1 - \frac{5}{20} \right) \fallingdotseq 1.2W$$

$$\theta i + \theta fin = \frac{125 - 85}{1.2} - 6.0 \fallingdotseq 27.33^{\circ} C/W$$

As a result, the heat sink with the thermal resistance of 28°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.

5-4-2 Installation to Heat sink

Selection of silicon grease

When the SI-8000JF 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:

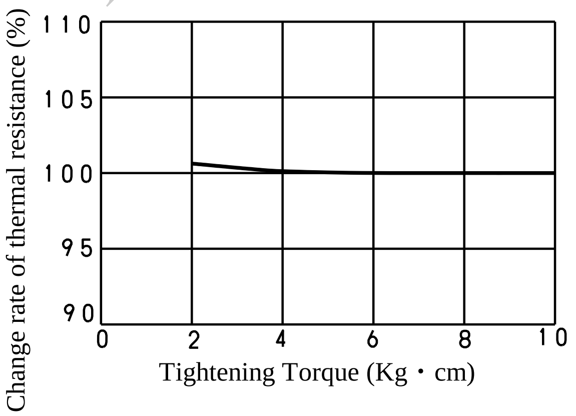
Types	Suppliers
G746	Shin-Etsu Chemical Co., Ltd.
SC102	Toray Silicone Co., Ltd.
YG6260	Momentive Performance Materials Inc.

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-8000JF, 58.8 – 68.6N cm (6.0 – 7.0 kg cm) are recommended.



* 1. The change rate of thermal resistance in the case that 6Kg cm is expressed as 100% is shown above.

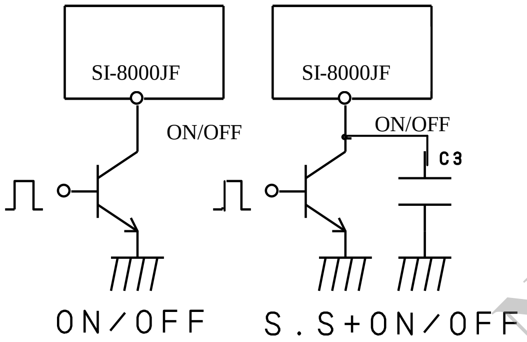
* 2. The silicon grease G746 shall be used.

6. Application

● 6-1 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 to a low level by such as open collector. It is possible to use the rising delay time setting together.

Since the ON / OFF terminal has been already pulled up, no voltage shall be applied from the external side.

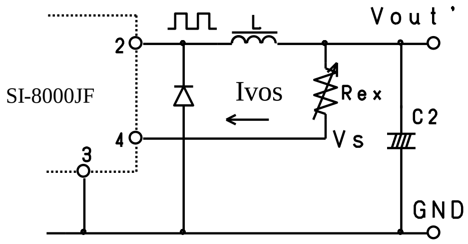


● 6-2 SI-8033JF,SI-8050JF,SI-8090JF,SI-8120JF Controllable Output Voltage

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

Please refer to page 8 for the output voltage setting method of SI-8015JF.

6-2-1 Variable Output Voltage by One External Resistor



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

$$\mathrm{Re}\,x = \frac{Vout' - Vos}{IVos} \qquad ---(1)$$

Vos: Set output voltage for product

Vout: Variable output voltage

Ivos: Vos terminal in-flow current ≒ 527uA

* 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)

$$Vout'MAX = VosMAX + RexMAX \times IvosMAX$$

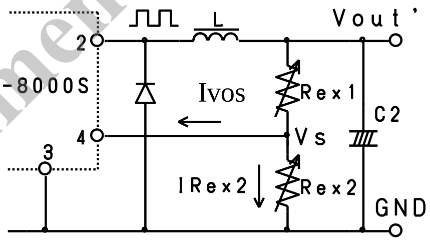
VosMAX: The maximum value of set output voltage. The MAX value of the set output voltage should be put, shown in the electrical characteristics of the specifications.
RexMAX: The maximum value of Rex. It is obtained from the allowable tolerance.
IvosMAX: The maximum in-flow current of Vos terminal. 658uA

- The minimum output voltage (Vout MIN)

$$Vout'MIN = VosMIN + RexMIN \times IvosMIN$$

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.
RexMAX: The minimum value of Rex. It is obtained from the allowable tolerance of resistance.
IvosMIN: The minimum in-flow current of Vos terminal. 439uA

6-2-2 Variable Output Voltage by Two External Resistors



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

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

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

S: Stability coefficient

The tolerance of temperature characteristics and output voltage is improved more by bypassing the current to Rex2 than the method 6-2-1.

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)

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

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.

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. 658uA

- The minimum output voltage (VoutMIN)

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

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.

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. 439uA

6-2-3 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.

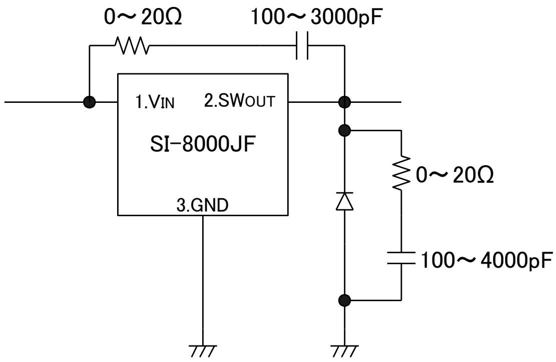
If it is varied drastically, the increase of coil capacitance value may be required since the overcurrent protection current is assumed to be lowered due to the increase in coil current.

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

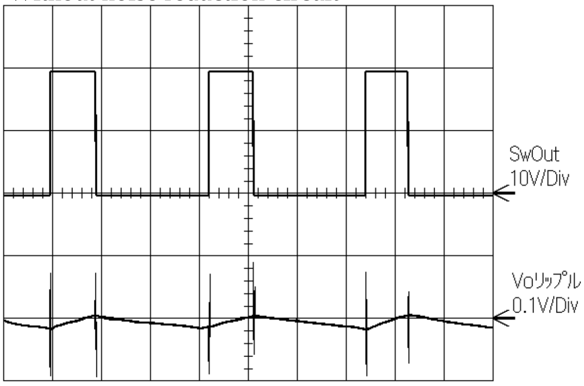
In addition, the MAX value of the set output voltage is recommended as for the lower limit of output voltage variation.

● **<u>6-3 Spike Noise Reduction</u>**

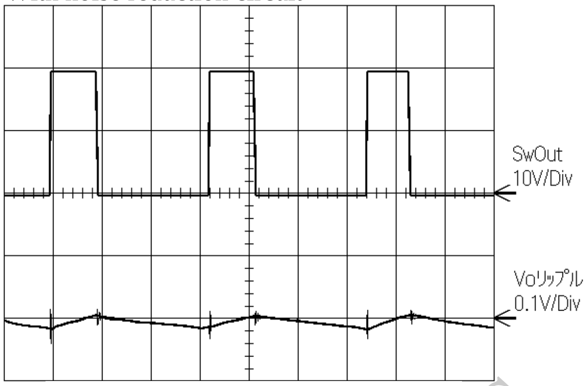
In order to reduce the spike noise, it is possible to compensate the output waveform of the SI-8000JF and the recovery time of the diode by a capacitor, but it should be noted that the efficiency is also slightly reduced.



Without noise reduction circuit



With noise reduction circuit

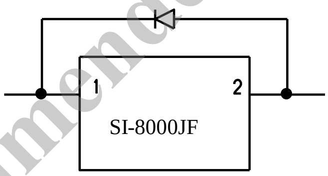


A resistor of 10Ω and a capacitor of 2200pF are connected to external resistor

*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.

● **<u>6-4 Reverse Bias Protection</u>**

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.



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 pacified value for a moment during instantaneous or normal operation.

- Electrical Characteristics

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

- PWM (Pulse Width Modulation)

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

- ESR (Equivalent Series Resistance)

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

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