Linear Regulator Series

BUxxTD3 Series Application Information

The information in this application note only provides hints for IC mounting. For this reason, these notes should not be considered as an IC quality explanation or a warranty. See the latest data sheet for the IC standard values. Also, note that the application circuits used in the explanations for each item have been simplified. Be sure to verify operations using the actual application.

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1. Typical Application Circuit

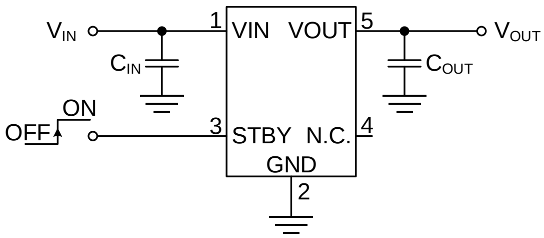


Figure 1-1. When using the output ON/OFF function

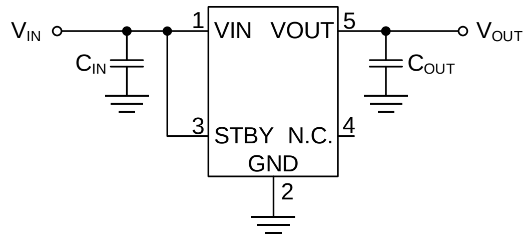
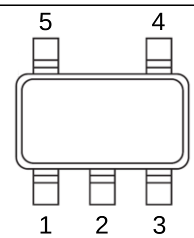


Figure 1-2. When not using the output ON/OFF function

Package	SSOP5
Pin configuration (Top View)	

Pin number	Pin name	Function
1	VIN	Input pin Power is supplied to the IC through the input pin. To stabilize the pin input, connect VIN and GND with a ceramic capacitor. Place the capacitor near the pin. → See page 5.
2	GND	Ground This is the ground for the regulator circuit.
3	STBY	Enable pin The IC can be set to shutdown status by using the STBY pin. Set to the pin to “High” to turn output on, and to “Low” to turn output off. → See page 3.
4	N.C.	Unconnected pin This is not connected to the internal circuit. Leave this open or connect GND.
5	VOUT	Output pin Supplies electrical power to the load. To prevent vibrations on this pin, connect VOUT and GND with a capacitor. → See page 4.

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2. Output voltage tolerance

The maximum output voltage tolerance is the sum of the output voltage tolerance, the line regulation tolerance and the load regulation tolerance.

3. Study of input/output voltage difference and characteristics

For the minimum value of the input voltage, the minimum input/output voltage at the load current to be used is read from the "Input/output voltage difference vs. output current" graph on the data sheet, to get the voltage added to the output voltage. As this time, this works as DC, but the control capacity is degraded. When there are fluctuations in the load, a large current cannot be supplied in a short period of time from input to output, as the input/output voltage difference is small. In other words, the load responsiveness will slow down. The slowness in responsiveness will also show up as a degradation in PSRR characteristics. If only the minimum voltage amount of the input/output voltage difference is ensured because efficiency is emphasized, the expected characteristics of the LDO will not be achieved. Increase the input voltage until the high-speed load responsiveness and PSRR capabilities are achieved, and find a compromise between efficiency and each characteristic.

4. Output control (STBY) pin

The output can be turned on/off by using the STBY pin. When STBY is at a low level, VOUT will turn off; and as the operations of the entire IC will be turned off, the current consumption will be zero. When STBY is at the high level, the IC turns on, and VOUT turns on. To make certain that IC is turned on/off, apply the voltage that is listed in the electrical characteristics on the data sheet for the STBY pin voltage. For the designed reference values, the threshold median value is approximately 0.8 V, the tolerance is around ±0.1 V, the temperature characteristic is around 1.0 V to 0.7 V (-40°C to +85°C), and overall is around 0.6 V to 1.1 V.

The STBY pin is an output voltage on/off control pin and operates as a switch, but is designed based on the assumption that switching between High/Low on the normal STBY input will be over a short time. Stabilize the STBY pin at the midpoint potential of the High/Low switch. At the intermediate potential, the output voltage may become unstable.

There are no restrictions on the start sequence for VIN and STBY.

When not using the output control function, connect the STBY pin to VIN. At this time, a series resistor is unnecessary.

The delay time between when the STBY pin reaches "High" and the output voltage starts is approximately 5 µs (design reference value; Figure 4-1).

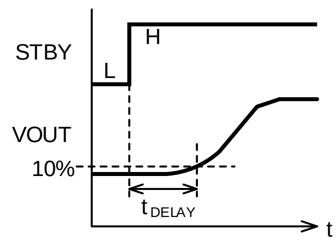

Figure 4-1. Definition of startup delay time

Controlling the STBY pin via mechanical switch may cause chattering in the output voltage, due to chattering in the switch. Insert an RC filter before the STBY pin, and make sure that the chattering waveform does not reach the STBY pin (upper part of Figure 4-2). If the wiring between the STBY pin and switch is long, a large pulse wave may be generated due to the inductance component of the wiring; and if this voltage exceeds the voltage capacity of the STBY pin, the IC may break down. It is necessary to insert an RC filter before the STBY pin, in order to lower the peak value of the pulse waveform (lower part of Figure 4-2). Change the C value to adjust the waveform.

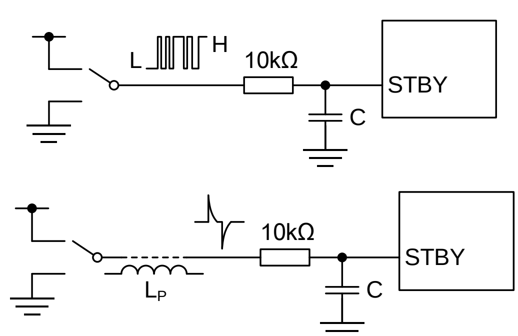

Figure 4-2. RC filter circuit for STBY pin

5. Output Discharge

An output discharge circuit is capable of synchronizing with timing to turn off the regulator output and forcedly discharging the output capacitor charge through the STBY pin. When power management is frequently (quickly) performed such as in a portable device, it takes time for the output capacitor to discharge naturally. By reducing this time with forced discharge, you may program the on/off sequence of each system block easily. The data sheet describe discharge resistance values.

To activate this function, voltage must be always supplied to the IC VIN pin and the output must be controlled through the STBY pin. By controlling output on/off using the voltage from the VIN pin, the voltage turns off on the VIN pin and the power supply to the output discharge circuit. Accordingly, this function is disabled, thus causing natural discharge.

6. Output capacitor

Place the output capacitor within 3 cm of the VOUT-GND pin IC, in order to stabilize the loop. Connect a capacitor with an actual capacitance of 0.22 µF or greater, considering the tolerance and temperature characteristics. If the capacitance is too small, oscillation may occur. Although there is no limit to the maximum value for the output capacitance, the following points must be considered. Increasing the capacitance will lengthen the charging time when the power is on, and the discharging time when the power is off. Since it is possible that the IC can be damaged when turning off the power due to an input and output voltage inversion, which causes a large current to flow back into the IC, connect a reverse current bypass diode or a reverse current protection diode.

Refer to Figure 6-1 for the ESR. This graph is based on an evaluation circuit for Figure 6-2, and is not perfectly equal to the capacitor that is actually used. Also, as this is based on the IC alone and the resistive load, it will change in reality due to the wiring impedance and input power impedance on the board. For this reason, check sufficiently whether there are oscillations by using the conditions of the final product.

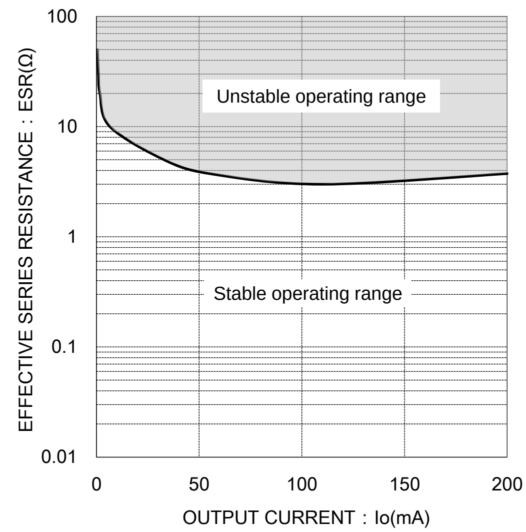

Figure 6-1. ESR stable operating range

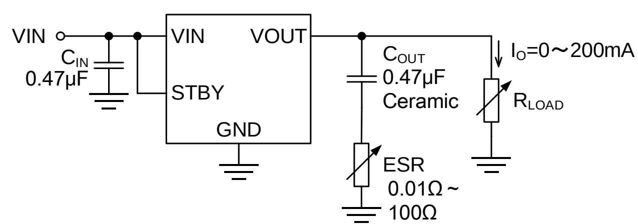

Figure 6-2. ESR stable operating range evaluation circuit

When using a ceramic capacitor, we recommend the use of an X5R or X7R, which have good temperature characteristics. Do not use Z5U, Y5V or F, which have large capacitance variances (Figure 6-3). Although the capacitance value will fall below the nominal value due to differences in tolerance, temperature characteristics and DC bias characteristics, set it so that the capacitance does not fall below the minimum value (0.22 µF). For the DC bias characteristics, the capacitance tends to drop more with smaller sizes (Figure 6-4).

STD	Char	Temperature Characteristic	
		TEMP Range	Capacity Change Rate
JIS	B	-25 to +85 °C	±10%
EIA	X5R	-55 to +85 °C	±15%
EIA	X7R	-55 to +125 °C	±15%
EIA	X7U	-55 to +125 °C	+22%, -56%
JIS	F	-25 to +85 °C	+30%, -80%
EIA	Y5V	-30 to +85 °C	+22%, -82%
EIA	Z5U	+10 to +85 °C	+22%, -56%
EIA	Z5V		+22%, -82%

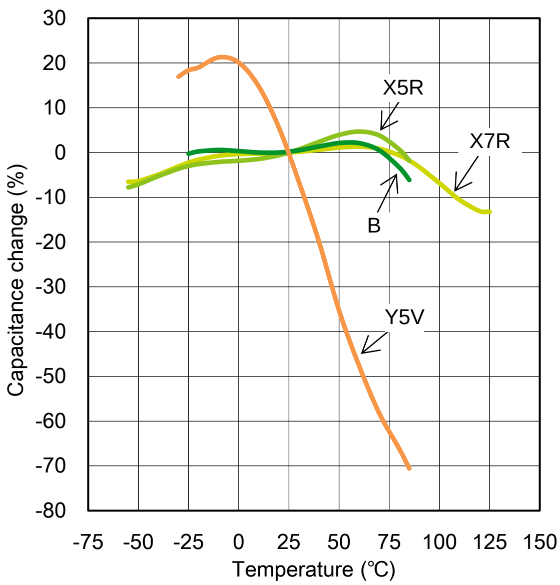

Figure 6-3. Temperature characteristic of major high dielectric constant multilayer ceramic capacitor

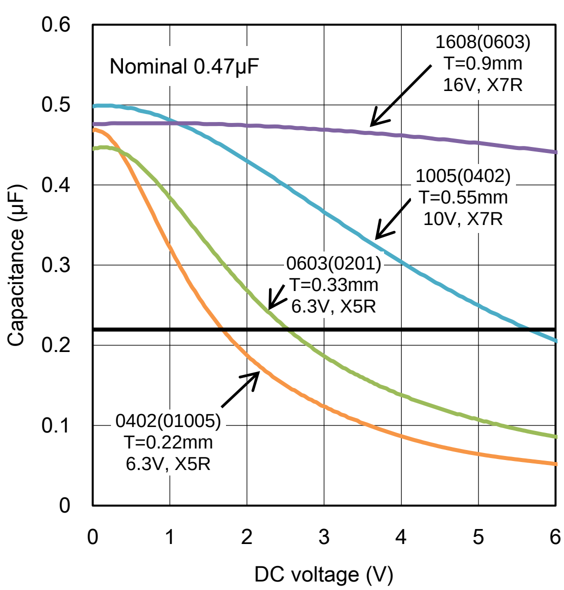

Figure 6-4. DC bias characteristic of high dielectric constant multilayer ceramic capacitor, comparison by size

Although electrolytic capacitors are inexpensive and offer a large capacitance, caution must be used, as the electrolyte may harden at low temperatures, leading to a sudden drop in capacitance and an increase in ESR. Also, if the heat from the LDO reaches the electrolytic capacitor, the electrolyte will become hot, which has an impact on the lifespan of the capacitor. To resolve this, place the electrolytic capacitor further away so that it does not get too hot, or reduce the width of the copper wiring to the minimum current capacity tolerance, so that heat is not easily transmitted from the LDO.

If the fluctuations in the load current are abrupt, ripple voltage may occur in output. To reduce the ripple voltage, increase the capacitance of the output capacitor. Since ceramic capacitors with a large capacitance are expensive, you can reduce costs by adding an aluminum electrolytic capacitor, using small-capacitance ceramic capacitors in parallel as a bulk capacitor. Increasing the output capacitance will increase the electrical charge that charges the output capacitor from the input side. For this reason, a voltage drop may occur if the load responsiveness of the input side power is not good. To prevent this, use a larger input capacitor that is appropriate for the output capacitance.

7. Input capacitor

The purpose of the input capacitor is to keep down the phase fluctuations in the power line during circuit operations, stabilizing the IC input. When the input trace is particularly long or when the input power impedance is high, the input capacitor is effective in ensuring the stability of the LDO input power. Connect the capacitor within 1 cm of the Vcc-GND pin IC. The purpose of the input capacitor is to make the source impedance smaller. For this reason, we recommend a ceramic capacitor with a small ESR. Connect a capacitor with an actual capacitance of 0.22 μF or greater. Although the capacitance value will fall below the nominal value due to differences in tolerance, temperature characteristics and DC bias characteristics, set it so that the capacitance does not fall below the minimum value (0.22 μF). If the output current changes drastically, increasing the capacitance of the output capacitor will reduce the ripple voltage. However, if there are momentary problems with the current supply potential on the input current side due to the larger output capacitor, the input voltage may drop. To prevent this, increase the capacitance of the input capacitor as well, so that it approximates the input capacitance. For the bulk capacitor, connect an aluminum electrolytic capacitor in parallel with the ceramic capacitor.

8. Load

As this IC has over current protection (OCP) characteristics resembling the number “7”, when the load is a constant current source or when the output voltage is negative when starting up, the output voltage will not rise if the load current exceeds the IC output (supply) current, and the IC will fail to start up.
The IC will operate when the constant current load is on after the IC’s output voltage is at the default value on startup; but afterwards, if the thermal shutdown circuit operates and the output goes off, the IC cannot be restarted. Further, if the IC cannot be started, constant current load will flow to the electrostatic breakdown protection diode (between VOUT-GND). Due to this, the chip temperature will rise depending on the current value, which may result in destruction of the IC or solder melting. For this reason, use of constant current load is not recommended.

9. Efficiency

The efficiency can be calculated with the following equation.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times (I_{OUT} + I_{IN})} \times 100 \quad [\%] \qquad (9\text{-}1)$$

V_{IN} : Input voltage $[V]$
V_{OUT} : Output voltage $[V]$
I_{OUT} : Output current $[A]$
I_{CC} : IC circuit current $[A]$

Note that when $I_{IN} \ll I_{OUT}$, efficiency can be calculated with the following equation.

$$\eta = \frac{V_{OUT}}{V_{IN}} \times 100 \quad [\%] \qquad (9\text{-}2)$$

We can see from the equation that smaller voltage differences between inputs/outputs result in better efficiency.

10. Thermal design

To ensure highly reliable operations, it is necessary to make sure that the IC junction temperature does not exceed 125°C. The junction temperature estimate can be calculated using the following two methods.

1. When measuring the IC temperature using the surface temperature, use thermal characteristic parameter ψ_{JT} for the calculation. If the thermocouple can be firmly stabilized at the package surface center, the temperature T_T at the package surface center can be precisely measured. Because of this, the junction temperature can be calculated precisely by using this thermal characteristic parameter.

$$T_J = T_T + \psi_{JT} \times P \quad [°C] \qquad (10\text{-}1)$$

T_T : Temperature at the center of the package surface [°C]
ψ_{JT} : Thermal characteristics parameter from junction to center of package surface [°C/W]
P : IC consumption power [W]

P can be calculated by the IC consumption power using the following equation.

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} + (V_{IN} \times I_{IN}) \quad [W] \qquad (10\text{-}2)$$

V_{IN} : Input voltage [V]
V_{OUT} : Output voltage [V]
I_{OUT} : Output current [A]
I_{IN} : IC circuit current [A]

Also, the peak output current that can flow constantly can be calculated with the following equation.

$$I_{OUT(MAX)} = \frac{T_{J(MAX)} - T_T}{(V_{IN} - V_{OUT}) \times \psi_{JT}} \quad [A] \qquad (10\text{-}3)$$

$T_{J(MAX)}$: Absolute maximum rating for junction temperature [°C]
T_T : Temperature at the center of the package surface [°C]
ψ_{JT} : Thermal characteristics parameter from junction to center of package surface [°C/W]
V_{IN} : Input voltage [V]
V_{OUT} : Output voltage [V]

2. Use thermal resistance θ_{JA} to easily calculate the junction temperature.

$$T_J = T_A + \theta_{JA} \times P \quad [°C] \qquad (10\text{-}4)$$

T_A : Ambient temperature [°C]
θ_{JA} : Thermal resistance between junction and ambient temperature [°C/W]
P : IC consumption power [W]

Also, the peak output current that can flow constantly can be calculated with the following equation.

$$I_{OUT(MAX)} = \frac{T_{J(MAX)} - T_A}{(V_{IN} - V_{OUT}) \times \theta_{JA}} \quad [A] \qquad (10\text{-}5)$$

$T_{J(MAX)}$: Absolute maximum rating for junction temperature [°C]
T_A : Ambient temperature [°C]
θ_{JA} : Thermal resistance between junction and ambient temperature [°C/W]
V_{IN} : Input voltage [V]
V_{OUT} : Output voltage [V]

The thermal characteristics parameter Ψ_{JT} and thermal resistance θ_{JA} are values measured using a specific PCB. As the influence of PCB characteristics, copper foil layout, parts layout, chassis shape, surrounding environment and so on cause heat radiation to change, the thermal characteristics parameter and thermal resistance will also change. It is necessary to consider that the values will differ from the actual equipment board.

SSOP5 package thermal characteristics parameters and thermal resistance

PCB type	ψ_{JT}(°C/W)	θ_{JA}(°C/W)
1 layer (1s)	59	264.8
2 layers (2s)	36	187.8
4 layers (2s2p)	34	143.6

Table 10-1 to 10-3 and Figure 10-1 through 10-13 shows the specifications for the PCB used in measurement.

SSOP5 package PCB specifications, 1 layer (1s)

Conforms to JEDEC standard JESD51-3

Item	Value
Board thickness	1.57 mm
Board outline dimensions	76.2 mm × 114.3 mm
Board material	FR-4
Trace thickness (Finish thickness)	70 µm (2 oz)
Lead width	0.254 mm
Copper foil area	Footprint

Table 10-1. 1-layer PCB specifications

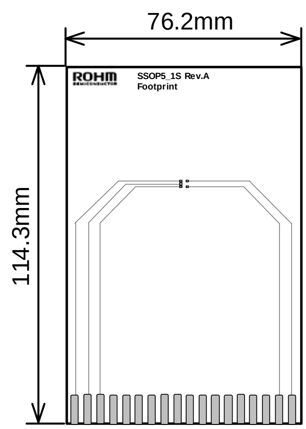

Figure 10-1. Top Layer Trace

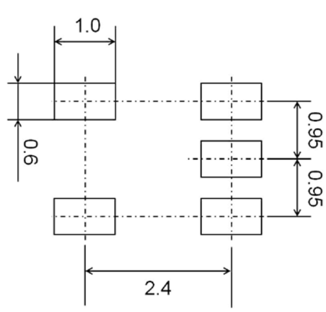

Figure 10-2. Footprint

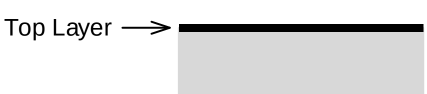

Figure 10-3. 1-layer board sectional view

SSOP5 package PCB specifications, 2 layers (2s)

Conforms to JEDEC standard JESD51-7

Item		Value
Board thickness		1.60 mm
Board outline dimensions		76.2 mm × 114.3 mm
Board material		FR-4
Trace thickness (Finish thickness)	Top Bottom	70 µm (2 oz) 70 µm (2 oz)
Lead width		0.254 mm
Copper foil area	Top Bottom	Footprint 5505 mm^2 (74.2 mm × 74.2 mm)

Table 10-2. 2-layer PCB specifications

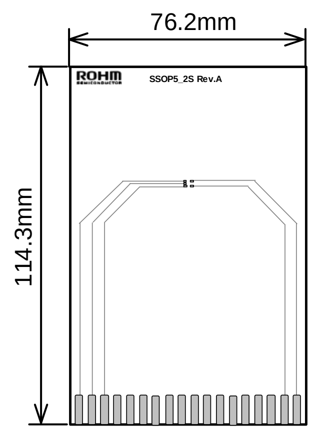

Figure 10-4.
Top Layer Trace

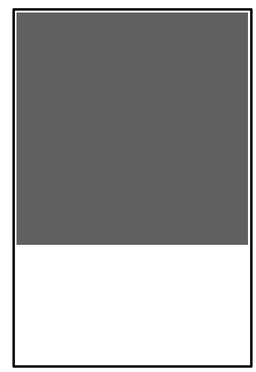

Figure 10-5.
Bottom Layer Trace

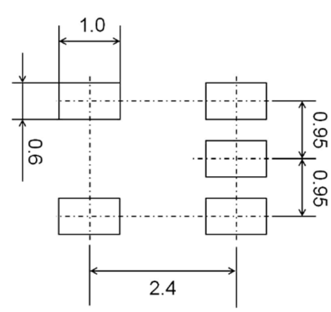

Figure 10-6. Footprint

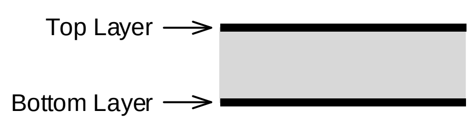

Figure 10-7. 2-layer board sectional view

SSOP5 package PCB specifications, 4 layers (2s2p)

Conforms to JEDEC standard JESD51-7

Item		Value
Board thickness		1.60 mm
Board outline dimensions		76.2 mm × 114.3 mm
Board material		FR-4
Trace thickness (Finish thickness)	Top	70 µm (2 oz)
	Middle 1	35 µm (1 oz)
	Middle 2	35 µm (1 oz)
	Bottom	70 µm (2 oz)
Lead width		0.254 mm
Copper foil area	Top	Footprint
	Middle 1	5505 mm^2 (74.2 mm × 74.2 mm)
	Middle 2	5505 mm^2 (74.2 mm × 74.2 mm)
	Bottom	5505 mm^2 (74.2 mm × 74.2 mm)

Table 10-3. 4-layer PCB specifications

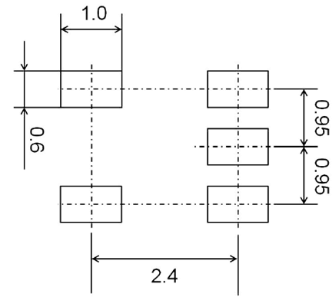

Figure 10-12. Footprint

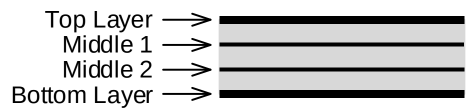

Figure 10-13. 4-layer board sectional view

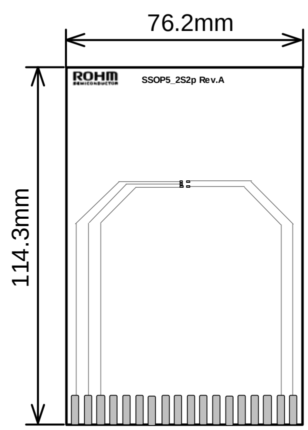

Figure 10-8.
Top Layer Trace

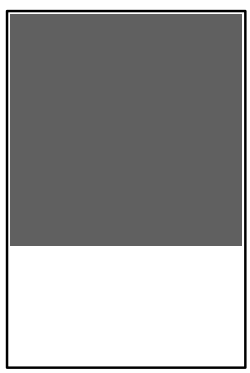

Figure 10-9.
Middle 1 Layer Trace

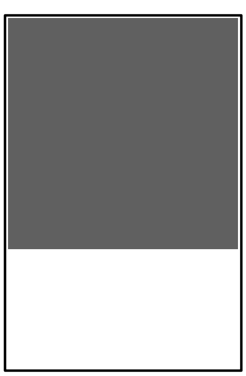

Figure 10-10.
Middle 2 Layer Trace

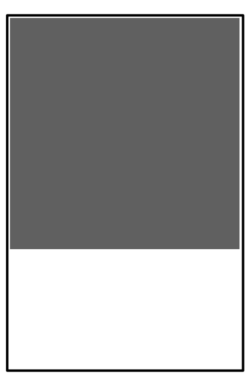

Figure 10-11.
Bottom Layer Trace

11. Terminal protection

If inverse or excess voltage is applied to the IC terminals, the device may be damaged or the output voltage may not rise. When the following conditions are anticipated, we recommend that the terminals be adequately protected.

1. When the input/output voltage conditions are reversed
   → Reverse current bypass
2. When the output load is conductive
   → Output reverse voltage protection
3. Possibility of input polarities connected in reverse
   → Input reverse voltage protection
4. Hot-plugging → Hot-plugging countermeasures
5. Load exists between disparate power sources
   → Reverse current bypass
6. Positive-negative power source (both power sources)

1. When the input/output voltage conditions are reversed

When the capacitance of the output capacitor is large, and a load remains in the output capacitor even after the input power shuts down, or the speed that the input power shuts down is extremely fast, reverse current will flow from output to input via parasitic elements in the IC because the input/output voltage state will be inverted. Operation is not guaranteed for parasitic elements, and this can degrade or destroy elements.

As a countermeasure, connect a reverse current bypass diode externally (Figure 11-1), so that the reverse current does not pass through the inside of the IC. Note that when the input side is left open and the IC is powered down, no degradation of parasitic elements or breakdown will occur due to the reverse current value being a slight IC bias current only. Owing to this, the bypass diode is not necessary (Figure 11-2).

It is necessary for the bypass diode to turn on before the parasitic element in the IC. As the voltage to turn on the internal parasitic element is approximately 0.6 V for the MOSFET type regulator, a low forward voltage of V_F is required. When the value of the reverse current is large, a considerable amount of diode leakage current will flow from input to output, even if the output is off during shutdown. For this reason, a small value (around 1 µA or less) must be selected. Select an inverse rated voltage that is larger than the input/output voltage difference (80% derating or less) to be used. Select a forward direction rated current that is larger than the reverse rated current value (50% derating or less) to be used. From the above conditions, we recommend a rectifier diode or Schottky barrier diode; but as the inverse current of many Schottky barrier diodes is generally large, select one with a small value.

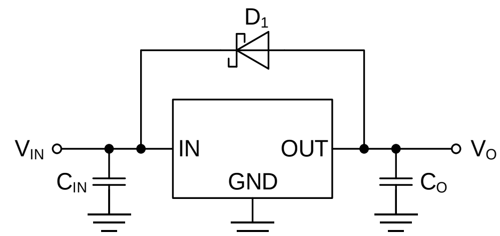

Figure 11-1. Reverse current bypass diode

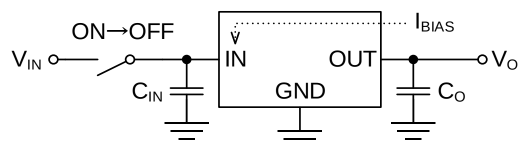

Figure 11-2. When the input is open

2. When the output load is conductive

When the output load is conductive, the energy stored in the conductive load at the instant the output voltage goes off will be shunted to ground. A diode is used between the IC output pin and GND pin to prevent electrostatic breakdown. If a large electric current flows to this diode, the IC may break down. To prevent this, connect a Schottky barrier diode in parallel to the electrostatic breakdown prevention diode (Figure 11-3).

When the IC output pin and load are connected via a long wire, a conductive load may occur. Measure the waveform using an oscilloscope. Aside from this, when the load is a motor, a diode is necessary due to counter electromotive force in the motor, which causes the same kind of current to flow.

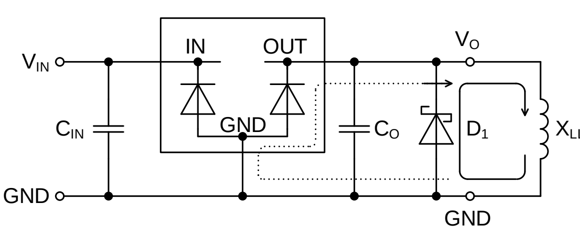

Figure 11-3. Conductive load current path (when output is off)

3. Possibility of input polarities connected in reverse

When connecting an input to power, if the positive and negative terminals are connected in reverse due to careless error, a large electric current may flow between the IC input pin and the GND pin to the electrostatic breakdown prevention diode (Figure 11-4). The easiest countermeasure is to connect a Schottky barrier diode or a rectifier diode in series with the power, as shown in Figure 11-5. Using the correct connection, a power loss will occur in $V_F \times I_O$ due to a voltage drop in the forward voltage V_F of the diode, so this is not suitable for a battery-operated circuit. The V_F for a Schottky barrier diode is lower than that of a rectifier diode, so the loss will be somewhat smaller. Since the diode will get hot, select a diode with a wide margin of power dissipation. When connected in reverse, current for the diode will flow in reverse, but the value will be slight.

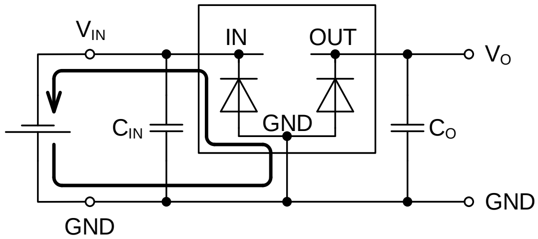

Figure 11-4. Current path when the input is connected in reverse

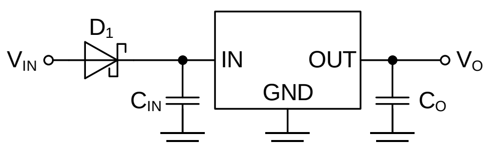

Figure 11-5. Countermeasure #1 against reverse connection

Figure 11-6 shows how to connect the diode in parallel with the power source. Since it is necessary for the diode to turn on faster than the electrostatic breakdown protection diode inside the IC, use a Schottky barrier diode with a low V_F. Using the correct connection, this will operate in the same way as without the diode. Since the total current will keep flowing to the diode when connected in reverse, heat will occur, which may lead to breakdown if the current capacity in the previous stage is too large. The prerequisites for this circuit are either to protect the circuit from accidental mistakes over the short-term, or for an over current protection circuit to be present in the previous stage.

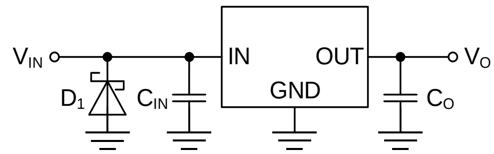

Figure 11-6. Countermeasure #2 against reverse connection

For placing greater emphasis on safety by using a protection circuit, connect the power source in series to the fuse. Although maintenance of the fuse is required, this will protect the circuit with even greater certainty (Figure 11-7).

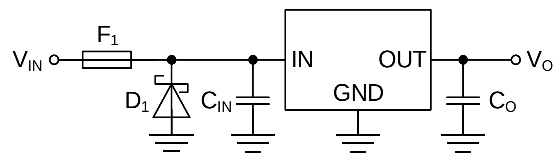

Figure 11-7. Countermeasure #3 against reverse connection

Figure 11-8 shows how to connect the P-ch MOSFET in series with the power source. The diode between the MOSFET drain-source is a body diode (parasitic element). Using the correct connection, the P-ch MOSFET will be on, and the voltage drop here will be the ON resistance of MOSFET times the output current I_O. As this is smaller than the voltage drop via diode (Figure 11-5), the power loss will be smaller. When connecting in reverse, MOSFET will not turn on, so there will be no current flow.

When this value exceeds the rated voltage between MOSFET gate-source (in consideration of derating), divide the resistance between gate and source, and lower the gate-source voltage as shown in Figure 11-9.

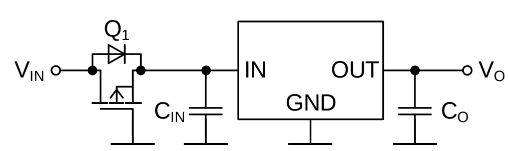

Figure 11-8. Countermeasure #4 against reverse connection

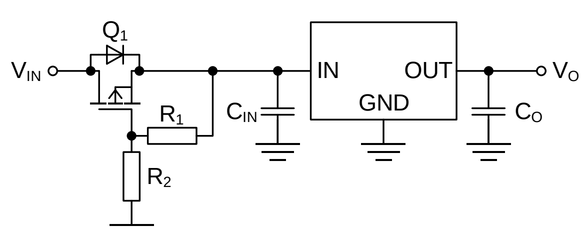

Figure 11-9. Countermeasure #5 against reverse connection

4. Hot-plugging

When connecting a wire to the IC input while the supply side power is on, a pulse waveform will be generated due to contact between the wiring inductance component and the metal of the connector plug. If this surge voltage exceeds the IC's absolute maximum rating, the IC may break down. Use a TVS (transient voltage suppressor) diode to absorb the surge, so that the surge voltage does not reach the IC input pin (Figure 11-10).

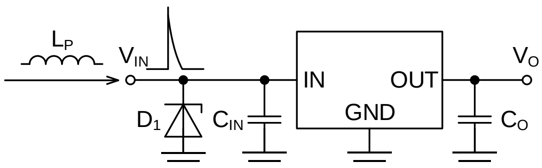

Figure 11-10. Hot-plugging countermeasure

5. Load exists between disparate power sources

As shown in Figure 11-11, when a load exists between disparate power sources, the timing for rises and drops are different, so current will flow to another power output terminal through the load. Reverse voltage will occur between IC inputs and outputs at this time, so a reverse current bypass diode is needed.

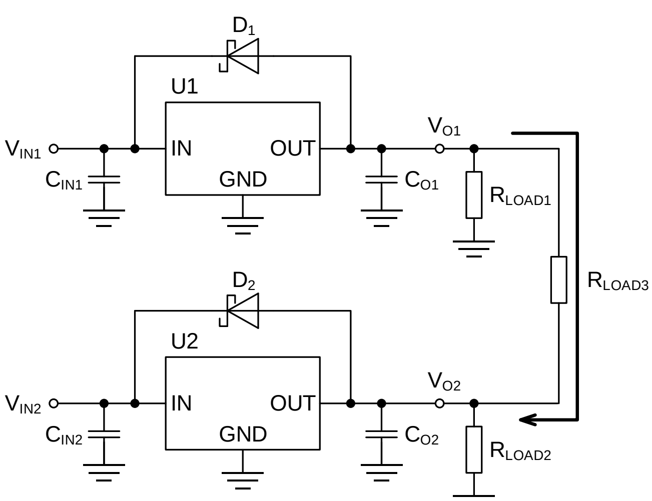

Figure 11-11. Current path and diode insertion between disparate power sources

6. Positive-negative power source (both power sources)

For positive-negative power supplies as shown in Figure 11-12, the speeds at which the power supplies rise are different. For this reason, when there is a load between positive and negative, the power source that started first pulls current from the other output through the load, which applies negative voltage to the output. Be sure to connect a Schottky barrier diode with a low V_F between the output and GND, to prevent damage to the IC and to prevent the output voltage from failing to rise.

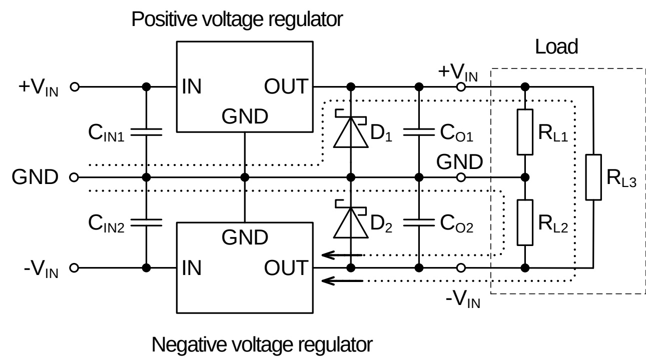

Figure 11-12. Inserting a diode between positive-negative power supplies; current path when negative power supply regulator starts first

12. Sequence for turning power on

There are no restrictions on the start sequence for VIN and STBY. The starting time depends on the rising time for VIN and STBY, as well as the capacitance of the output capacitor. These differences are shown below.

1. When the circuit turns on in order of VIN → STBY

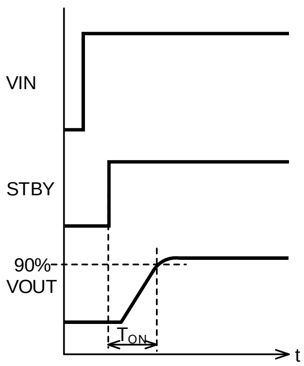

Figure 12-1.
When STBY turns on abruptly
When the output capacitor value is small

Figure 12-1 shows the startup characteristics for when STBY abruptly turns on after VIN rises. The circuit begins operating at the time when STBY starts up. When the capacitance of the output capacitor is small, the inrush current during startup remains lower than the value at which the over current protection circuit activates, and the current is not limited.

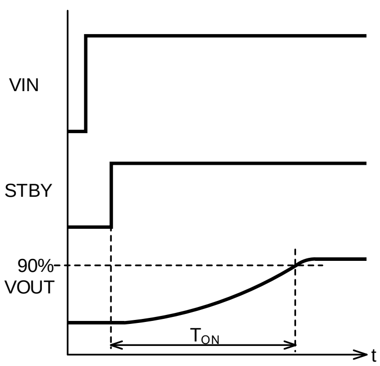

Figure 12-2.
When STBY turns on abruptly
When the output capacitor value is large

Figure 12-2 shows the startup characteristics when the output capacitor value on Figure 12-1 is large. Since the inrush current at startup time becomes longer and current is limited as a result of the over current protection circuit, the charging current to the capacitor will be limited, and the startup time will get longer as the capacitor's capacitance increases.

Co	T_{ON}		
	VOUT=1.0V	VOUT=1.8V	VOUT=3.4V
0.47µF	5 µs	8 µs	20 µs
1µF	7.5 µs	10 µs	33 µs
2.2µF	15 µs	22 µs	65 µs

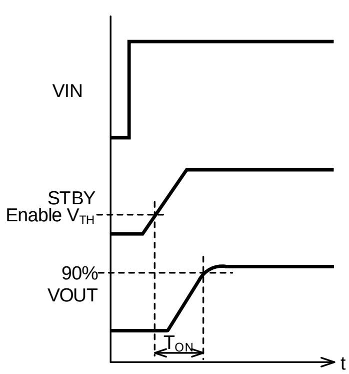

Figure 12-3.
When STBY turns on gradually
When the output capacitor value is small

Figure 12-3 shows the startup characteristics when STBY turns on gradually, and when the output capacitor value is small. The circuit begins operating and the output voltage rises at the time when the voltage of STBY exceeds the threshold value. When the output capacitor is large, the output voltage rise waveform will be as shown in Figure 12-2, the same as when the circuit begins operating.

12. Sequence for turning power on (continued)

2. When the circuit turns on in order of STBY → VIN

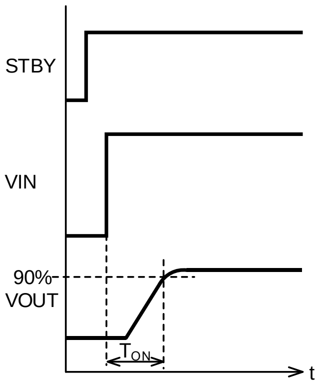

Figure 12-4.
When VIN turns on abruptly
When the output capacitor value is small

Figure 12-4 shows the startup characteristics when VIN abruptly turns on after the STBY rises. The circuit begins operating at the time when VIN starts up. When the capacitance of the output capacitor is small, the inrush current during startup remains lower than the value at which the over current protection circuit activates, and the current is not limited.

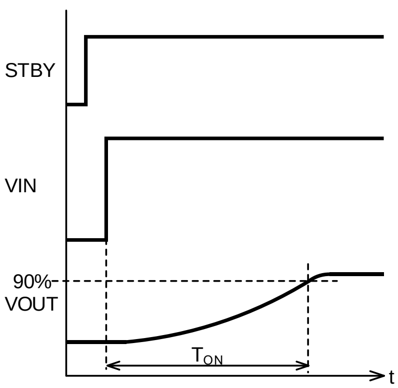

Figure 12-5.
When VIN turns on abruptly
When the output capacitor value is large

Figure 12-5 shows the startup characteristics when the output capacitor value on Figure 12-4 is large. Since the inrush current at startup time becomes longer and current is limited as a result of the over current protection circuit, the charging current to the capacitor will be limited, and the startup time will get longer as the capacitor's capacitance increases.

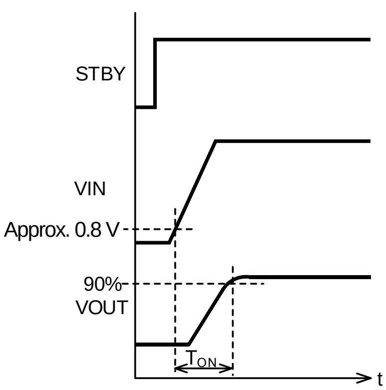

Figure 12-6.
When VIN turns on gradually
When the output capacitor value is small

Figure 12-6 shows the startup characteristics when VIN turns on gradually, and when the output capacitor value is small. The circuit begins operating and the output voltage rises at the time when the voltage of VIN exceeds approximately 0.8 V. When the output capacitor is large, the output voltage rise waveform will be as shown in Figure 12-5, the same as when the circuit begins operating.

12. Sequence for turning power on (continued)

3. When VIN and STBY turn on at the same time

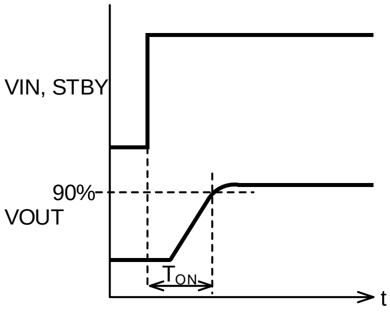

Figure 12-7.
When VIN and STBY turns on abruptly
When the output capacitor value is small

Figure 12-7 shows the startup characteristics when VIN and STBY abruptly turn on at the same time. The circuit begins operating at the time when VIN and STBY start up. When the capacitance of the output capacitor is small, the inrush current during startup remains lower than the value at which the over current protection circuit activates, and the current is not limited.

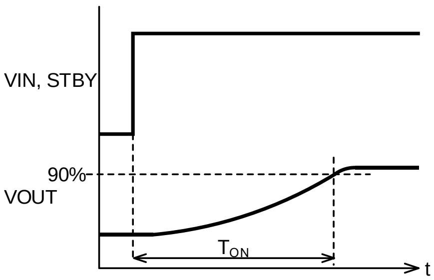

Figure 12-8.
When VIN and STBY turns on abruptly
When the output capacitor value is large

Figure 12-8 shows the startup characteristics when the output capacitor value on Figure 12-7 is large. Since the inrush current at startup time becomes longer and current is limited as a result of the over current protection circuit, the charging current to the capacitor will be limited, and the startup time will get longer as the capacitor's capacitance increases.

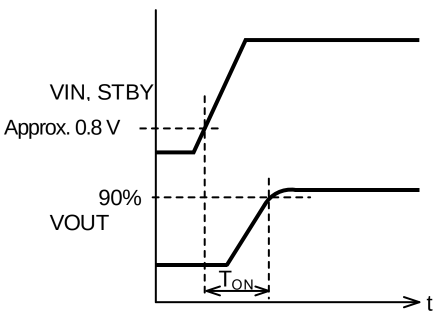

Figure 12-9.
When VIN and STBY turns on gradually
When the output capacitor value is small

Figure 12-9 shows the startup characteristics when VIN and STBY turn on gradually at the same time, and when the output capacitor value is small. The circuit begins operating and the output voltage rises at the time when the voltage of VIN exceeds approximately 0.8 V. When the output capacitor is large, the output voltage rise waveform will be as shown in Figure 12-8, the same as when the circuit begins operating.

13. Sequence for turning power off

The output voltage fall times differ, depending on the order in which VIN and STBY are turned off. These differences are shown below.

1. When the circuit turns off in order of STBY → VIN

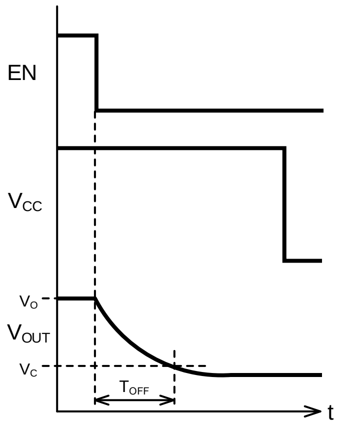

Figure 13-1.
When STBY turns off abruptly

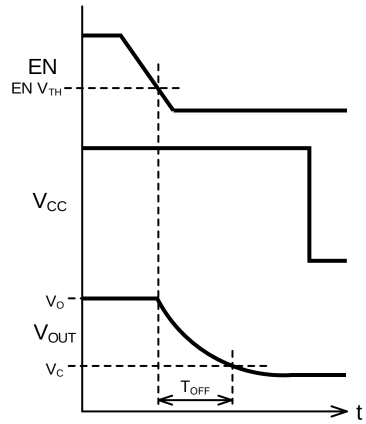

Figure 13-2.
When STBY turns off gradually

Figure 13-1 shows the startup characteristics when STBY abruptly turns off at the same time. When STBY is turned off, the output transistor turns off and the discharge circuit operates. As a result, the electrical charge in the output capacitor is discharged through the discharge resistor in the IC, and the output voltage will fall. Other discharge paths besides this resistor include the load and the feedback resistor (output voltage setting resistor) in the IC. Turn off VIN after the output voltage falls completely. If the discharge path is the discharge resistor in the IC, the output voltage falling time can be calculated with the following equation.

$$T_{OFF} = -C_O \times R_{DSC} \times \ln\left(\frac{V_C}{V_O}\right) \quad [sec] \qquad (15\text{-}1)$$

C_O : Output capacitor $[F]$
R_{DSC} : Discharge resistance in the IC (20 to 80) $[\Omega]$
V_O : Output voltage $[V]$
V_C : Final dropped voltage $[V]$

Figure 13-2 shows the power off characteristics when STBY gradually turns off. The output transistor turns off and the discharge circuit operates when the voltage of STBY falls below the threshold value. The output voltage will fall. The fall time for the output voltage is the same as that shown on Figure 13-1.

13. Sequence for turning power off (continued)

2. When the circuit turns off in order of VIN → STBY

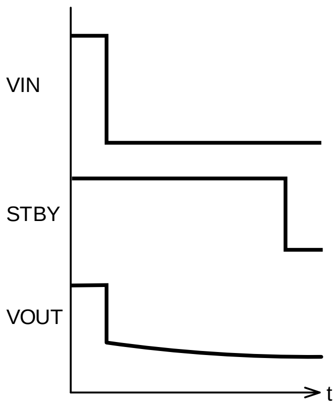

Figure 13-3.
When VIN turns off abruptly

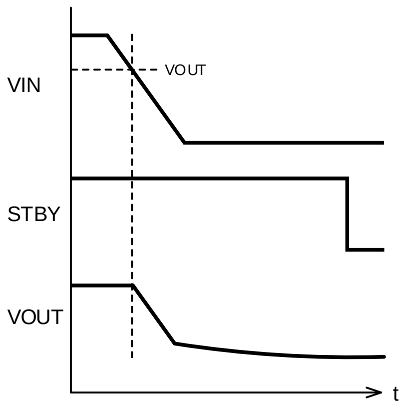

Figure 13-4.
When VIN turns off gradually

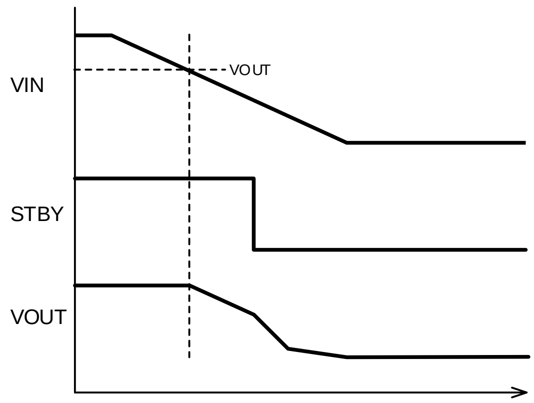

Figure 13-5.
When VIN turns off gradually, and STBY turns off while VIN is falling

Figure 13-3 shows the power off characteristics when VIN abruptly turns off. When VIN abruptly turns off, the electrical charge of the output capacitor is shunted to the input side through the output transistor body diode (parasitic diode), in order to invert the input/output voltage. As a result, the output voltage abruptly falls following the input voltage; and when VIN reaches 0 V, the body diode voltage (approximately 0.5 V) is left and falls gradually. Then, the voltage falls in time constant with the load resistance.

Figure 13-4 shows the power off characteristics when VIN gradually turns off. When the voltage of VIN falls, the electrical charge of the output capacitor is shunted to the input side through the output transistor body diode (parasitic diode), when the input/output voltage reaches the inversion point. As a result, the output voltage falls following the input voltage; and when VIN reaches 0 V, the body diode voltage (approximately 0.5 V) is left and falls even more gradually. Then, the voltage falls in time constant with the load resistance.

Figure 13-5 shows the power off characteristics when STBY abruptly turns off while VIN gradually turns off. When the voltage of VIN falls, the electrical charge of the output capacitor is shunted to the input side through the output transistor body diode (parasitic diode), when the input/output voltage reaches the inversion point. Thus, the output voltage falls following the input voltage. When STBY is abruptly turned off while the VIN voltage is falling, the output transistor turns off and the discharge circuit operates. The output will rapidly drop. When VIN falls below the operating voltage of the IC, the discharge circuit stops operating as well. Therefore, the output falls following the input voltage again.

13. Sequence for turning power off (continued)

3. When VIN and STBY turn off at the same time

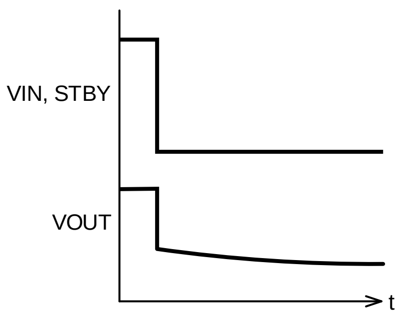

Figure 13-6.
When VIN and STBY turn off abruptly

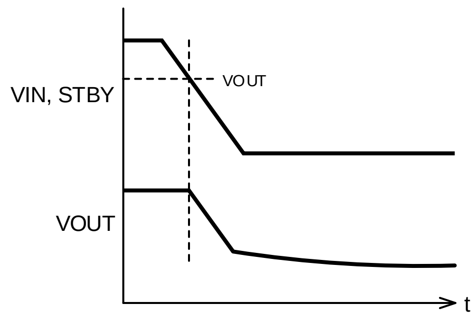

Figure 13-7.
When VIN and STBY turn off gradually

Figure 13-6 shows the power off characteristics when VIN and STBY abruptly turn off. When VIN abruptly turns off, the electrical charge of the output capacitor is shunted to the input side through the output transistor body diode (parasitic diode), in order to invert the input/output voltage. As a result, the output voltage abruptly falls following the input voltage; and when VIN reaches 0 V, the body diode voltage (approximately 0.5 V) is left and falls gradually. Then, the voltage falls in time constant with the load resistance.

Figure 13-7 shows the power off characteristics when VIN and STBY gradually turn off. When the voltage of VIN falls and the input/output voltage reaches the inversion point, the electrical charge of the output capacitor is shunted to the input side through the output transistor body diode (parasitic diode). As a result, the output voltage falls following the input voltage; and when VIN reaches 0 V, the body diode voltage (approximately 0.5 V) is left and falls even more gradually. Then, the voltage falls in time constant with the load resistance. Note that, since VIN falls below the operating voltage of the IC before the STBY pin reaches the “OFF” level, the output discharge circuit will not operate.

14. Inrush current

An inrush current flows to electrically charge the output capacitor of the IC during startup. Even if the output current value exceeds the maximum value of the recommended operating range, the over current protection (OCP) circuit limits the current, so there are no problems in operation. Note that it is necessary to make sure that the IC junction temperature does not exceed 125°C due to overcurrent. The junction temperature T_J during short-term overcurrent can be estimated by the following equation using the transient thermal resistance Z_{TH}.

$$T_J = T_A + Z_{TH} \times P \quad [°C] \qquad (14\text{-}1)$$

T_A : Ambient temperature [°C]
Z_{TH} : Transient thermal resistance between junction and ambient temperature [°C/W]
P : IC consumption power [W]

P can be calculated by the IC consumption power using the following equation.

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} + (V_{IN} \times I_{IN}) \quad [W] \qquad (14\text{-}2)$$

Note that when $I_{OUT} \gg I_{IN}$, the following equation is used.

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} \quad [W] \qquad (14\text{-}3)$$

V_{IN} : Input voltage [V]
V_{OUT} : Output voltage [V]
I_{OUT} : Output current [A]
I_{IN} : IC circuit current [A]

In the SSOP5 package, considering that 0.3 A of inrush current at an ambient temperature of T_A=60°C flows for 1 ms, the transient thermal resistance in 1 ms is 11°C/W from Figure 14-1.
The junction temperature Tj is calculated as follows.

$$T_J = T_A + Z_{TH} \times P$$
$$= 60\ °C + 11 \times (5\ V - 3.3\ V) \times 0.3\ A = 65.6\ °C$$

The junction temperature Tj is 125°C or less, so there is no problem.
In this way, since the rise in chip temperature is slight when the inrush current is around 1 ms (a short time), problems with rising temperatures are minimal.

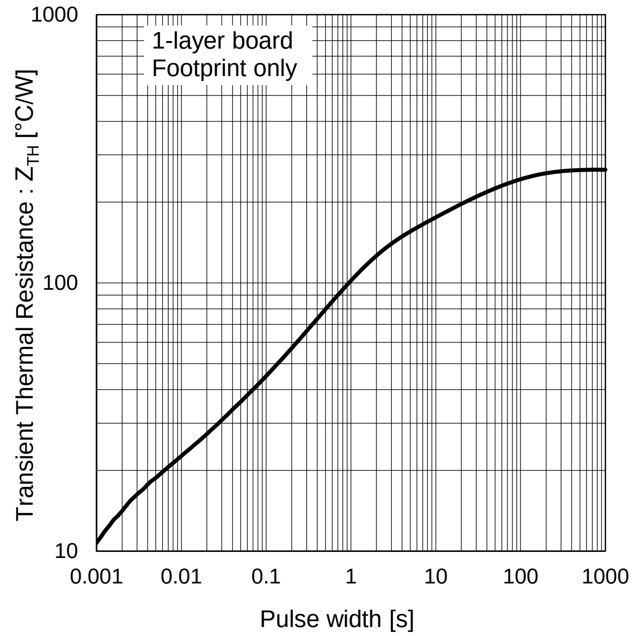

Figure 14-1. Transient thermal resistance of the SSOP5 package

15. Over current protection (OCP)

An over current protection circuit is included, in order to prevent IC breakdown due to overcurrent when the IC output shorts out the GND. This protective function prevents the IC from breaking down; thus, when used for the purpose of protection as per the original set, we consider that it will be used on a fuse or other current limit device.

The over current protection characteristics are as shown in Figure 15-1, and the characteristics look like a number "7" (or a "fold back characteristic" in English). The reference value for point A at over current protection detected current is approximately 0.4 A. The lower limit value for variations in the detected current will not fall below the maximum value of the recommended output current. When overcurrent is detected, the current fold back circuit operates, and the output voltage drops. Along with the drop in output voltage, the circuit repeatedly works to limit the current, reaching point B. Point B is the output short circuit current. As for the power loss at point B, we can say that this is a safe protection circuit that protects the IC from breaking down, due to small power loss and a smaller degree of heat. Note that this condition will continue until the cause of the overcurrent is eliminated. The output voltage is automatically restored when the overcurrent condition is removed.

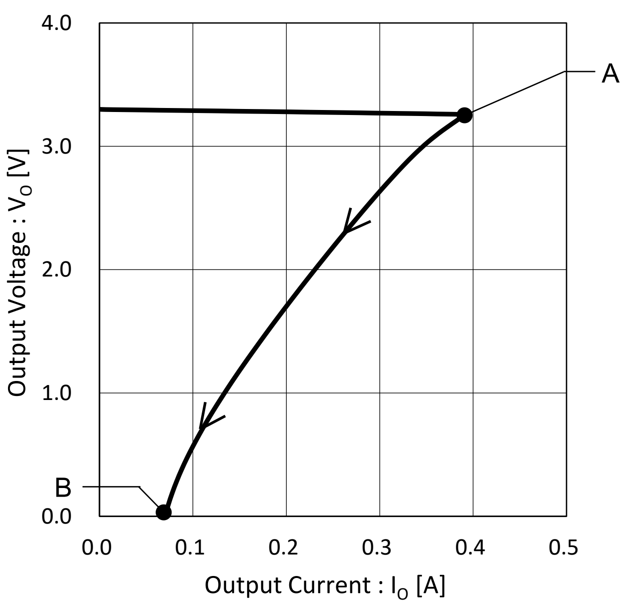

Figure 15-1. Characteristics of over current protection

The region between the maximum value of the recommended output current and the over current protection detected value operates as a linear regulator. However, the electrical characteristics are not guaranteed. When continuing to operate beyond the power dissipation, the thermal shutdown circuit will activate and shut off the output.

16. Thermal shutdown (TSD)

Thermal shutdown protects the IC from damage due to overheating, which occurs when the IC chip temperature exceeds the junction temperature due to an output short or increased power loss. This is not intended to supplant the original thermal shutdown feature of the set.

When the thermal shutdown circuit exceeds the reference value of approximately 180°C, the regulator output turns off, shutting off the output current and lowering the chip temperature. Although there are variations in the detected temperature, this will never fall below the junction temperature (125°C). If the chip temperature falls to approximately 165°C, the output turns on again, and the output current supply begins. The output will turn on and off repeatedly until the cause of the rise in chip temperature is eliminated. If this condition continues, the IC will not break down right away, but continued operation should be avoided, as it will lead to degradation or breakdown.

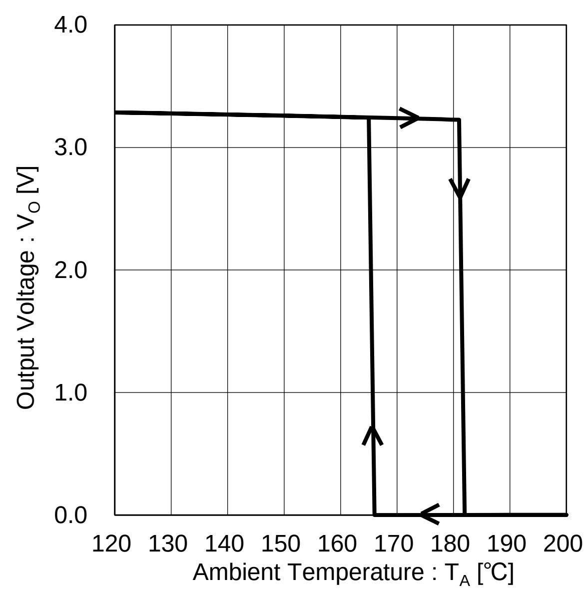

Figure 16-1. Thermal shutdown characteristics

17. Input-output equivalent circuit

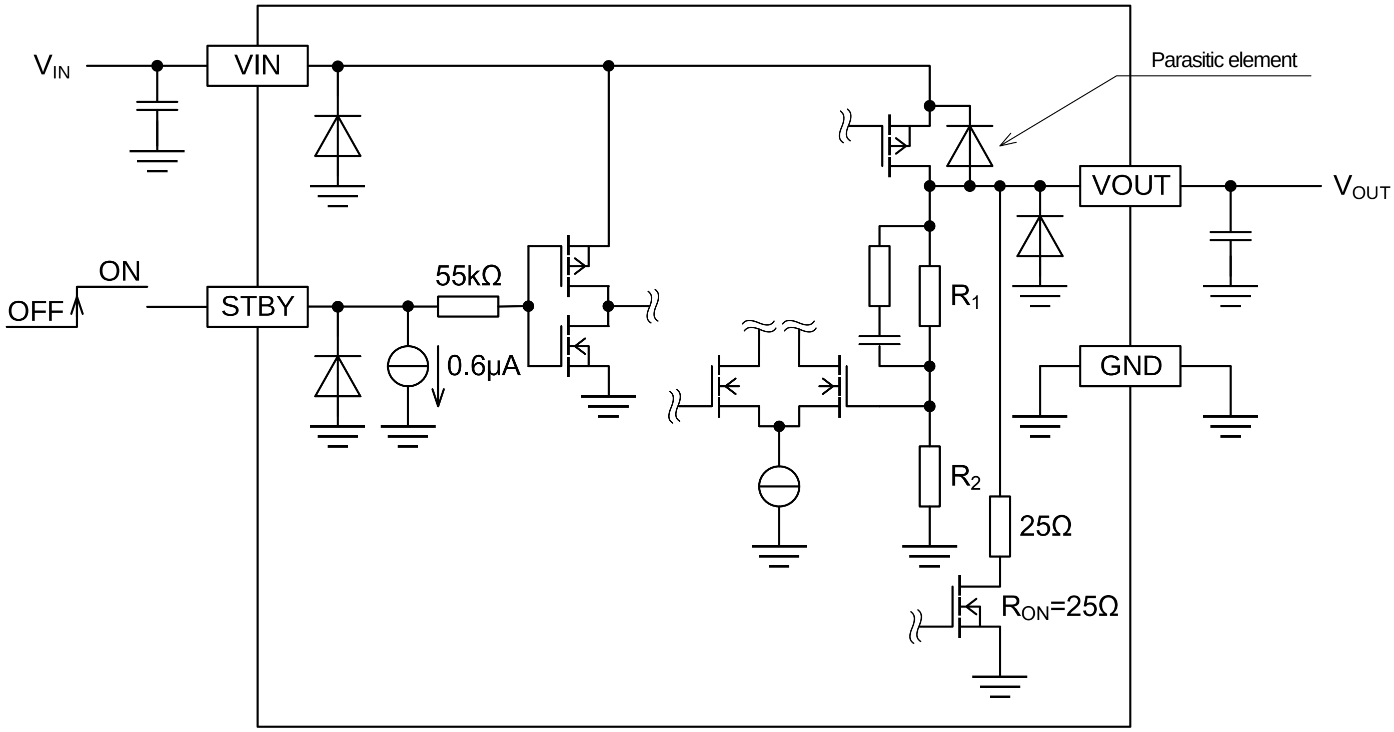

Figure 17-1. Input-output equivalent circuit

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