TOSHIBA

e-Learning

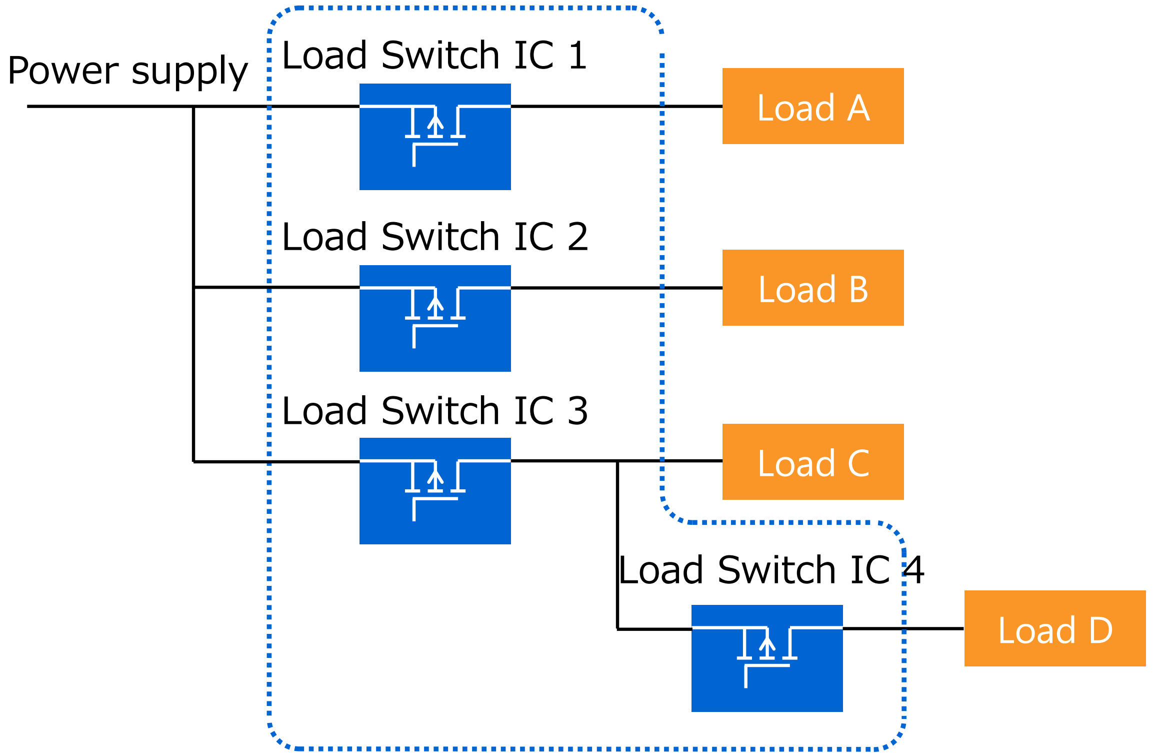
Basics of Load Switch ICs

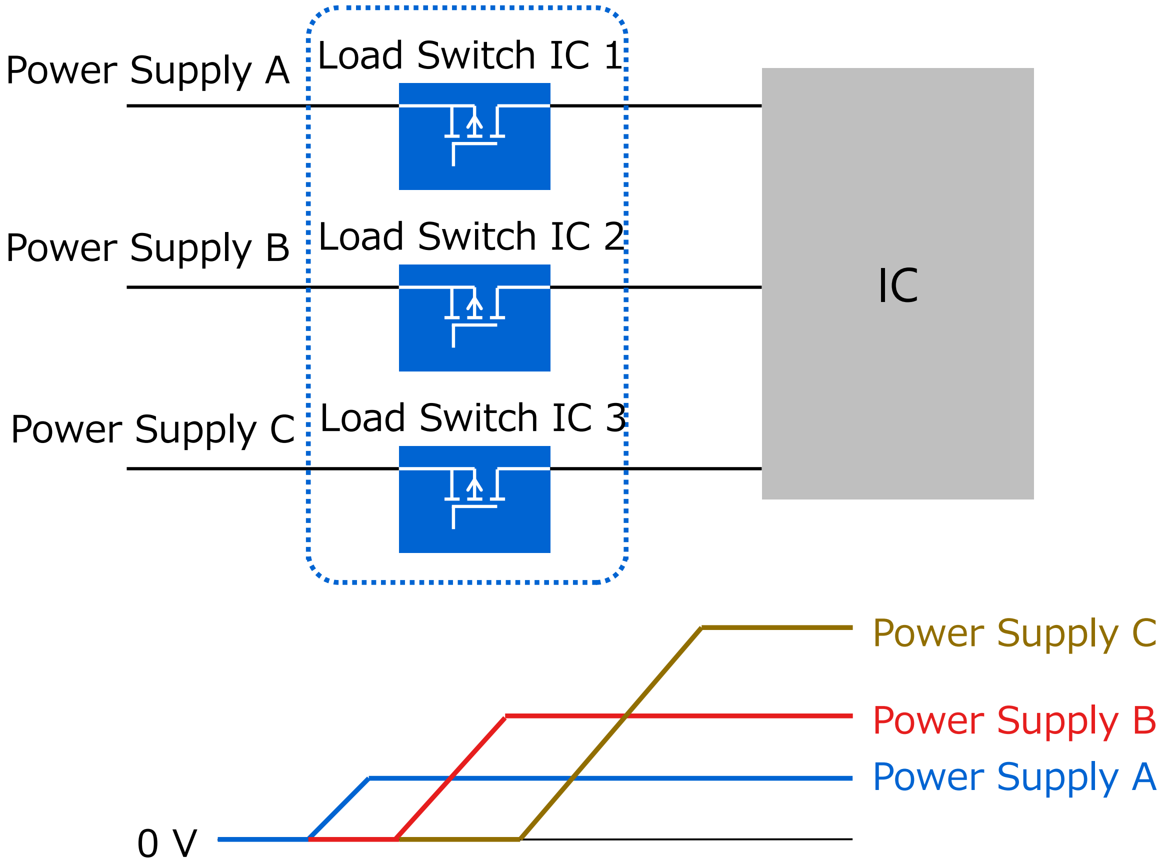
Toshiba Electronic Devices & Storage Corporation

Chapter1 Introduction to Load Switch ICs

What is a load switch IC?

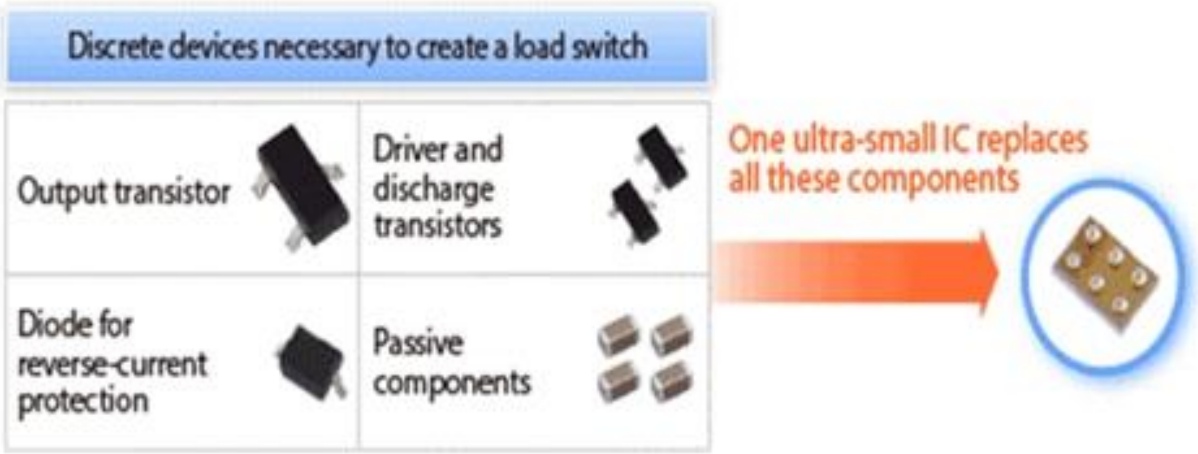
A load switch IC is a semiconductor switch inserted in series between a power supply and a load circuit or IC. The use of load switch ICs simplifies: 1) the supplying of power to each system block, 2) power supply sequencing for ICs, and 3) circuit protection from system failure.
Take, for example, mobile devices and energy-saving equipment powered by a lithium-ion or other type of battery. These electronic systems save power by enabling only the essential circuit blocks and shutting down all the others.





What is a load switch IC?

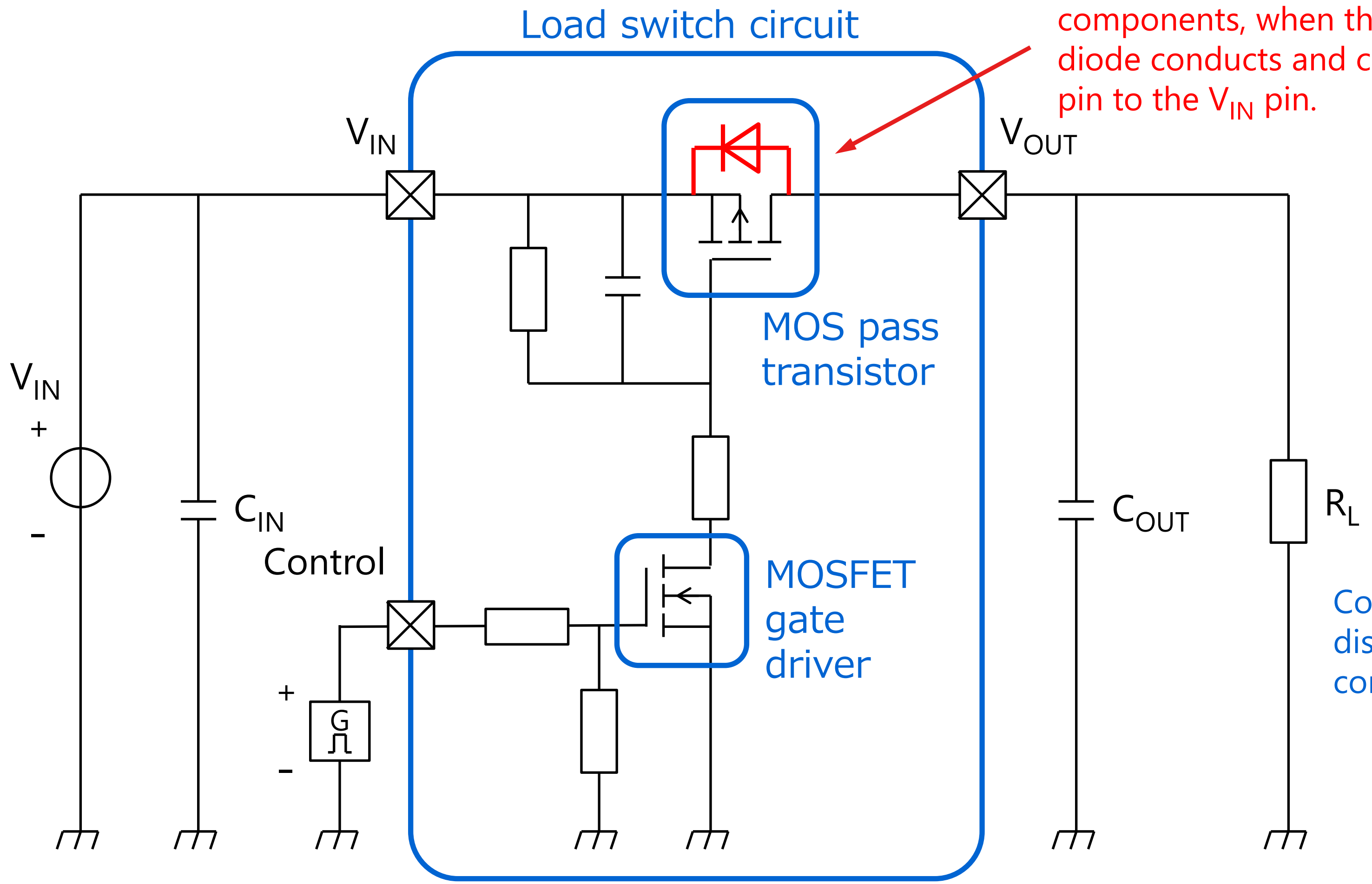
Load switch ICs are power management ICs with an internal switch that exhibit a minimal voltage drop and power dissipation because of low on-resistance and low quiescent current. Load switch ICs help improve the stability and reduce the size of an electronic system because they incorporate various protection functions and require fewer components than a load switch circuit composed of discrete devices.



Benefits of using load switch ICs

Figure shows an example of a simple load switch composed of discrete devices.
This circuit consists of a MOS pass transistor, a MOSFET gate driver, resistors, capacitors, and input and output smoothing capacitors.

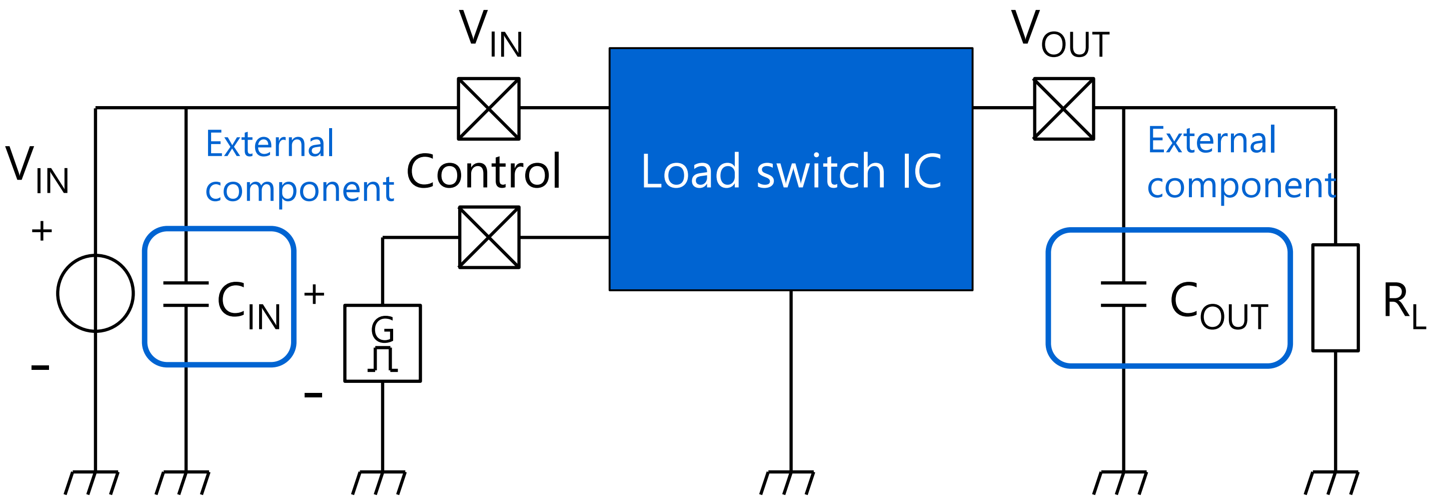
In a simple load-switch circuit configured with discrete components, when the condition $V_{OUT}>V_{IN}$, the body diode conducts and current flows back from the V_{OUT} pin to the V_{IN} pin.



Constructing load switch circuit by discrete devices requires many components.

Benefits of using load switch ICs

Figure shows an application circuit for a load switch IC.
In contrast to a load switch circuit composed of discrete devices, it consists of only three components: a load switch IC plus input and output smoothing capacitors.
One of the major advantages of load switch ICs is that they incorporate various functions, including inrush current limiting, auto discharge, overcurrent protection, thermal shutdown, undervoltage lockout, and reverse-current blocking.
Therefore, load switch ICs help reduce the board area and improve system stability.



A load switch IC requires only two external components to compose a load switch circuit while providing various features.

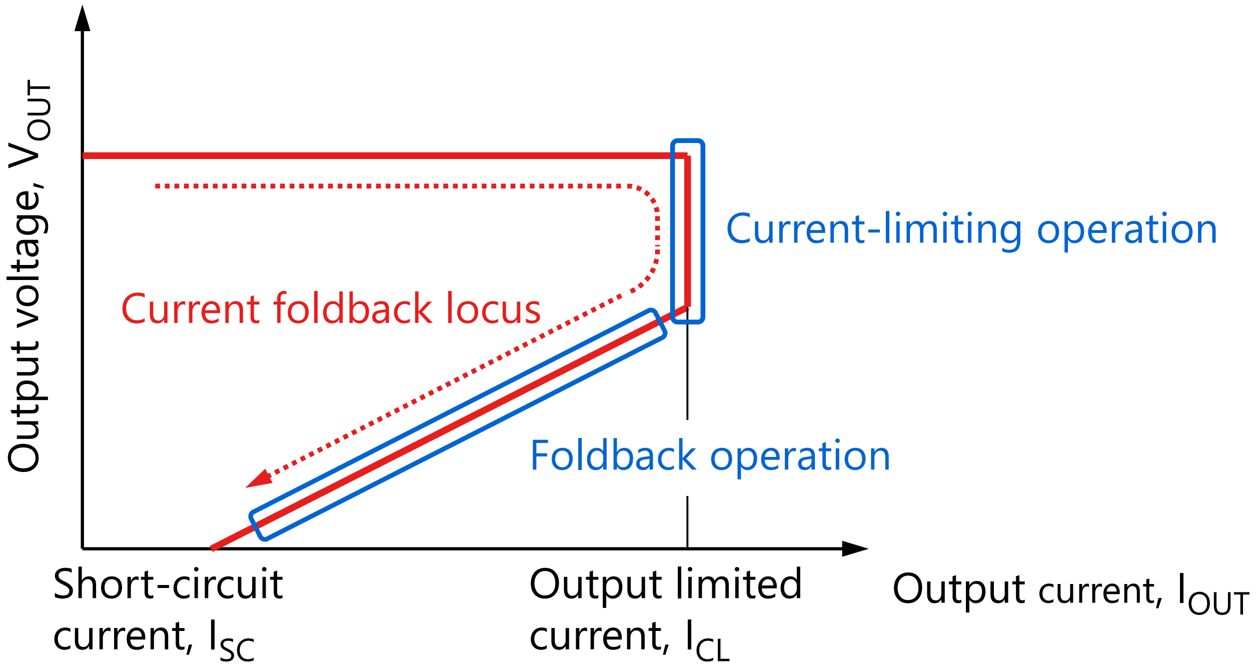
Chapter2　Convenient functions load switch ICs

Useful functions available with load switch ICs

Integrated function	Description
Overcurrent protection	This function limits the output current to protect a system in the event of excessive current flowing to a load switch IC, for example, when the load connected to the V_{OUT} pin is short-circuited to GND.
Thermal shutdown	This function turns off a load switch IC when the heat it generates exceeds the heat dissipation capacity or when an increase in ambient temperature causes an excessive rise in junction temperature.
Inrush current limiting (slew rate control, soft start)	This function slowly raises the output voltage of a load switch IC at turn-on to ensure system stability. Inrush current limiting is also known as slew rate control or soft start.
Auto discharge	When a load switch IC turns off, this function quickly discharges the smoothing capacitor connected to the V_{OUT} pin to facilitate power supply sequencing.
Undervoltage lockout (UVLO)	When the input voltage of a load switch IC drops below a threshold, for example, because of noise or a decrease in battery voltage, this function turns off its output to prevent a system from becoming unstable.
Reverse-current blocking	This function prevents the load current from flowing in the reverse direction from the V_{OUT} pin to the V_{IN} pin when the V_{OUT} voltage becomes higher than the V_{IN} voltage. There are two types of reverse-current blocking: reverse-current blocking that blocks reverse current only when the internal MOS pass transistor is off and true reverse-current blocking that blocks reverse current regardless of whether it is on or off.

Operation of overcurrent protection

In the event of a system failure, for example, when the load connected to the V_{OUT} pin is short-circuited to GND, the overcurrent protection function limits the output current to protect the load switch IC and the system in which it is used. When a drop in output voltage (V_{OUT}) causes excessive current to flow, Toshiba's load switch ICs limit the output current to the set output limited current (I_{CL}) level by tripping a current limiting circuit. When V_{OUT} drops further, Toshiba's load switch ICs perform current limiting called foldback. In the event of excessive current higher than the internal threshold, foldback reduces the output current (I_{OUT}) as the output voltage (V_{OUT}) decreases. Even when the output voltage is zero, a short-circuit current (I_{SC}) continues flowing at the internally set level. The term "foldback" is derived from the shape of the output current (I_{OUT})-vs-output voltage (V_{OUT}) curve that folds back during protection operation. When a faulty condition causing overcurrent disappears, the load switch IC automatically recovers from overcurrent protection, returning the output voltage to the normal level.

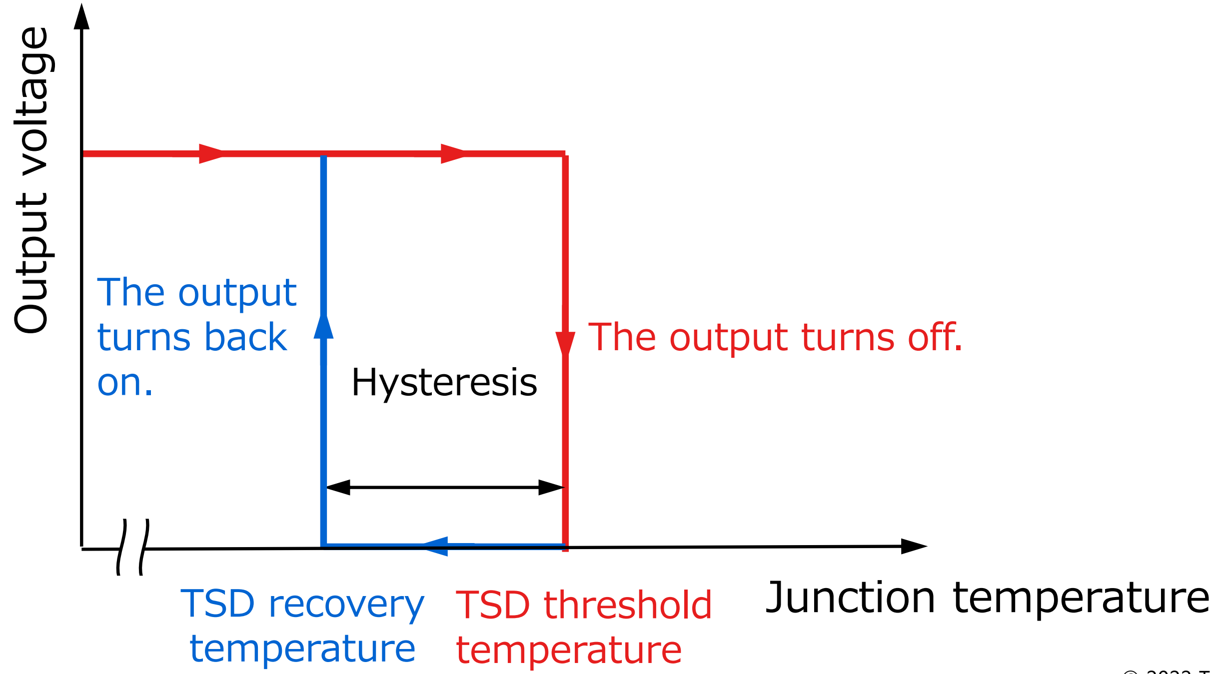


Operation of thermal shutdown

In the event of excessive power dissipation or the junction temperature exceeding a threshold due to an excessive increase in ambient temperature, the thermal shutdown (TSD) function turns off a load switch IC to protect itself and the system in which it is used.

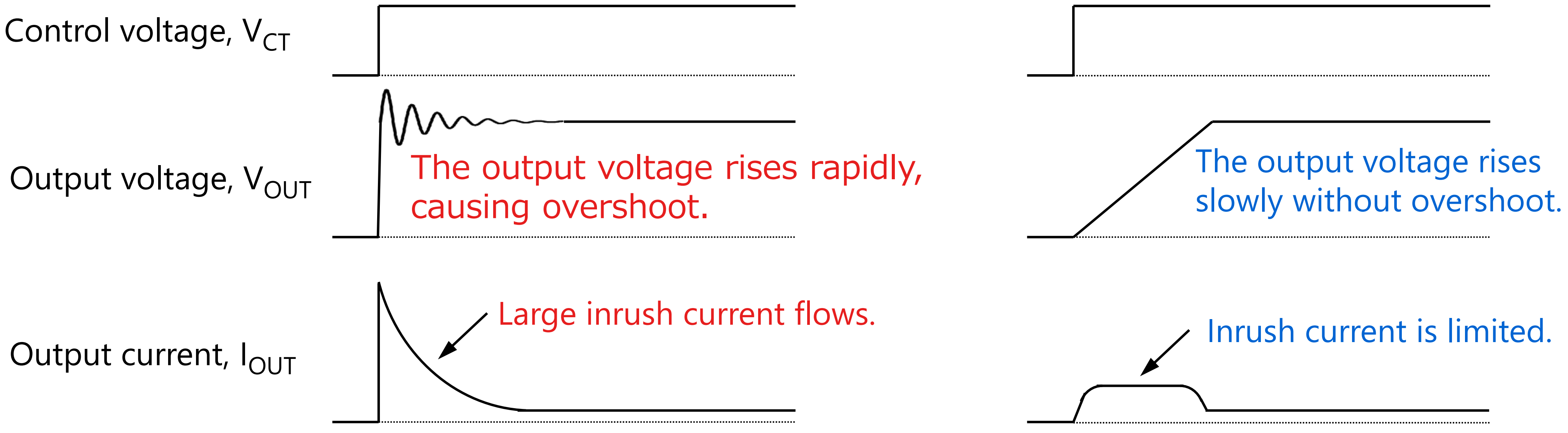
Load switch ICs have a thermal shutdown temperature and a recovery temperature. The thermal shutdown temperature is the temperature at which TSD is tripped to turn off a load switch IC. When TSD is tripped, the resulting reduction in power dissipation causes its junction temperature to fall. Once it reaches a certain temperature, the load switch IC turns back on automatically. This temperature is the recovery temperature.

Unless the cause of the tripping of TSD is removed, the junction temperature rises back up, causing a load switch IC to enter the following loop: a turn-off of a load switch IC → a decrease in junction temperature → a turn-on of the load switch IC → an increase in junction temperature.



Inrush current reducing

Once a load switch IC turns on, its output voltage increases instantaneously, causing overshoot that might exceed the rated voltage of the load IC or circuit.
In addition, a large inrush current flows into the load switch IC to charge the output smoothing capacitor connected to the V_{OUT} pin. Inrush current occurs during the period from the time when the load switch IC turns on to the time when the output voltage stabilizes. If the V_{IN} pin is connected with a board trace with large impedance, the input voltage might sag because of a voltage drop that occurs across the trace impedance due to inrush current. This makes the load switch IC unable to provide a normal output voltage level.
After the load switch IC turns on, the inrush current limiting function raises the output current slowly to limit the inrush current, thereby suppressing the output voltage overshoot and the input voltage drop. Therefore, inrush current limiting helps improve system stability.
Inrush current limiting is also called slew rate control or soft start.

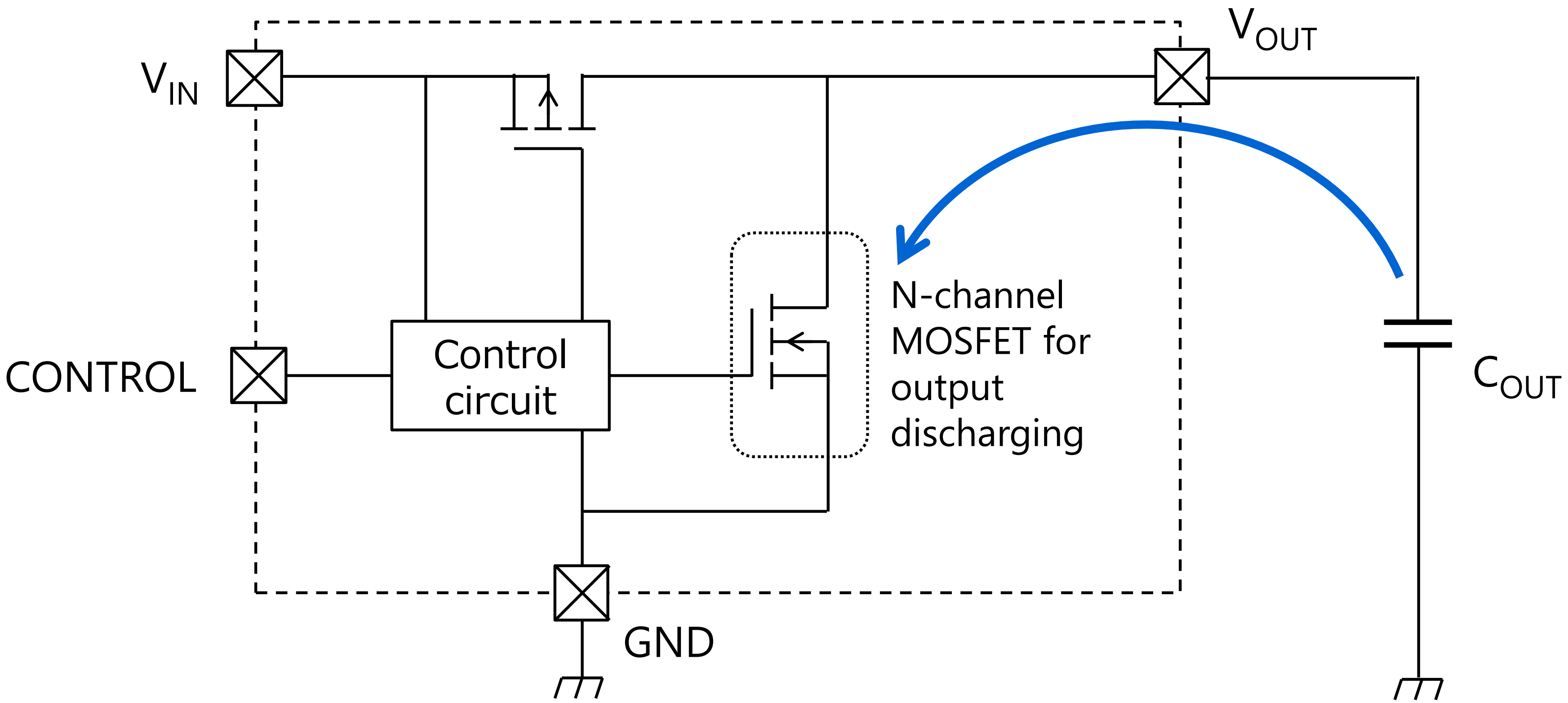


Load switch IC without an inrush current limiting function

Load switch IC with an inrush current limiting function

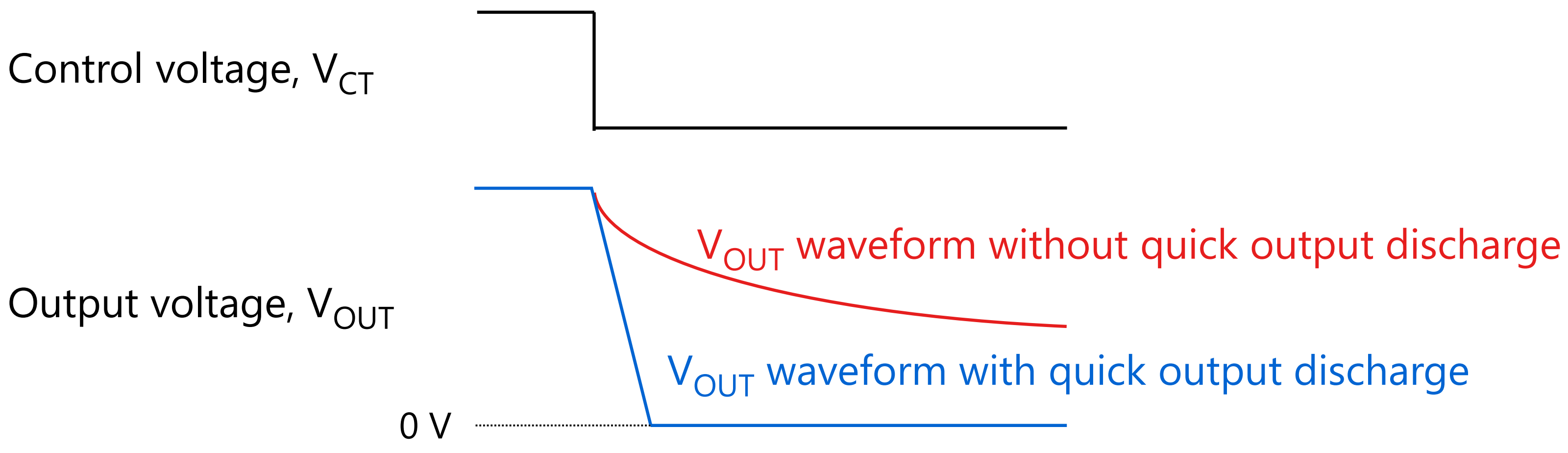
Auto discharge

An electronic system consists of multiple ICs and circuits. For the system to work properly, it is necessary to set a power supply sequence, i.e., the order in which to supply power to the constituent ICs and circuits. A relatively large capacitor is connected to the VOUT pin of a load switch IC in order to smooth the output voltage. Unless this smoothing capacitor is discharged properly, it is difficult to set a power supply sequence for a system. When a load switch IC turns off, the auto discharge function discharges the smoothing capacitor quickly via the internal N-channel MOSFET connected between the VOUT and GND pins, thereby facilitating power supply sequencing.



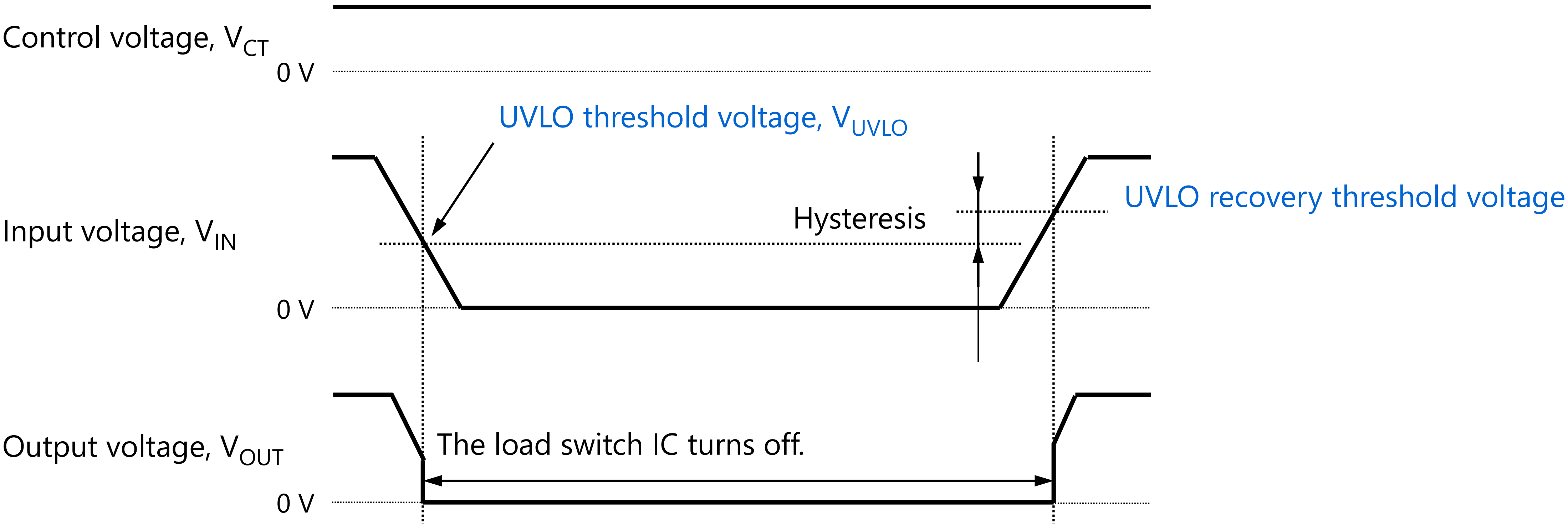
Auto discharge

As shown in the figure, the discharge time of the capacitor connected to the output terminal varies with or without the output discharge function. Auto discharge function is effective not only when you want to reduce the output voltage in a short time, but also to prevent malfunction of the subsequent system due to the charge remaining in the capacitor connected to the output terminal.



Undervoltage lockout (UVLO)

This function comes in handy because system operation might become unstable if the voltage supplied to a constituent IC or circuit drops. When the input voltage of a load switch IC drops below the internal threshold, the undervoltage lockout (UVLO) function turns off its output to ensure system stability. Undervoltage lockout has a hysteresis. When the input voltage rises back above the recovery threshold, the output automatically turns back on.

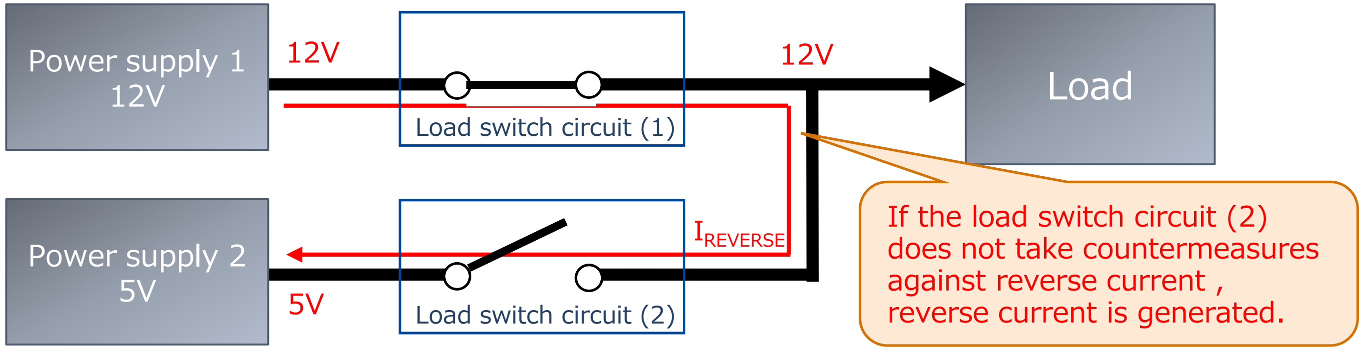


Reverse-current protection

The reverse-current blocking circuit blocks the current flowing in the reverse direction from the V_{OUT} pin to the V_{IN} pin when output voltage (V_{OUT}) > input voltage (V_{IN}).
Toshiba's load switch ICs are available with two types of reverse-current blocking circuit:

a) Reverse-current blocking activated only when a load switch IC is off

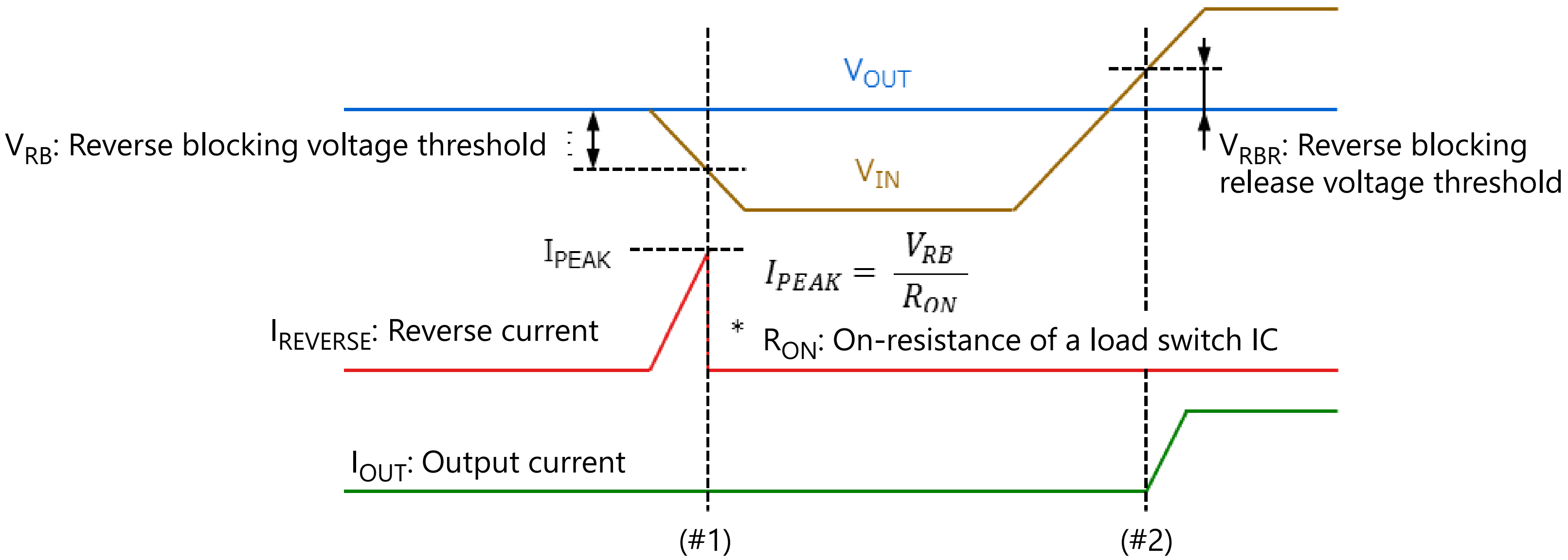
When the MOS pass transistor turns off, V_{IN} becomes lower than V_{OUT} to prevent reverse current from flowing from the V_{OUT} pin to the V_{IN} pin. Reverse-current blocking is disabled while the MOS pass transistor is on.



Reverse-current protection

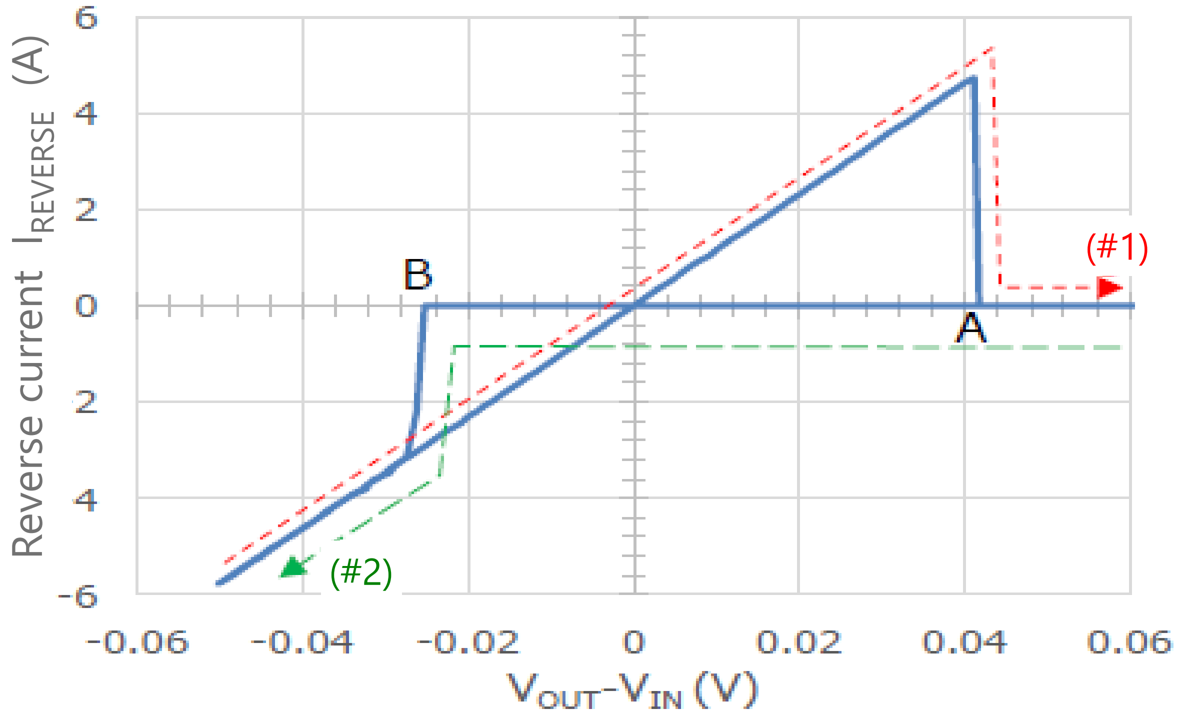
b) True reverse-current blocking

A true reverse-current blocking function prevents reverse current from flowing from the V_{OUT} pin to the V_{IN} pin regardless of whether the MOS pass transistor is on or off. The reverse-current blocking circuit is enabled when V_{OUT} becomes higher than V_{IN} by V_{RB} (reverse blocking voltage threshold) and is disabled when V_{OUT} becomes lower than V_{IN} by V_{RBR} (reverse blocking release voltage threshold).



Reverse-current protection

The following figure shows the reverse-current characteristics of a load switch IC with a true reverse-current blocking function. As highlighted by the red line (#1), $I_{REVERSE}$ increases as the difference between V_{OUT} and V_{IN} ($V_{OUT} - V_{IN}$) increases. Reverse-current blocking is enabled when $V_{OUT} - V_{IN}$ reaches Point A at which it is approximately 40 mV, blocking $I_{REVERSE}$. When V_{IN} becomes higher than V_{OUT} by roughly 30 mV (at Point B) as highlighted by the green line (#2), reverse-current blocking is disabled, causing current to begin flowing again from the V_{IN} pin to the V_{OUT} pin.



Chapter3 Glossary of terms used in the datasheets for load switch ICs

Glossary of terms used in the datasheets for load switch ICs

Characteristic	Symbol	Description
Input voltage	V_{IN}	The input voltage range in which a load switch IC operates properly
Quiescent current (ON state)	I_Q	The amount of quiescent current that flows through a load switch IC when it is on
Quiescent current (OFF state)	$I_{Q(OFF)}$	The amount of quiescent current that flows through a load switch IC when it is off
Switch leakage current (OFF state)	$I_{SD(OFF)}$	The amount of leakage current flowing out of the V_{OUT} pin when a load switch IC is off
CONTROL High-level input voltage	V_{IH}	The minimum voltage at which the Control pin of a load switch IC is regarded as being in the logic High state
CONTROL Low-level input voltage	V_{IL}	The maximum voltage at which the Control pin of a load switch IC is regarded as being in the logic Low state
On-resistance	R_{ON}	On-resistance between the drain and source of the MOSFET connected between the V_{IN} and V_{OUT} pins
Reverse blocking current	I_{RB}	The amount of current that flows into a load switch IC from the V_{OUT} pin when the voltage at the V_{OUT} pin is higher than the voltage at the V_{IN} pin
Reverse blocking voltage threshold	V_{RB}	The difference in voltage between the V_{OUT} and V_{IN} pins (V_{OUT}-V_{IN}) at which the reverse-current blocking circuit is tripped when $V_{OUT} > V_{IN}$. V_{RB} is specified for load switch ICs with a true reverse-current blocking function.
Reverse blocking release voltage threshold	V_{RBR}	The difference in voltage between the V_{OUT} and V_{IN} pins (V_{OUT}-V_{IN}) at which the reverse-current blocking circuit is disabled when V_{IN} rises back above V_{OUT} after it is tripped. V_{RBR} is specified for load switch ICs with a true reverse-current blocking function.

Glossary of terms used in the datasheets for load switch ICs

Characteristic	Symbol	Description
Undervoltage lockout (UVLO) rising threshold	V_{UVL_RI}	The threshold voltage at which UVLO is disabled when V_{IN} rises. A load switch IC turns on when V_{IN} exceeds V_{UVL_RI}.
Undervoltage lockout (UVLO) falling threshold	V_{UVL_FA}	The threshold voltage at which UVLO is tripped when V_{IN} falls. A load switch IC is disabled when V_{IN} drops below V_{UVL_FA}.
Overvoltage lockout (OVLO) rising threshold	V_{OVL_RI}	The threshold voltage at which OVLO is tripped when V_{IN} rises. A load switch IC is disabled when V_{IN} exceeds V_{OVL_RI}.
Overvoltage lockout (OVLO) falling threshold	V_{OLV_FA}	The threshold voltage at which OVLO is disabled when V_{IN} falls. A load switch IC is enabled when V_{IN} falls below V_{OLV_FA}.
Output discharge on-resistance	R_{SD}	The on-resistance of the internal N-channel MOSFET connected between the V_{OUT} and GND pins of a load switch IC for discharging the external smoothing capacitor connected to the V_{OUT} pin
Output limited current	I_{CL}	The current level to which the output current is limited by the overcurrent protection function

Chapter4 Power loss calculation for load switch IC

Calculating the power dissipation of a load switch IC and heat dissipation

The junction temperature T_j of a load switch IC can be calculated as follows:

$$P = I_{OUT}^2 \times R_{ON} + V_{IN} \times I_Q \quad \cdots (1)$$

When the term $V_{IN} \times I_Q$ is negligibly small, Equation 1 can be approximated as follows:

$$P = I_{OUT}^2 \times R_{ON} \quad \cdots (2)$$

The junction of a load switch IC (T_j) can also be calculated in the following manner:

$$T_j = P \times R_{th(j-a)} + T_a \quad \cdots (3)$$

where $R_{th(j-a)}$ is the thermal resistance of the load switch IC when it is mounted on a board. If $R_{th(j-a)}$ is not shown in the datasheet, you can calculate it from the power dissipation (P_D) value:

$$R_{th(j-a)} = \frac{T_{j(max)} - 25}{P_D} \quad \cdots (4)$$

Substituting Equation 4 into Equation 3, we obtain:

$$T_j = P \times \frac{T_{j(max)} - 25}{P_D} + T_a \quad \cdots (5)$$

P	:	Power dissipation of a load switch IC (W)
P_D	:	Power dissipation of a load switch IC when it is mounted on a board of the size specified in a datasheet (W)
$R_{th(j-a)}$	:	Thermal resistance of a load switch IC when it is mounted on a board of the size specified in a datasheet (°C/W)
$T_{j(max)}$	:	Maximum rated junction temperature specified in the datasheet (°C)
T_j	:	Junction temperature (°C)
T_a	:	Ambient temperature (°C)

Substituting Equation 5 into Equation 2, we obtain:

$$T_j = I_{OUT}{}^2 \times R_{ON} \times \frac{T_{j(max)} - 25}{P_D} + T_a \quad \cdots (6)$$

The power dissipation of a load switch IC can be calculated as shown above.

The on-resistance of the load switch IC depends on temperature. Use an appropriate on-resistance value according to the actual usage temperature.
Note that the power dissipation and thermal resistance values in the datasheet are the values under the specified board conditions. It is therefore necessary to evaluate load switch ICs carefully to ensure that they work properly under actual usage conditions.

