Application Note

Surface Molding Chopper Type Switching Regulator IC

SI-8010GL

October 2013 Rev.2.0

SANKEN ELECTRIC CO., LTD.

——— Contents ———

1. General Description

The SI-8010GL is a chopper type switching regulator IC which is provided with various functions required for the buck switching regulator and protection functions. A high speed, high precision and high efficiency switching regulator of 250 KHz operating frequency can be composed. The package unifying the GND pin of IC and the inner frame is used to reduce thermal resistance significantly.

● 1-1 Features

- Compact size and large output current of 3A

  The maximum output current of 1.5A for the outline of DIP8
- High efficiency of 86% (V_{IN} = 20V / Vo / Io = 5V / 1A)

  As the DMOS is used in the output stage, heat generation can be reduced and heat dissipation pattern can be made smaller.
- 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)
- 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.
- The output voltage can be adjusted by an external resistor.

  By using 2 pieces of external resistors, the output voltage is variable in the range of +1V to + 14V.

● 1-2 Applications

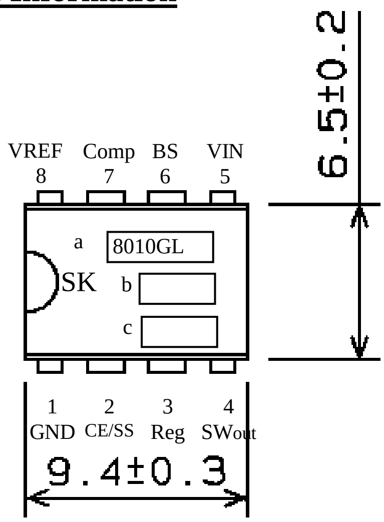
For on-board local power supplies, power supplies for OA equipment, stabilization of secondary output voltage of regulator and power supply for communication equipment

● 1-3 Type

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

2. Specification

2-1 Package Information



a. Type number

b. Lot number (three digit)

1st letter The last digit of year

2nd letter Month

1 to 9 for Jan. to Sept.,

O for Oct.

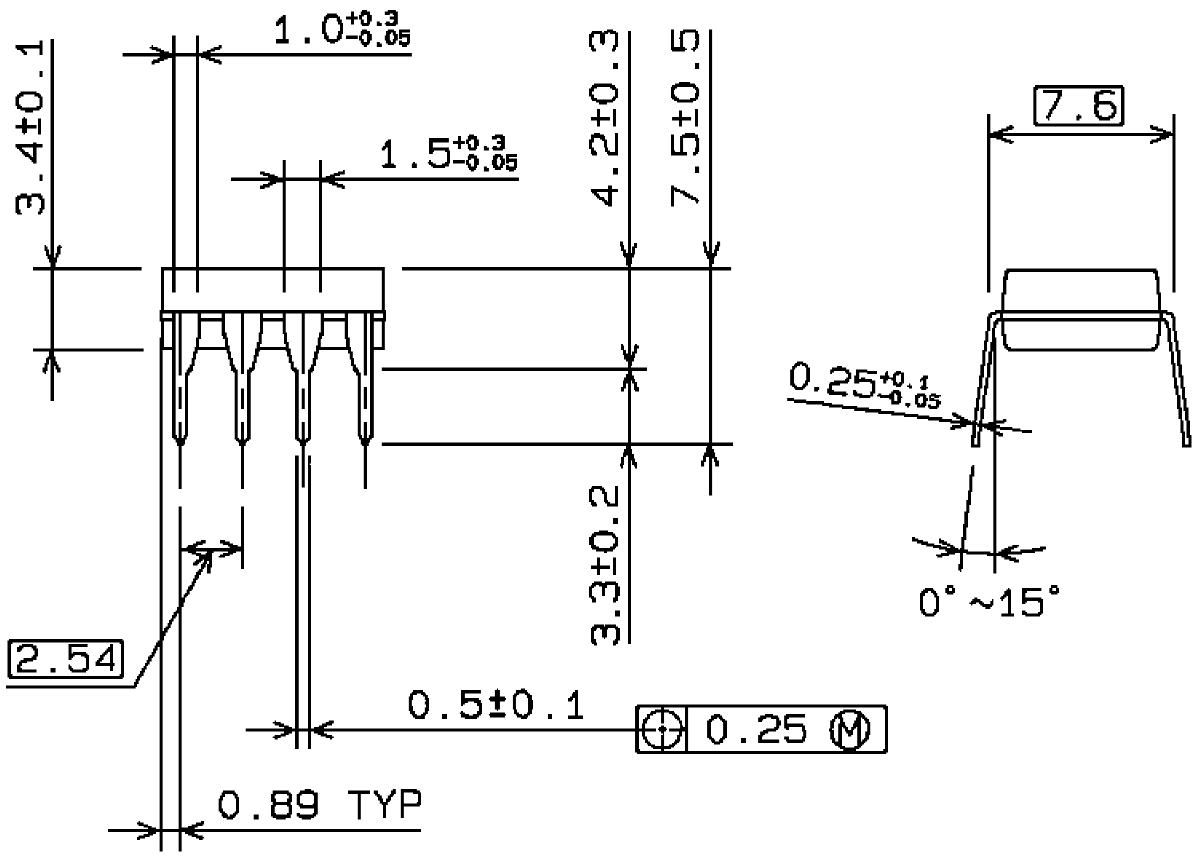
N for Nov.

D for Dec.

3rd letter Assembly span

1-3: Arabic Numerical

c. Control number (four digit)



● 2-2 Ratings

Table 1 Absolute Maximum Rating

Parameter	Symbol	Rating	Unit	Condition
Input Voltage	VIN	53	V	
Allowable Power Dissipation	Pd	1	W	Glass epoxy board: 7000mm^2 (Copper foil area in package: 3080mm^2)
Junction Temperature	Tj	125	°C	
Storage Temperature	Tstg	-40 - 125	°C	
Thermal Resistance (Junction and case)	θj-c	28	°C /W	Glass epoxy board: 7000mm^2 (Copper foil area in package: 3080mm^2)
Thermal Resistance (Junction and ambient)	θj-a	100	°C /W	Glass epoxy board: 7000mm^2 (Copper foil area in package: 3080mm^2)

Table 2 Recommended conditions

Parameter	Symbol	Ratings		Unit	Conditions
		MIN	MAX		
Input Voltage	V_{CC}	8 or V_O+3	50	V	
Output Voltage	Vo	1	14	V	
Output Current *1	I_{OUT}	0.02	1.5	A	
Junction Temperature in Operation	Tjop	-30	125	°C	
Operation Temperature	Top	-30	85	°C	

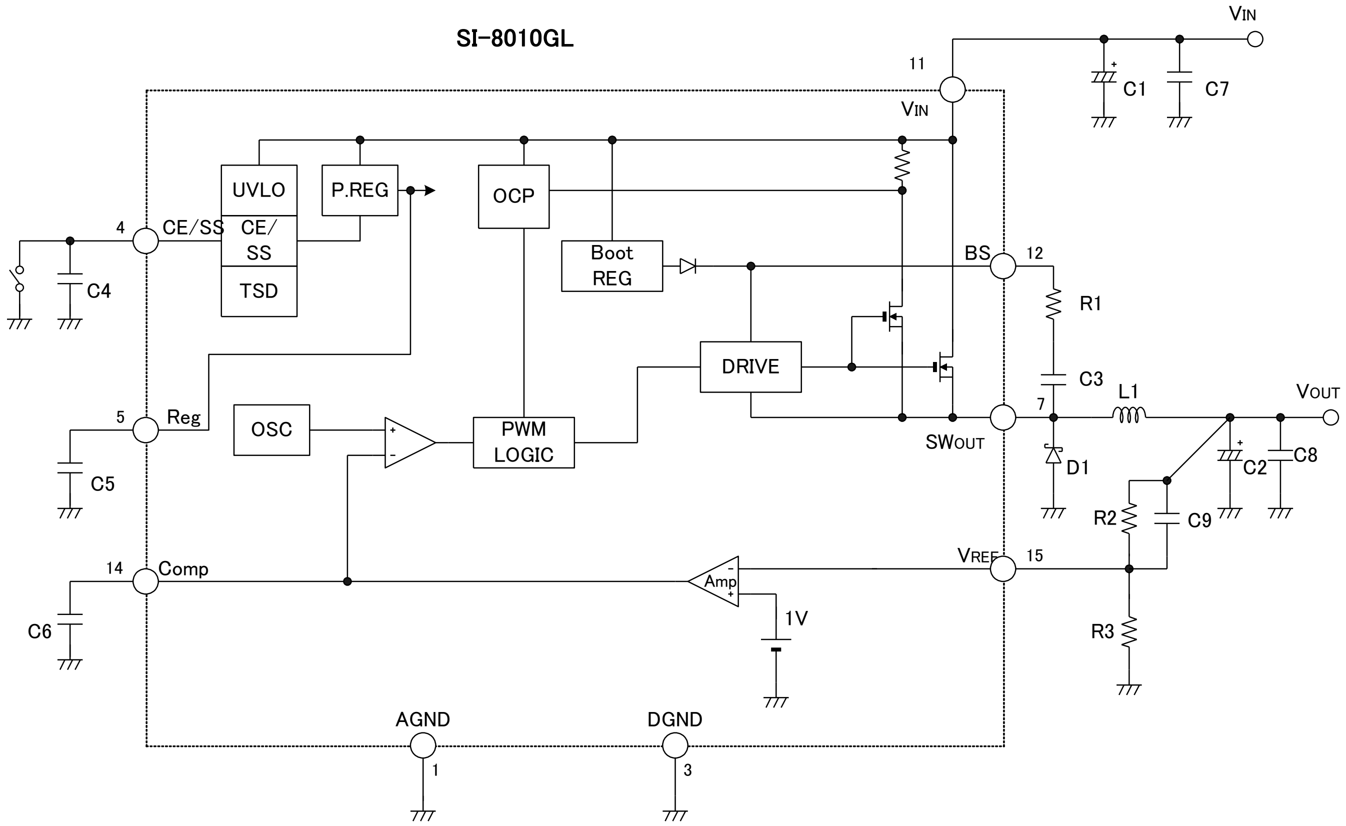
*1: It is strongly recommended to apply over 20mA on output current. It may cause unstable output voltage if output current is less than 20mA.

Table 3 Electrical Characteristics (Ta = 25°C)

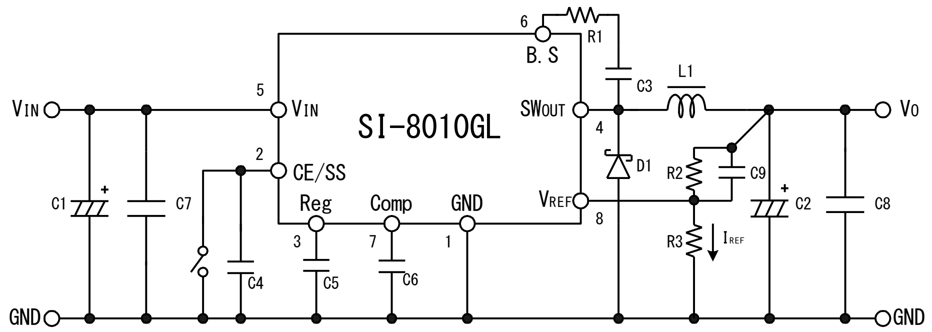
Parameter		Symbol	Ratings			Unit	Conditions
			MIN	TYP	MAX		
Setting Reference Voltage		VREF	0.97	1.00	1.03	V	V_{IN} = 12V, I_O = 1A
Output Voltage Temperature Coefficient		⊿VREF/⊿T		±0.5		mV/°C	
Efficiency		Eff		86		%	V_{IN} = 20V, I_O = 1A, V_O = 5V
Operation Frequency		fosc		250		kHz	V_{IN} = 12V, I_O = 1A
Line Regulation		VLine		20	40	mV	V_{IN} = 10 - 30V, I_O = 1A
Load Regulation		VLoad		10	30	mV	V_{IN} = 12V, I_O = 0.1 - 1.5A
Overcurrent Protection Start Current		IS	1.6			A	V_{IN} = 12V
Circuit Current in Non-operation 1		Iq		7		mA	V_{IN} = 12V, I_O = 0A
Circuit Current in Non-operation 2		Iq(off)			400	μA	V_{IN} = 12V $V_{ON/OFF}$ = 0.3V
CE/SS terminal	Low Level Voltage	VSSL			0.5	V	
	Flow-out Current at Low Level Voltage	ISSL			50	μA	VSSL = 0V

● **2-3 Circuit Diagram**

2-3-1 Internal Equivalent Circuit



2-3-2 Typical Connection Diagram



C1: 220μF / 63V
C2: 470μF / 25V
C3: 0.1μF
C4: 1000pF
C5: 0.1μF
C6: 0.047μF
C7: 0.1μF
C8: 0.1μF
C9: 6800pF
R1: 47Ω
L1: 47μH
D1: RK16

2-3-3 Main Components List

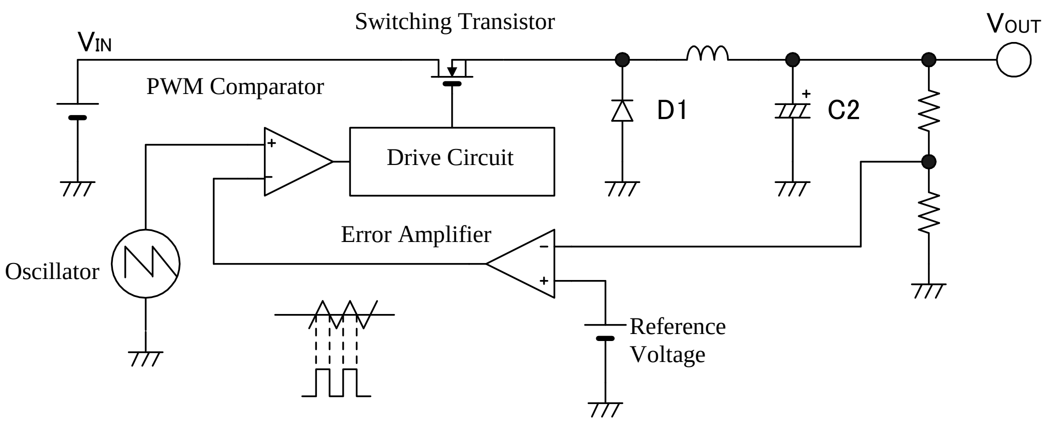
Component	Spec	Recommended materials
C1	220μF / 63V / Electrolytic capacitor	EMVY630GTR221MLHoS (Nippon Chemi-Con)
C2	470μF / 25V / Electrolytic capacitor	UUD1E471MNR1GS (nichicon)
C3, C5	0.1μF / 10V / Ceramic capacitor	GRM31BR11A105MA01B (MURATA)
C4	0.1μF / 50V / Ceramic capacitor	GRM21BR11H104MA01B (MURATA)
C6	0.1μF / 50V / Ceramic capacitor	GRM21BR11H104MA01B (MURATA)
C7, C8	0.1μF / 50V / Ceramic capacitor	GRM21BR11H104MA01B (MURATA)
C9	0.1μF / 50V / Ceramic capacitor	GRM21BR11H104MA01B (MURATA)
L1	47μH / Inductor	SLF12575T-470M2R7 (TDK)
D1, D2	1.5A / 60V / Schottky barrier diode	RK16 (Sanken)
R1	47Ω	-
R2	2kΩ (V_O = 5V)	-
R3	500Ω	-

3. Operational Description

● 3-1 PWM Output Voltage Control

In the SI-8010GL series, the output voltage is controlled by the PWM system and the IC incorporates the PWM comparator, oscillator, error amplifier, reference voltage, output transistor drive circuit etc. The triangular wave output (≈ 250KHz) 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.

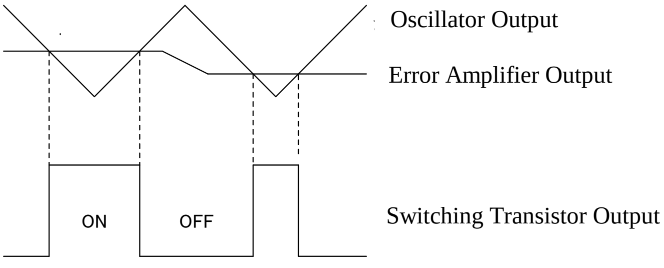
PWM Control Chopper Type Regulator Basic Configuration



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. When the output of the error amplifier is lowered, the time period where it exceeds the triangular wave of the oscillator is decreased 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 Diagram

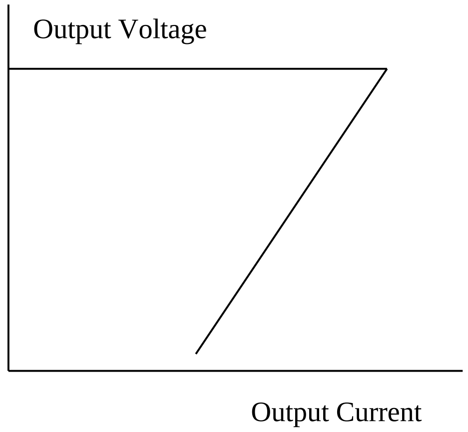


The rectangular wave output of the switching transistor is smoothed by the LC low pass filter composed of a choke coil and a capacitor to supply stabilized DC voltage to the load.

● 3-2 Overcurrent Protection / Thermal Shutdown

The SI-8010GL 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. When the overcurrent condition is released, the output voltage will be automatically restored.

Output Voltage Characteristic on Overcurrent

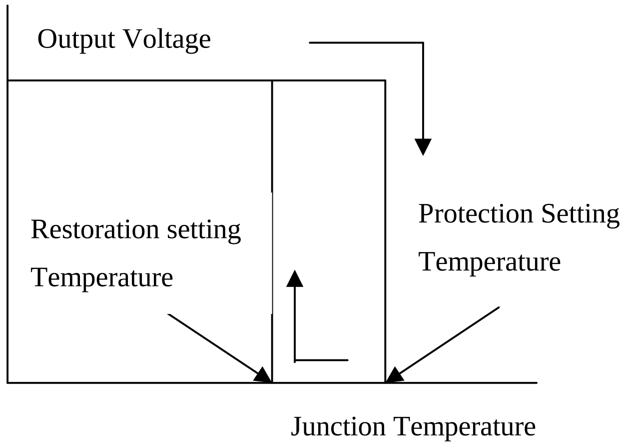


The thermal shutdown circuit detects the semiconductor junction temperature of the IC and when the junction temperature exceeds the set value, the output transistor is stopped and the output is turned OFF. When the junction temperature drops from the set value for overheat protection by around 15°C,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

Output Voltage Characteristic on Thermal Shutdown



4. Cautions

● 4-1 External Components

4-1-1 Choke coil L

The choke coil L1 plays a main role 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.

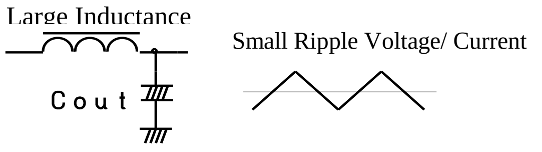
a) The choke coil should be fit for the switching regulator.

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

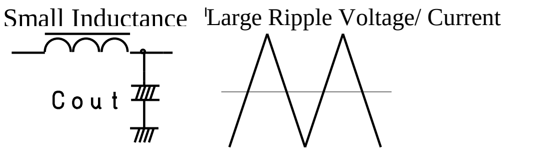
b) The inductance value should be appropriate.

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-8010GL: output current × 0.2- 0.3
- In the case that the output current to be used is approximately 1A 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 = 0.35A, frequency = 250kHz,

$$L1 = \frac{(25-5)\times 5}{0.35\times 25\times 250\times 10^{3}} \fallingdotseq 45.7uH$$

As shown above, the coil of about 47μH 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) 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 placed as close as to the regulator IC.

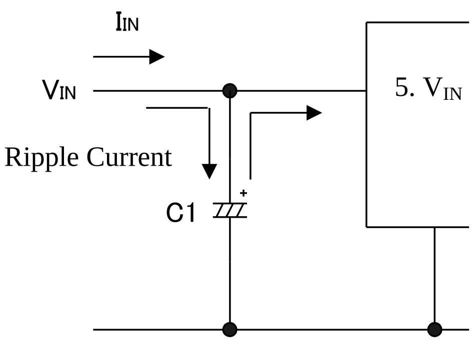
In addition, in the case that the smoothing capacitor of the AC rectifier circuit is located in the input circuit, the input capacitor may be also used as a smoothing capacitor, but similar attention should be paid.

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

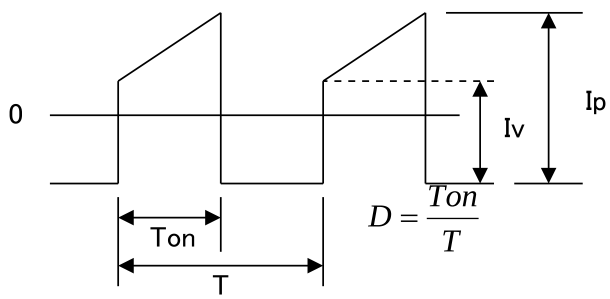
a) The requirement of withstand voltage shall be met.

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

Current Flow of C1



Current Waveform 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 = 3A, V_{IN} = 20V, Vo = 5V,

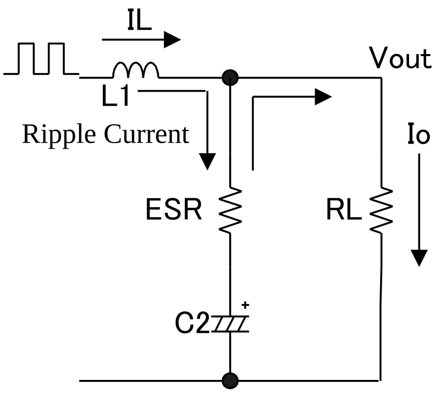
$$Irms \approx 1.2 \times \frac{5}{20} \times 3 = 0.9A$$

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

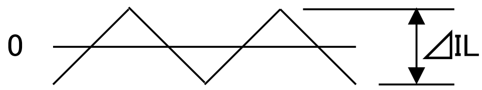
4-1-3 Output Capacitor C2

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.
The following points should be taken into consideration.

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.

a) 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.
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

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

b) DC equivalent series resistance (ESR)

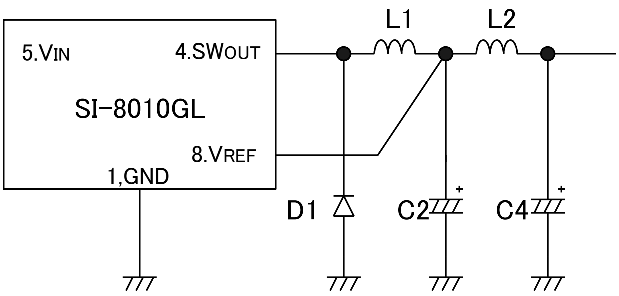
It is necessary for the stable operation to select the ESR properly. When the ESR is too large or too small, abnormal oscillation due to increase of ripple voltage or insufficient phase margin occurs respectively.

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, 25mV where 0.5% at V_{OUT} = 5V.) 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.

$$Vrip \approx \frac{(Vin - Vout)Vout}{L \cdot Vin \cdot f} ESR \quad ---(5)$$

$$Vrip \approx \Delta IL \cdot ESR \qquad ---(6)$$

However, if the ESR of the output capacitor is too low (10 - 20mΩ 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: 20μH

C4: 200μF

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.

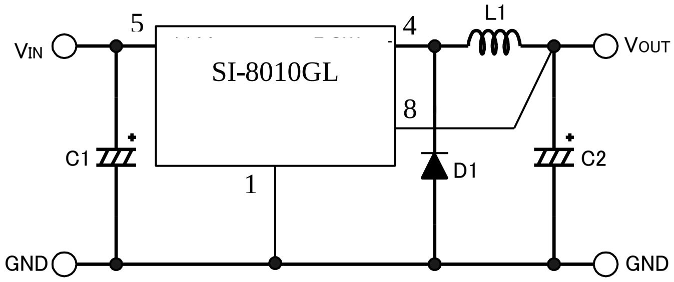
4-1-4 Flywheel Diode D1

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 destroyed by applying reverse voltage due to the recovery and ON voltage. In addition, since the output voltage from the SW_{OUT} terminal (pin 4) of the SI-8010GL series is almost equivalent to the input voltage, the flywheel diode with the reverse withstand voltage of the input voltage × 1.2 or higher should be used.

● 4-2 Pattern Design Notes

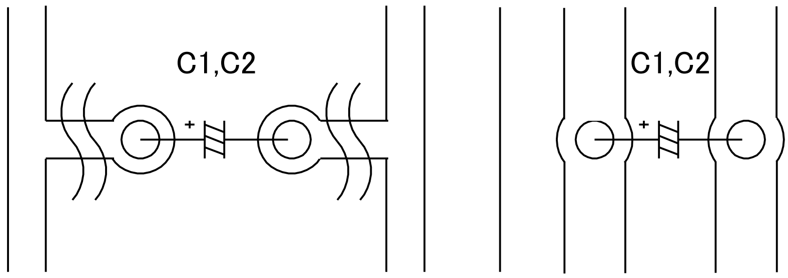
4-2-1 High Current Line

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



4-2-2 Input / Output Capacitor

The input capacitor C1 and the output capacitor C2 should be placed to the IC as close as possible. If the rectifying capacitor for AC rectifier circuit is on the input side, it can be used as an input capacitor. However, if it is not close to the IC, the input capacitor should be connected in addition to the rectifying capacitor. Since high current is discharged and charged through the leads of input/output capacitor at high speed, the leads should be as short as possible. A similar care should be taken for the patterning of the capacitor.



Improper Pattern Example Proper Pattern Example

4-2-3 Sensing Terminal

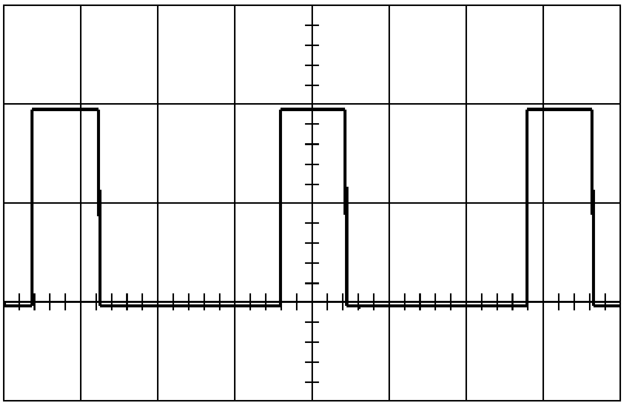
The output voltage sensing terminal Vos shall be connected near the output capacitor C2 as much as possible. If it is connected far from C2, it should be noted that abnormal oscillation may happen due to the low regulation and increased switching ripple.

● 4-3 Operation Waveform Check

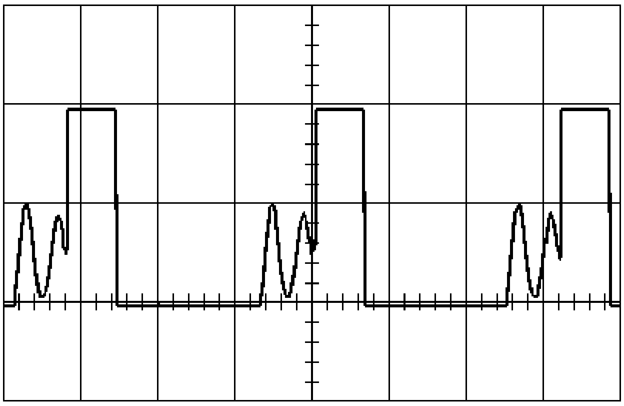
It can be checked by the waveform between the pin 1 and 4 (SW_{OUT} - GND waveform) of the SI-8010GL whether the switching operation is normal or not.

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

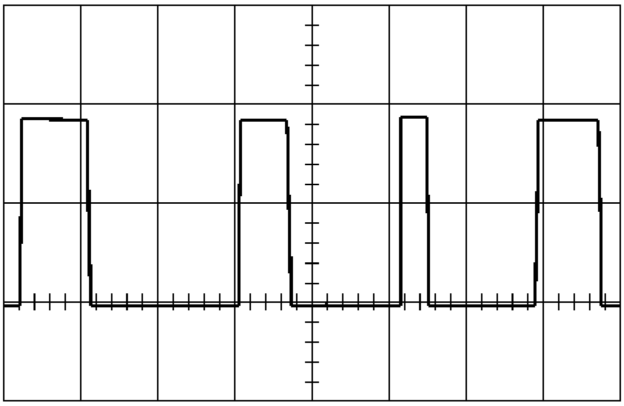
1. Normal Operation (continuous area)



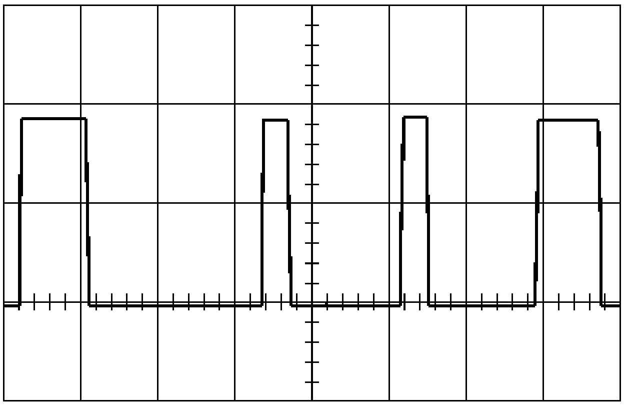
2. Normal Operation (discontinuous area)



3. When C1 is far from IC



4. When C2 is far 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.

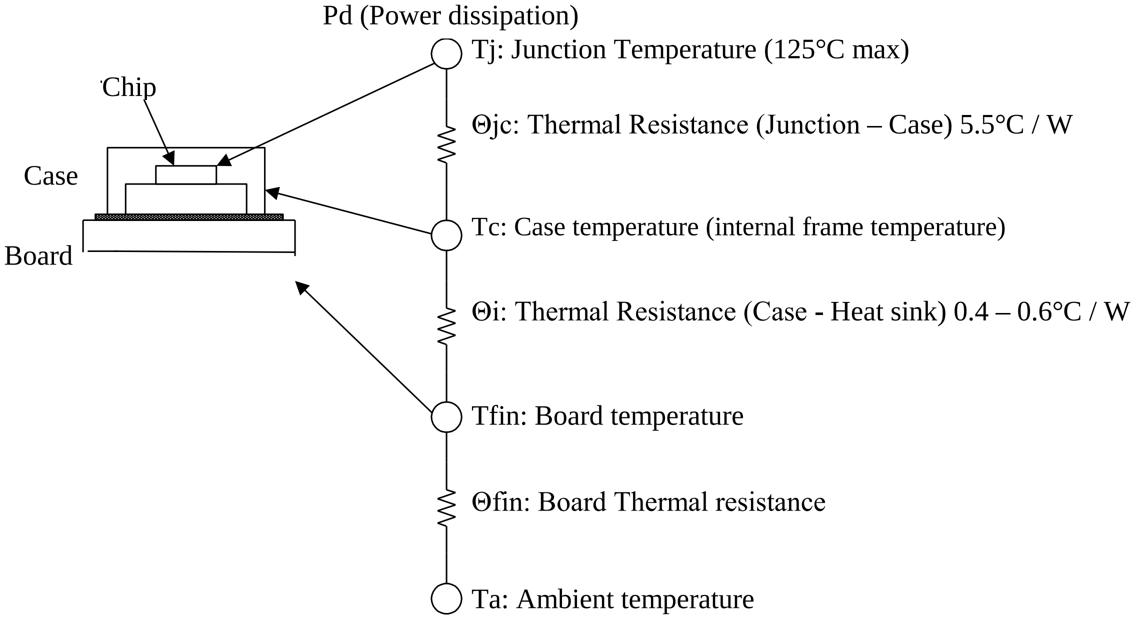
In the continuous area, the switching waveform is formed in the normal rectangular waveform (waveform 1) and in the discontinuous area, damped oscillation is caused in the switching waveform (waveform 2), but this is a normal operation without any problem.

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 Thermal Design

4-4-1 Calculation of Heat Dissipation

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



$$Pd = \frac{Tj - Tc}{\theta jc} \qquad --(7)$$

$$Pd = \frac{Tj - Tfin}{\theta jc + \theta i} \qquad --(8)$$

$$Pd = \frac{Tj - Ta}{\theta jc + \theta i + \theta fin} \qquad --(9)$$

The TjMAX is an inherent value for each product, therefore it must be strictly observed.

For this purpose, it is required to design the board pattern 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.

$$Pd = Vo \cdot Io\left(\frac{100}{\eta x} - 1\right) - Vf \cdot Io\left(1 - \frac{Vo}{Vin}\right) \qquad ---(10)$$

* 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:

$$\theta i + \theta fin = \frac{Tj - Ta}{Pd} - \theta jc \qquad ---(11)$$

An example of heat calculation for using SI-8010GL under the conditions of V_{IN} = 10V, V_{OUT} = 5V, I_{OUT} = 1.5A and Ta = 85°C is shown below. Where efficiency η = 87% , Vf = 0.5V from the typical characteristics,

$$Pd = 5 \times 1.5 \times \left(\frac{100}{87} - 1 \right) - 0.5 \times 1.5 \times \left(1 - \frac{5}{10} \right) \fallingdotseq 0.75W$$

$$\theta i + \theta fin = \frac{125 - 85}{0.75} - 28 \fallingdotseq 25.33^{\circ} C/W$$

As a result, the heat sink with the thermal resistance of 25°C /W or less is required. As described above, the thermal resistance of board 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, board temperature or case temperature at mounted should be checked.

4-4-2 Installation to Board

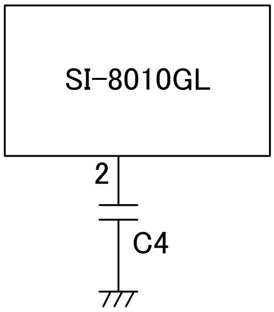
GND pattern

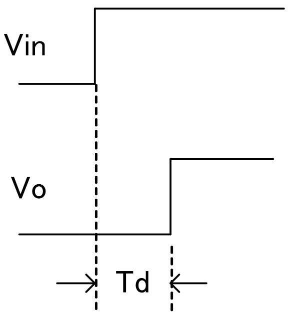
The SI-8010GL adopts a package which unifies the GND terminal (No.1 pin) and a frame in the IC. In order to enhance the heat dissipation effect, it is recommended to make the GND pattern wide.

5. Applications

5-1 Soft Start

When a capacitor is connected to No.2 terminal of the SI-8010GL, soft start operation can be made for the purpose of providing delay time from the application of input voltage to the rise of output voltage. By means of this operation, the state of high input voltage is realized prior to the operation of a regulator. In the case of the buck converter type switching regulator, as the input voltage becomes higher the input current is reduced, therefore the operation can be started with less current. In the case of the actual equipment, more or less variation takes place because of the influence from the rise time of input power supply. The C4 should be used with 4700 pF or less.



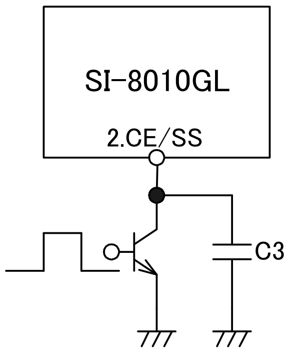


$$Td = \frac{3.2 \times C4}{15 \times 10^{-6}} (Sec)$$

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.



CE/SS + ON/OFF

5-3 Controllable Output Voltage

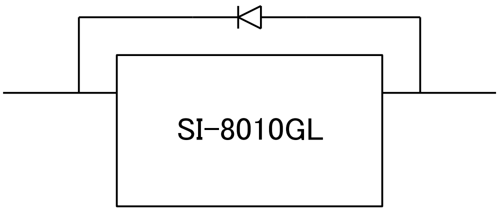
R2 and R3 are resistors for setting the output voltage. It should be set in a manner that I_{REF} is around 2mA.

The equation by which the values of R2 and R3 can be obtained is as follows:

$$R2 = \frac{(V_{OUT} - V_{REF})}{I_{REF}} = \frac{(V_{OUT} - 1)}{2 \times 10^{-3}} (\Omega), \quad R3 = \frac{V_{REF}}{I_{REF}} = \frac{1}{2 \times 10^{-3}} \fallingdotseq 500 (\Omega)$$

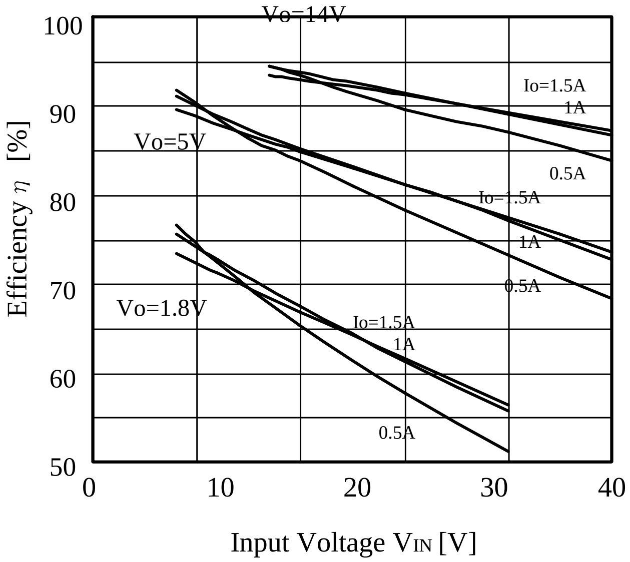
● 5-4 Reverse Bias Protection

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

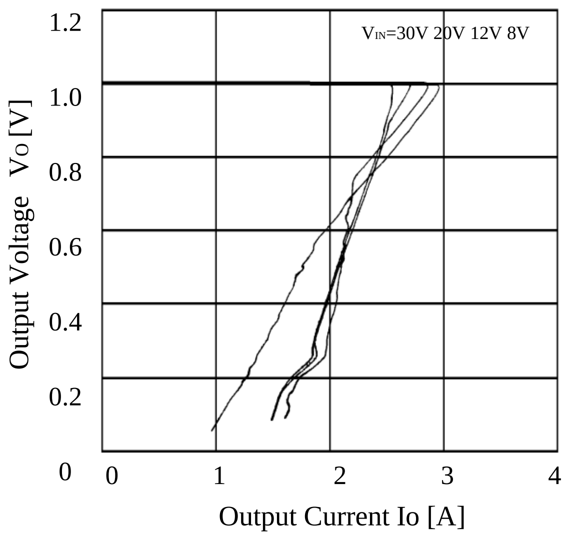


6. Typical Characteristics

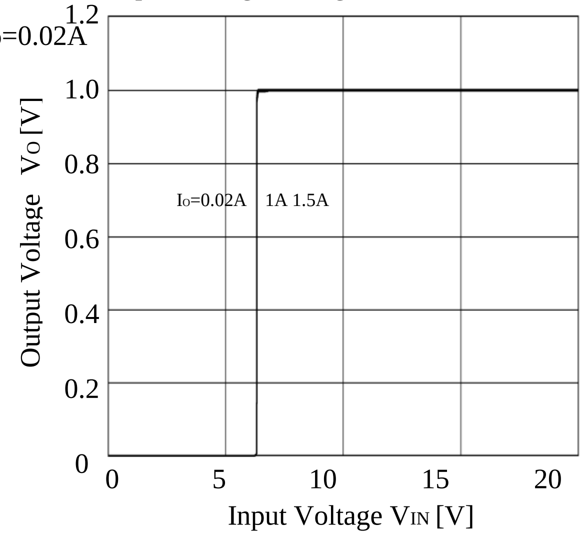
Efficiency



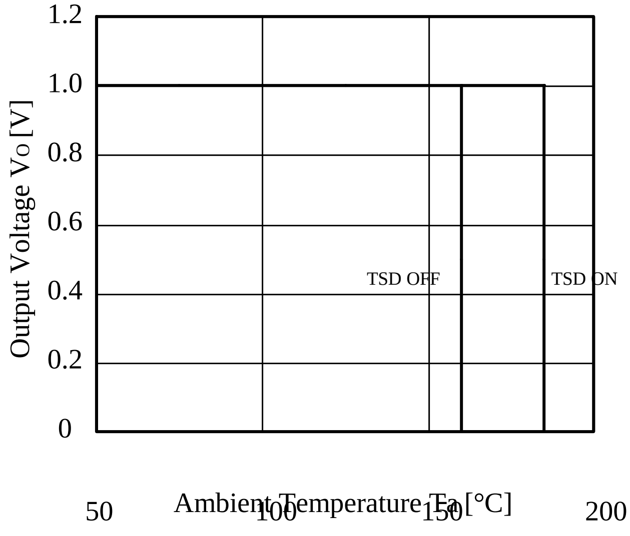
Characteristic of Overcurrent



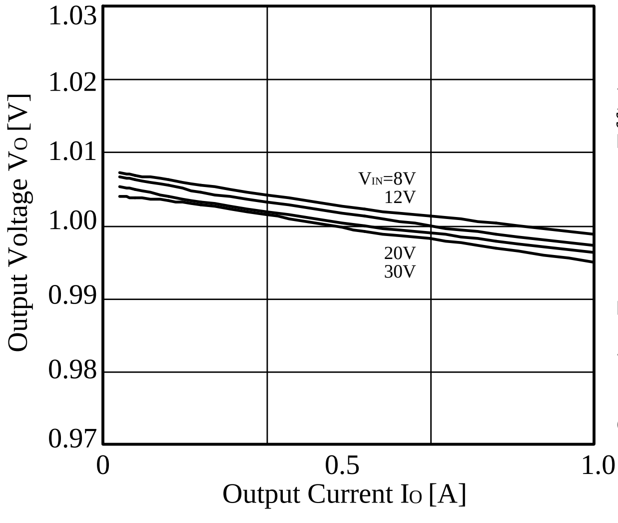
Output Voltage Rising *Load = C.R
IO=0.02A



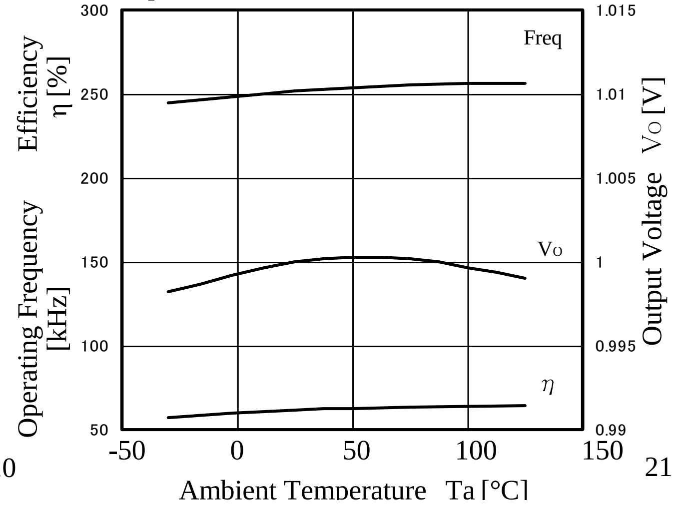
Thermal Shutdown Protection VIN=12V,



Load Regulation Characteristics



Temperature Characteristics VIN=12V, IO=1A



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.

Notice

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