Application Note

Low loss Series Regulator IC

SI-3000KF series

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SANKEN ELECTRIC CO., LTD.

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1. General Description

The SI-3000KF is a series regulator IC using a hyposaturation type PNP bipolar transistor in the power section and it can be used with the low difference of input/output voltages. It is provided with an ON / OFF terminal which operates in Active High mode and the current consumption of circuits at OFF time is zero.

● 1-1 Features

- Output current 1A

  Output current is 1A at maximum with the outline of TO220F-5.

- Hyposaturation (Vdif = 0.6 Vmax / Io = 1A)

  It can be designed with low difference of input/output voltages.

- ON/OFF function

  The ON/OFF terminal which can be directly controlled by TTL logic signals is provided.

- Low current consumption

  Current consumption of circuits at OFF time is zero.

  Dark current at no load is 600μA at maximum.

- High ripple attenuation ratio

  75dB: F = 100 - 120kHz at Vo = 5V

- Built-in Overcurrent protection / Thermal shutdown

  The automatic restoration and Foldback type overcurrent protection and Thermal shutdown circuit are built in.

● 1-2 Application

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

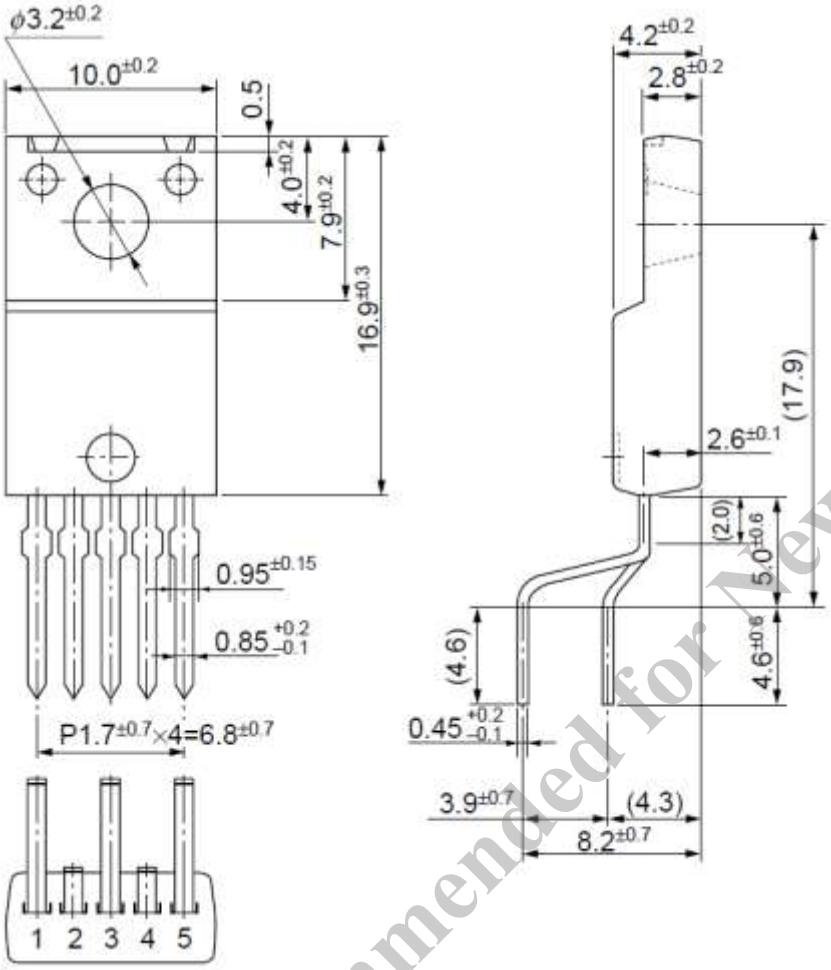
● 1-3 Type

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

2. Specification

Unit: mm

● 2-1 Package Information



Pin assignment

1. Vc
2. V_{IN}
3. GND
4. Vout
5. ADJ

Resin sealed type

Non-combustibility: UL standards 94V-0

Product mass: about 2.3 g

● 2-2 Ratings

2-2-1 Absolute Maximum Ratings Ta = 25°C

Parameter	Symbol	Ratings	Unit	Remarks
		SI-3010KF		
DC Input Voltage	V_{IN}	35*1	V	
Output Control Terminal Voltage	Vc	V_{IN}	V	
DC Output Current	Io	1.0	A	
Power Dissipation	P_{D1}	16.6	W	With infinite heatsink
	P_{D2}	1.72	W	Without heatsink, stand-alone operation
Junction Temperature	Tj	−40 to +125	°C	
Storage Temperature	Tstg	−40 to +125	°C	
Operating Ambient Temperature	Top	−40 to +100	°C	
Thermal Resistance (Junction to Case)	θj-c	6.0	°C/W	
Thermal Resistance (Junction to Ambient Air)	θj-a	58	°C/W	Without heatsink, stand-alone operation

*1: A built-in input-overvoltage-protection circuit shuts down the output voltage at the Input Overvoltage Shutdown Voltage of the electrical characteristics.

2-2-2 Recommended Conditions

Parameter	Symbol	Ratings	Unit
		SI-3010KF	
Input Voltage Range	V_{IN}	2.4*2 to 27*1	V
Output Current Range	Io	0 to 1.0*1	A
Output Voltage Variable Range	V_{OADJ}	1.1 to 16	V
Operating Ambient Temperature	T_{op}	−30 to +85	°C
Operating Junction Temperature	T_j	−20 to +100	°C

*1: V_{IN} (max) and Io (max) are restricted by the relationship P_D (max) = (V_{IN} – Vo) × Io = 16.6W.

*2: Refer to the Dropout Voltage parameter.

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

Parameter		Symbol	Ratings SI-3010KF min.	typ.	max.	Unit
Reference Voltage		V_{ADJ}	0.98	1.00	1.02	V
		Conditions		V_{IN}=7V, I_O=0.01A, V_C=2V, V_O=5A		
Line Regulation		ΔV_{OLINE}			30	mV
		Conditions		V_{IN}=6 to 15V, I_O=0.01A, V_C=2V, V_O=5A		
Load Regulation		ΔV_{OLOAD}			75	mV
		Conditions		V_{IN}=7V, I_O=0 to 1A, V_C=2V, V_O=5A		
Dropout Voltage		V_{DIF}			0.3	V
		Conditions		I_O=0.5A, V_C=2V, V_O=5V		
					0.5	
		Conditions		I_O=1.0A, V_C=2V, V_O=5V		
Quiescent Circuit Current		I_q			600	μA
		Conditions		V_{IN}=7V, I_O=0A, V_C=2V		
Circuit Current at Output OFF		I_q (OFF)			1	μA
		Conditions		V_{IN}=7V, V_C=0V		
Temperature Coefficient of Output Voltage		$\Delta V_O/\Delta T_a$		±0.5		mV/°C
		Conditions		V_{IN}=7V, I_O=0.01A, V_C=2V, Tj=0 to 100°C, V_O=2.5V		
Ripple Rejection		R_{REJ}		75		dB
		Conditions		V_{IN}=7V, I_O=0.1A, V_C=2V, f=100 to 120Hz, V_O=5V		
Overcurrent Protection Starting Current*3		I_{S1}	1.1			A
		Conditions		V_{IN}=7V, V_C=2V		
Vc Terminal	Control Voltage (Output ON)*4	$V_{C, IH}$	2			V
		Conditions		V_{IN}=7V		
	Control Voltage (Output OFF)	$V_{C, IL}$			0.8	V
		Conditions		V_{IN}=7V		
	Control Current (Output ON)	$I_{C, IH}$			40	μA
		Conditions		V_{IN}=7V, V_C=2V		
	Control Current (Output OFF)	$I_{C, IL}$	–5	0		μA
		Conditions		V_{IN}=7V, V_C=0V		
Input Overvoltage Shutdown Voltage		V_{OVP}	33			V
		Conditions		I_O=0.01A		

*1: Is1 is specified at the 5% drop point of output voltage Vo on the condition that VIN = overcurrent protection starting current, Io = 10mA.

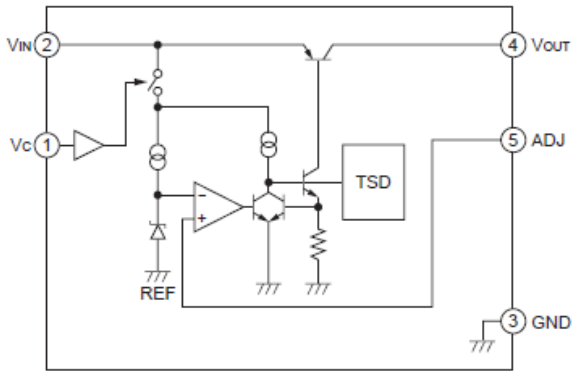
*2: Output is OFF when the output control terminal Vc is open. Each input level is equivalent to LS-TTL level. Therefore, the device can be driven directly by LS-TTLs.

*3: SI-3000KFE cannot be used in the following applications because the built-in foldback-type overcurrent protection may cause errors during start-up stage;

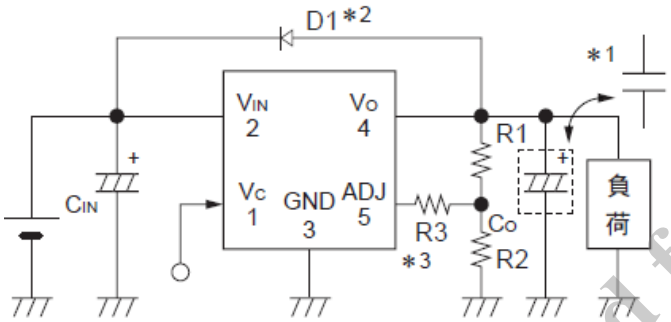
(1) Constant current load (2) Positive and negative power supply (3) Series-connected power supply (4) Vo adjustment by raising ground voltage

● 2-3 Circuit Diagram

2-3-1 Block Diagram



2-3-2 Typical Connection Diagram



C_{IN}: Input Capacitor (over 22μF)

Co: Output Capacitor (over 47μF)

In the case that capacitors having low ESR such as ceramic capacitors are used for output capacitors, they may oscillate.

*1: D1: Reverse biased protection diodes

In the case of reverse bias between input and output, this diode will be required.

(Recommended diodes: SJPL-H2 made by Sanken)

R1, R2: resistors for setting output voltages

Output voltages can be adjusted by connecting R1 and R2 as shown in the above figure.

R2: 10kΩ is recommended.

$$R1=(Vo-V_{ADJ}) \quad / \quad (V_{ADJ}/R2)$$

*2: In the case that Vo ≤ 1.5V is set, R3 should be inserted. 10kΩ is recommended for R3.

3. Operational Description

● 3-1 Voltage Control

In the SI-3000KF series, the driving circuit is controlled by comparing the reference voltage with the ADJ terminal voltage (voltage divided by Vo detection resistor in fixed output products) to stabilize the output voltage by varying the voltage between the emitter and collector of a main PNP power transistor. The product of voltage between emitter and collector and the output current at this moment is consumed as heat.

● 3-2 Overcurrent Protection

3-2-1 Overcurrent Protection Characterization for SI-3010KF

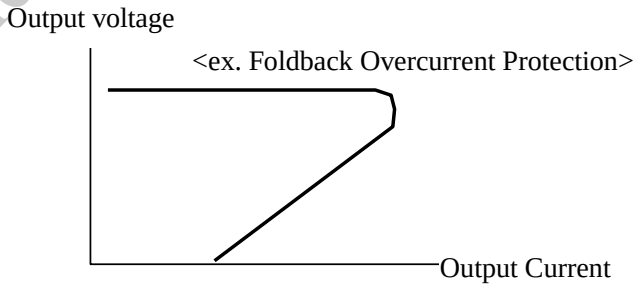
The foldback type overcurrent protection function is provided in the SI-3010KF. After operation of the overcurrent protection function, if the load resistance decreases and the output voltage drops, the output current of products is squeezed to reduce the increase of loss. However, in the case of the foldback type overcurrent protection function, since current limiting is also made at start-up, the function may not be used for the following applications, as it may cause a start-up error.

(1) Constant current loads

(2) Plus/minus power supply

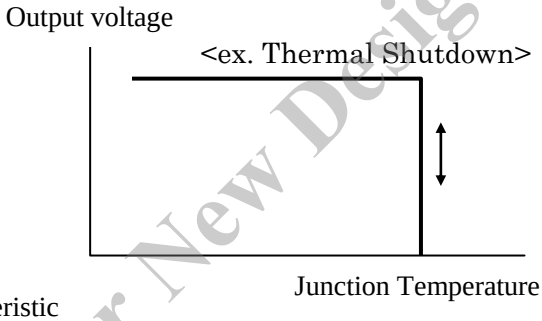
(3) DC power supply

(4) Output voltage adjustment by grounding-up



● 3-3 Thermal Shutdown

This IC is provided with the overheat protection circuit which detects the semiconductor junction temperature of the IC to limit the driving current, when the junction temperature exceeds the set value (around 150°C). Since the minimum operating temperature of the overheat protection circuit is 130°C, the thermal design of Tj <125°C is required. Since the overheat protection has no hysteresis, as soon as the overload state is released and Tj falls below the set temperature, the normal operation is automatically restored. When the overheat protection function is operated in the overload state, the output voltage falls, but at the same time the output current is decreased and in the consequence, overheat protection operation and automatic restoration are repeated in a short interval, resulting eventually in the waveforms of output voltage oscillation.



*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 Input Capacitor CIN

The input capacitor is required to eliminate noise and stabilize the operation and values of 0.47μF - 22μF are recommended. Any of ceramic capacitors or electrolytic ones may be used for the input capacitor.

4-1-2 Output Capacitor Co

In the output capacitor Co, larger capacitance than the recommended value is required for phase compensation. Equivalent series resistance values (ESR) of capacitors are limited, and depending on products, therefore the type of recommended capacitors is limited.

- Recommended values of SI-3010KF: 2Ω > ESR > 0.2Ω

It is recommended to use electrolytic capacitors. When capacitors with extremely high ESR such as ceramic capacitors, functional polymer capacitors etc., are used, phase margin is decreased, possibly causing the oscillation of output voltage. Therefore these capacitors can not be used.

4-1-3 Reverse bias protection diode D1

In the case of falling-down of the input voltage, it is recommended to insert a protection diode D1 against the reverse bias between input and output. However, in the case of setting the Vout < 3.3V or lower, D1 is not required including the case of reverse bias. In order to select a suitable D1, it should be taken into consideration that the diode has adequate forward current withstand voltage against the instantaneous discharge of energy stored in Cout.

The permissible value of the forward current per unit time of diode is specified in I_{FSM} (A) and in the case of our diode, it is specified at 50Hz half wave (10ms), but it should be noted that different companies may specify different times. The selection of diode should be made by converting the specified time into the actual discharging time so as to meet the required I_{FSM} (A). The discharging time of Co is normally shorter than 1ms, but it is recommended to do the conversion with 1ms in consideration of margin.

For conversion into I_{FSM}, calculation should be made by using the equations (1) and (2).

$$\left(\frac{I_{FSM}}{\sqrt{2}}\right)^2 * t1 = X \qquad \text{--- (1)}$$

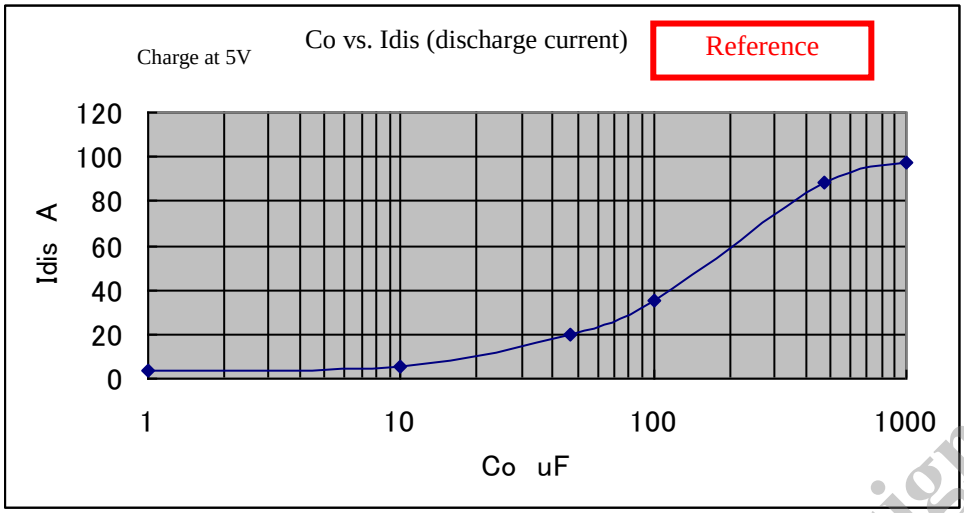
As for I_{FSM}, please refer to the catalog of each company.

t1 = specified time in catalog of each company

$$\text{Converted IFSM} = \sqrt{\frac{2 * X}{t2}} \qquad \text{--- (2)}$$

t2: converted time (discharging time of Co)

<Graph 1>



On the assumption of Cout = 470μF, I_{FSM} of around 90A or more (in 1ms time period) is required and according to our specifications of diode, I_{FSM} is specified for 10ms, therefore the diode of 30A has the tolerated dose of 94.8A (in 1ms) to prove that it is usable.

● 4-2 Pattern Design Notes

4-2-1 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 no close to the IC, the input capacitor should be connected in addition to the rectifying capacitor.

4-2-2 ADJ Terminal (Output Voltage Set-up for SI-3010KF)

The ADJ terminal is a feedback detection terminal for controlling the output voltage. The output voltage set-up is achieved by connecting R1 and R2.

SI-3010KF: it should be set in a manner that I_{ADJ} is around 100μA.

R1, R2 and output voltage can be obtained by the following equations:

$I_{ADJ}=V_{ADJ}/R2$ (*V_{ADJ} = 1. 0V ± 2% (SI-3010KF), R2 = 10kΩ recommended)

$R1 = (Vo-V_{ADJ}) / I_{ADJ}$ $R2 = V_{ADJ} / I_{ADJ}$

$Vout = R1\times (V_{ADJ} / R2) + V_{ADJ}$

5. Applications

● 5-1 Output ON / OFF Control

The ON/OFF control of output can be made by directly applying voltage to No. 1 Vc terminal. When the Vc terminal is open, the operation is in OFF. The Vc terminal is in OFF below 0.8V and in ON at above 2V.

● 5-2 Thermal Design

5-2-1 Calculation of heat dissipation

As the junction temperature Tj (MAX) is a product-specific value, it must be observed strictly. For this purpose, heat sink design (decision of θfin) which is appropriate for Pd (MAX) and Ta MAX is required. This is graphically shown in the heat derating curve for easy understanding. The heat dissipation design is done in the following procedure.

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

2) The maximum loss PdMAX which varies the input/output conditions is obtained.

$$Pd = (V_{IN} - V_{OUT})xI_{OUT}$$

3) The area of heat sink is determined from the intersection point in the heat derating curve.

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:

$$\theta fin = \frac{Tj - Ta}{Pd} - \theta jc$$

An example of heat calculation for using SI-3010KF under the conditions of V_{IN} = 8V, Vo = 5V, Io = 1A and Ta = 85°C is shown below. As Tjmax = 125° C,

$$Pd = (8V - 5V)x1A = 3W \qquad \theta j\text{-}c: 6°C/W$$

$$\theta fin = \frac{125-85}{3} - 6 \doteqdot 7.33^{\circ} C/W$$

As a result, the heat sink with the thermal resistance of 7.33°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.

5-2-2 Installation to Heat Sink

Selection of silicon grease

When the SI-8000FFE 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:

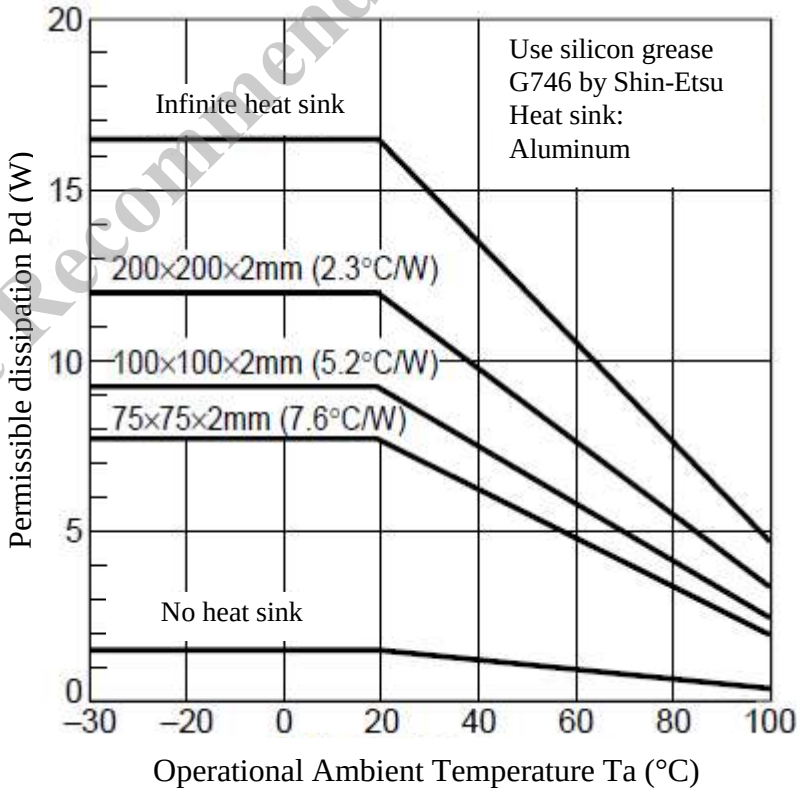
Types	Suppliers
G746	Shin-Etsu Chemical Co., Ltd.
SC102	Toray Silicone Co., Ltd.
YG6260	Momentive Performance Materials Inc.

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-3000KF, 58.8 - 68.6N cm (6.0 - 7.0kg cm) are recommended.

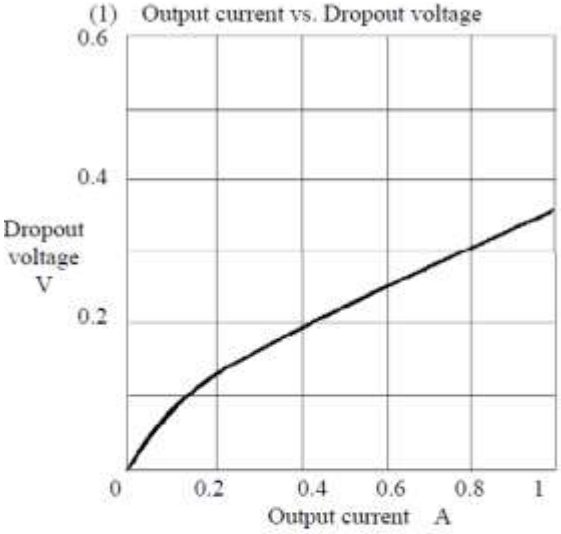
- SI-3000KF derating curve



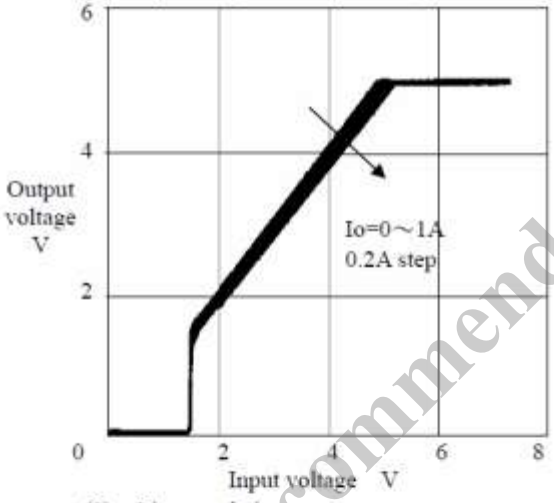
6. Typical Characteristics

(Ta = 25°C) *Set Vout = 5V (R2 = 10kΩ)

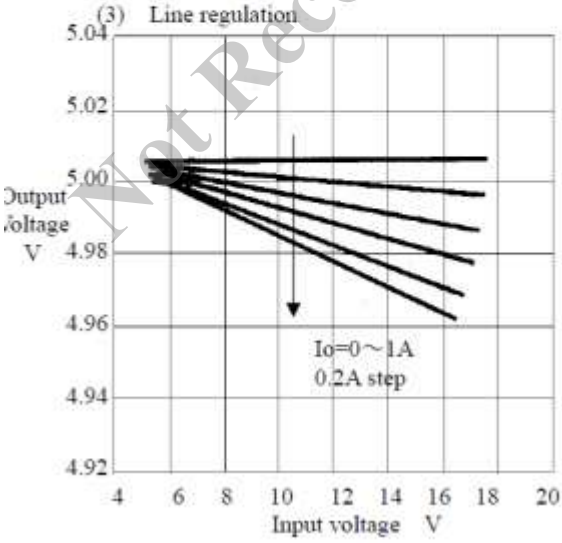
(1) Output current vs. Dropout voltage



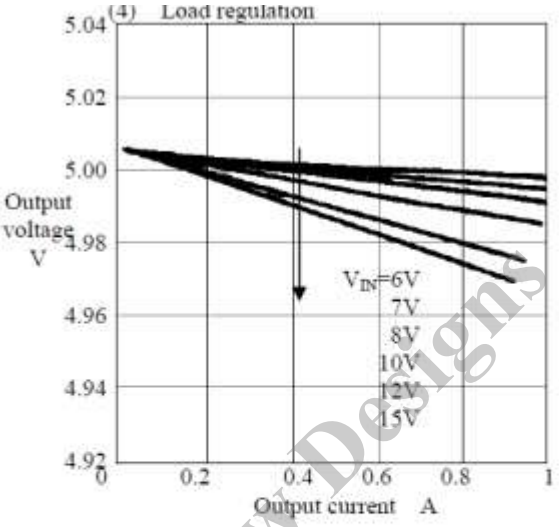
(2) Input voltage vs. Output voltage



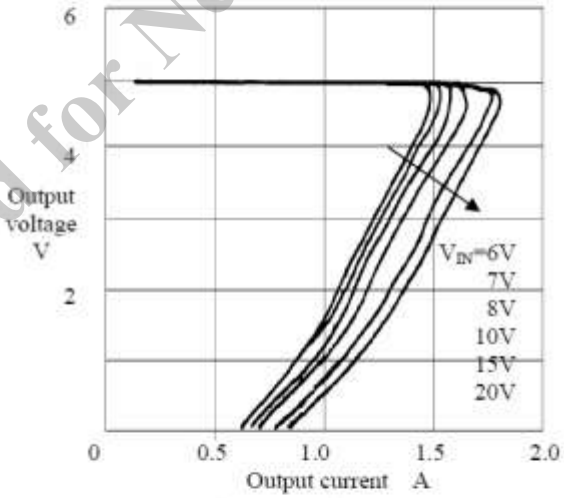
(3) Line regulation



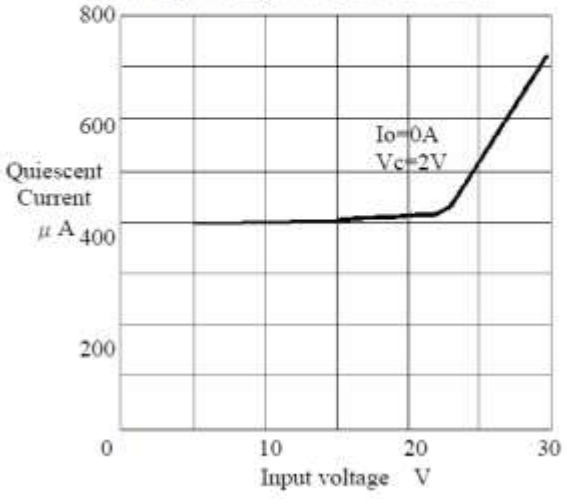
(4) Load regulation



(5) Over current protection

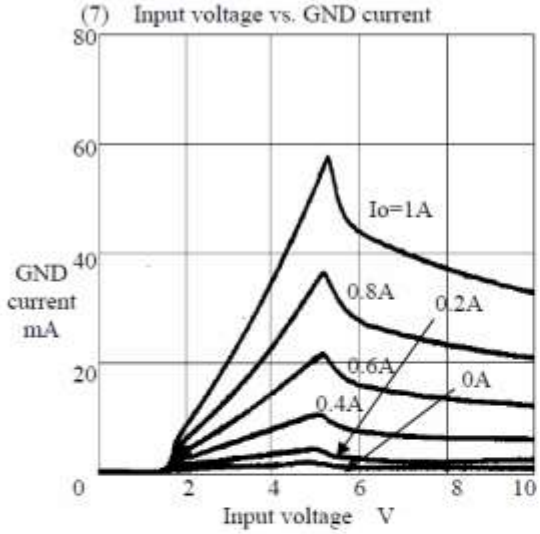


(6) Input voltage vs. Quiescent current

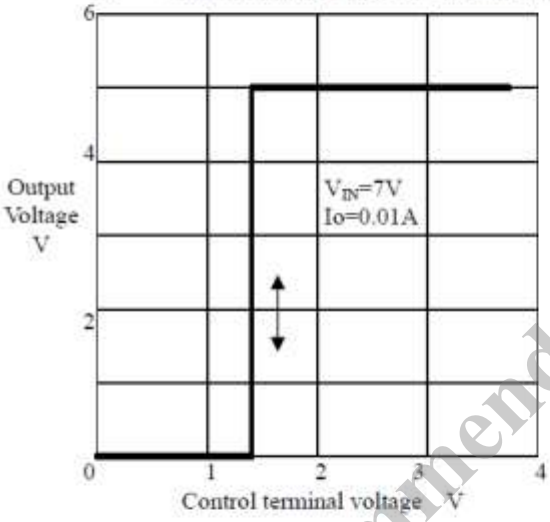


(Ta = 25°C)　*Set Vout = 5V (R2 = 10kΩ)

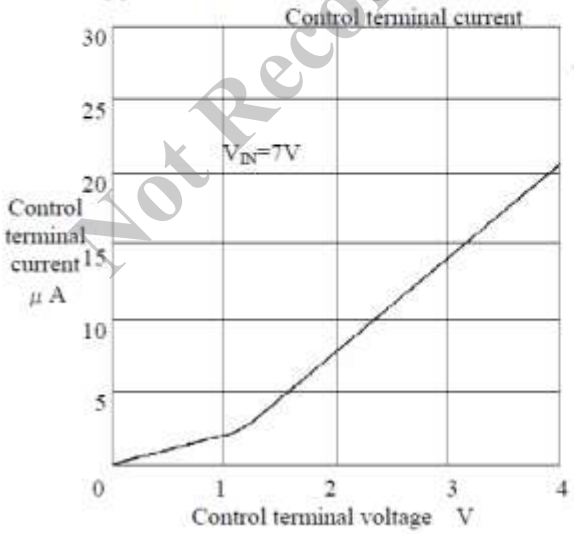
(7) Input voltage vs. GND current



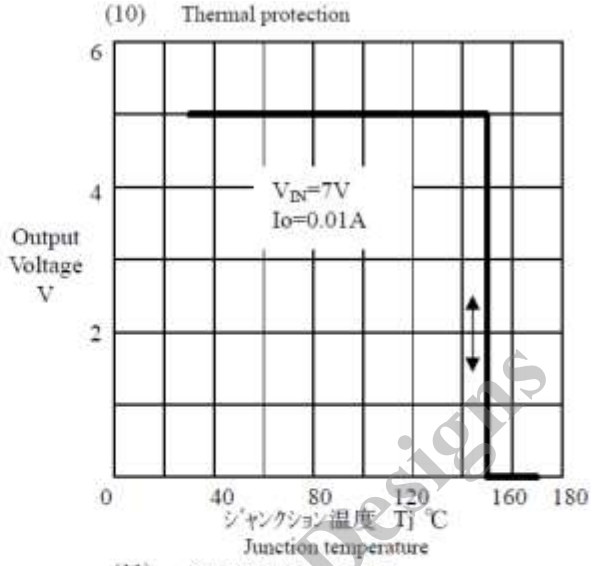
(8) Control terminal voltage vs. Output voltage



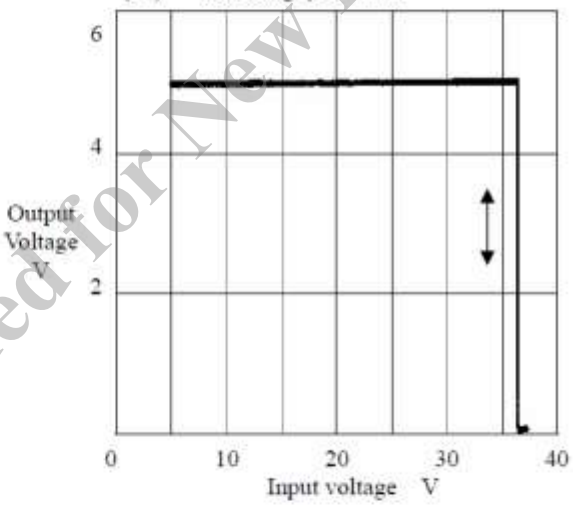
(9) Control terminal voltage vs. Control terminal current



(10) Thermal protection



(11) Over Voltage protection



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