Basics of Load Switch ICs

Outline:

The load switch IC is located between the power supply and the load. The ICs are used for power management to control the power supply to the load. Similar switches can be constructed with mechanical relays and semiconductors such as MOSFET, but load switch ICs can be miniaturized and consume less power.

It has a variety of built-in protection functions and is expected to improve the reliability of the system.

Table of Contents

List of Figures

1. Introduction

Mobile and other electronic devices are becoming increasingly sophisticated and versatile. Although it is necessary to reduce power consumption to conserve battery life, these devices incorporate increasingly sophisticated ICs and circuits requiring complicated and advanced power management. This application note discusses the operations and features of semiconductor switches called load switch ICs that are utilized to reduce system power consumption and improve system stability.

2. What is a load switch IC?

A load switch is a high-side semiconductor switch connected in series between a power supply and a load. Since it is desirable to minimize the voltage drop and power dissipation of a pass element, a low-on-resistance MOSFET is mainly used as a pass element. Load switches are utilized to set a power supply sequence necessary for reliable operation of a complicated system and to disconnect idle circuit blocks in order to reduce system power consumption.

Load switch ICs incorporate various protection features as well as a FLAG output that indicates a faulty condition externally. Therefore, load switch ICs are more suitable than load switches composed of discrete semiconductor devices for reducing the size and enhancing the reliability of an electronic device.

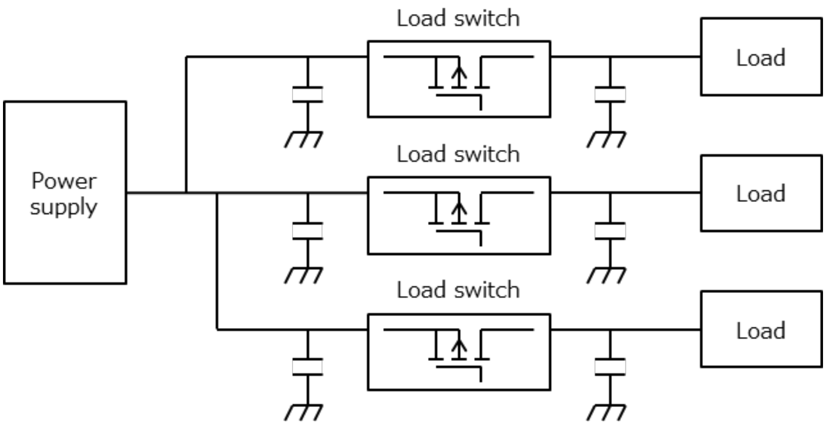

Figure 2.1 Application example of load switch ICs

3. Block diagram and description of a load switch IC

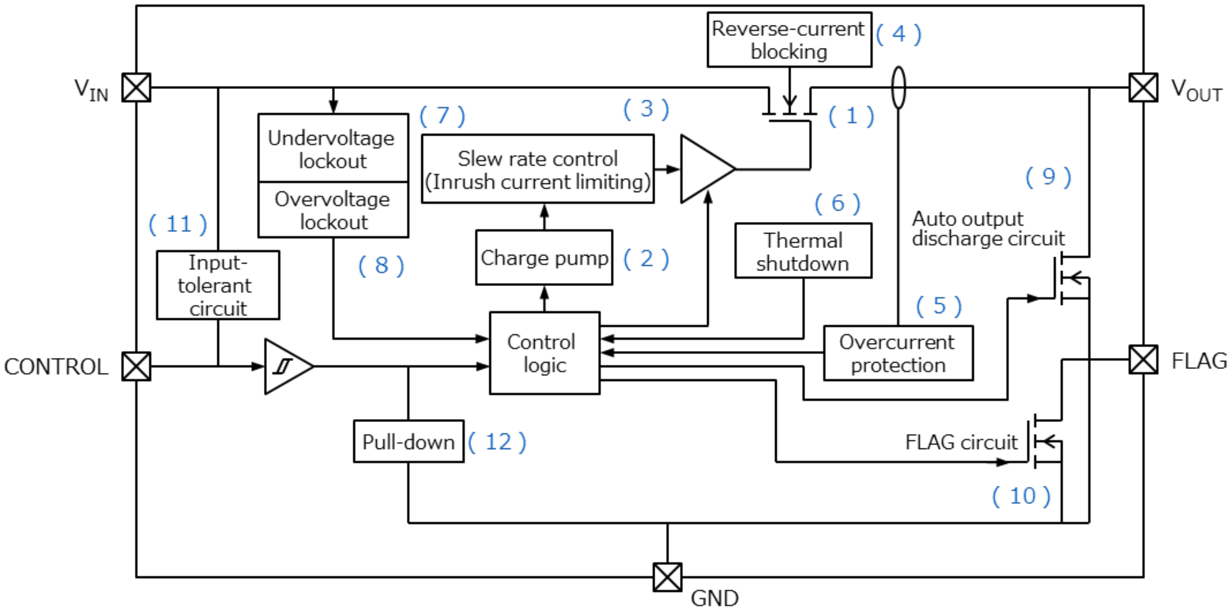

Figure 3.1 Block diagram of a load switch IC

(1) MOS pass transistor

Either an N-channel or a P-channel MOSFET is used as a pass transistor, depending on the purpose of the load switch IC. The N-channel MOSFET uses electrons as majority carriers to conduct current whereas the P-channel MOSFET uses holes as majority carriers. Because electrons have greater mobility than holes, the N-channel MOSFET provides lower on-resistance than the P-channel MOSFET with the same area.

In order for the N-channel MOSFET to operate in the linear region where on-resistance is low, the gate voltage must be sufficiently higher than the source voltage. Since a load switch IC has a high-side switch configuration, the source and drain voltages of the N-channel MOS pass transistor are almost equal when it is on. Therefore, the gate voltage must be higher than the drain voltage (input supply voltage). For this reason, a load switch IC with an N-channel MOS pass transistor (hereinafter referred to as an “N-channel load switch IC”) incorporates a charge pump circuit to raise the gate drive voltage. Although this tends to cause quiescent current to increase, the N-channel load switch IC is favored in terms of on-resistance (R_{ON}), an important parameter for load switches.

In contrast, a P-channel MOSFET turns on when its gate voltage is pulled down to the GND level. While this simplifies control circuitry, sufficient gate-source voltage cannot be applied when the input supply voltage is low. Therefore, the P-channel MOSFET tends to have high on-resistance. However, a load switch IC with a P-channel MOS pass transistor (simply referred to as “a P-channel load switch IC”) eliminates the need for a charge pump circuit and thus provides low quiescent current. The N-channel load switch IC provides low on-resistance even at low input supply voltage as shown in Figure 3.4.

To reduce power consumption, it is important to use an appropriate type of load switch IC according to the application requirements.

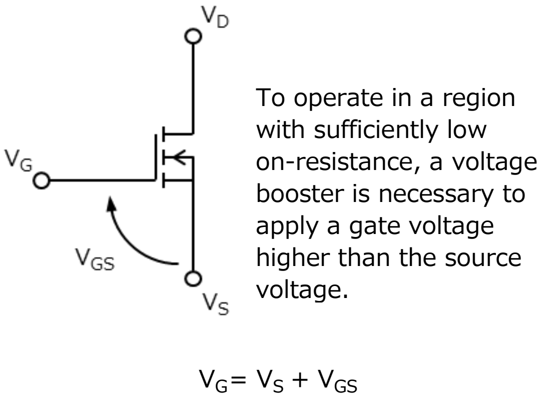

Figure 3.2 Application of gate voltage to the N-channel MOSFET

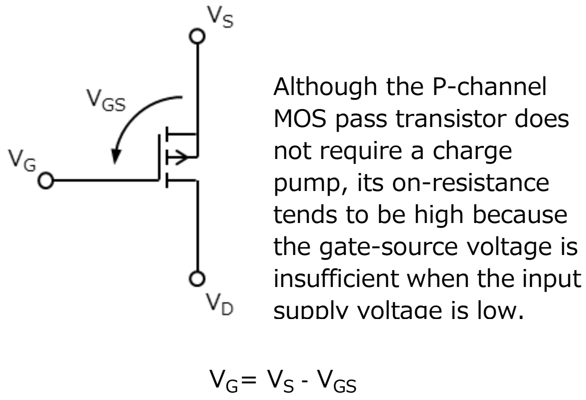

Figure 3.3 Application of gate voltage to the P-channel MOSFET

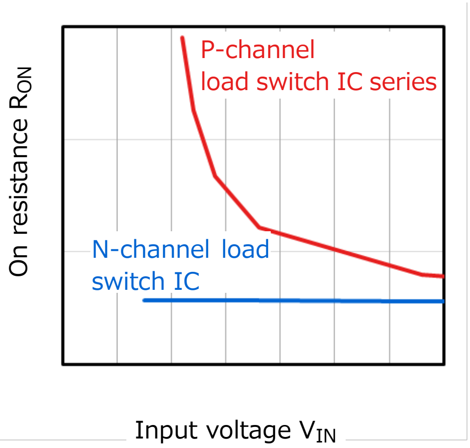

Figure 3.4 R_{on} - V_{IN} curves of P-channel and N-channel load switch ICs

(2) Charge pump

A charge pump is a voltage booster that generates a voltage for the gate drive of an N-channel MOS pass transistor. As an example, the following paragraphs describe the basic operation of a cross-coupled charge pump shown in Figure 3.5. This charge pump alternates between (a) and (b) to double the V_{DD} voltage across a load. Toshiba's load switch ICs incorporate different types of charge pump according to their characteristics.

(a) S_1 and S_4 are on, and S_2 and S_3 are off.

When S_1 and S_4 turn on, C_1 is charged from V_{DD}.

(b) S_1 and S_4 are off, and S_2 and S_3 are on.

When S_2 and S_3 turn on, the voltage at the midpoint between S_2 and S_4 (V_a) becomes equal to V_{DD}. Since C_1 is charged at V_{DD}, the voltage at the midpoint between S_1 and S_4 (V_b) rises to 2 × V_{DD}, charging C_{OUT}.

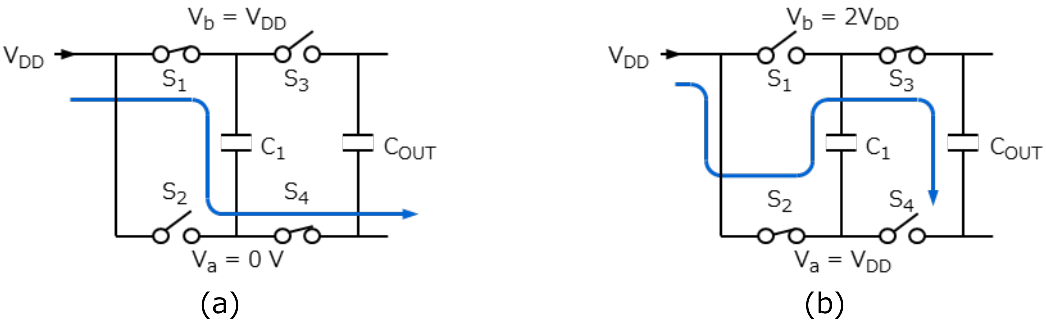

Figure 3.5 Basic operation of a charge pump

(3) Slew rate control circuit (inrush current limiting function)

Inrush current is limited by a slew rate control circuit. When a large capacitive load is connected to the MOS pass transistor, turning on the pass transistor at high speed causes a large current to flow to charge the load. At this time, V_{IN} drops instantaneously because of the impedance of board traces on the V_{IN} side of a load switch IC, causing system instability or malfunction. To prevent this situation, the load switch IC incorporates a slew rate control circuit, which turns on the MOS pass transistor at a low slew rate, slowly charging the capacitive load and thereby ensuring a stable system start-up.

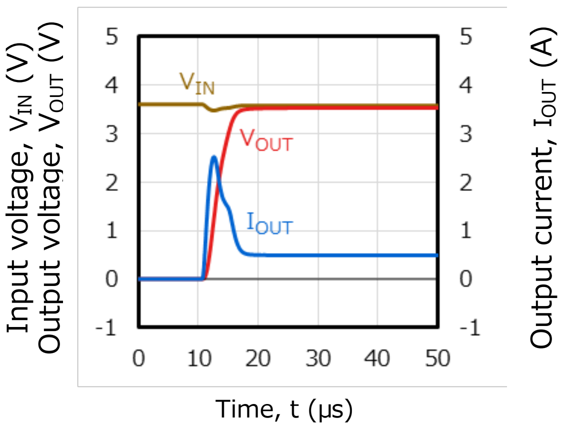

Figure 3.6 Operating waveforms of a load switch IC without a slew rate control circuit

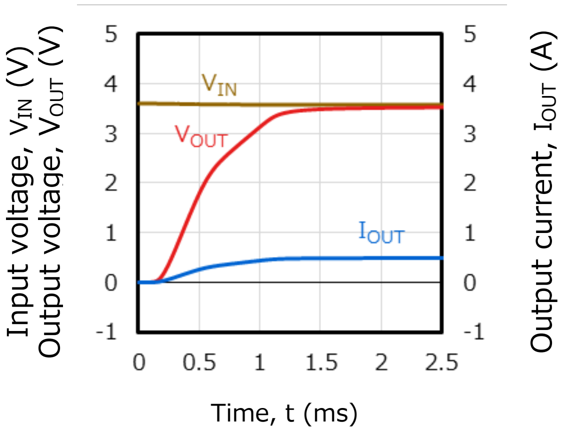

Figure 3.7 Operating waveforms of a load switch IC with a slew rate control circuit

To perform a parametric search of load switch ICs incorporating an inrush current limiting circuit → Click Here

(4) Reverse-current blocking circuit

The reverse-current blocking circuit blocks the current flowing in the direction from the V_{OUT} terminal to the V_{IN} terminal when output supply voltage (V_{OUT}) > input supply 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 turned off

When the MOS pass transistor turns off (i.e., when control voltage (V_{CT}) is 0 V), V_{IN} becomes lower than V_{OUT} to prevent reverse current from flowing from the V_{OUT} terminal to the V_{IN} terminal. However, when the MOS pass transistor is on, the reverse-current blocking function is disabled.

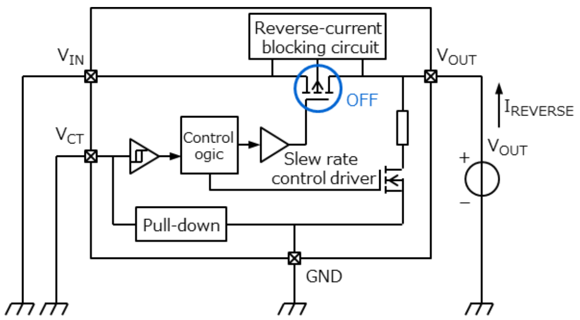

Figure 3.8 Example of reverse-current blocking during turn-off

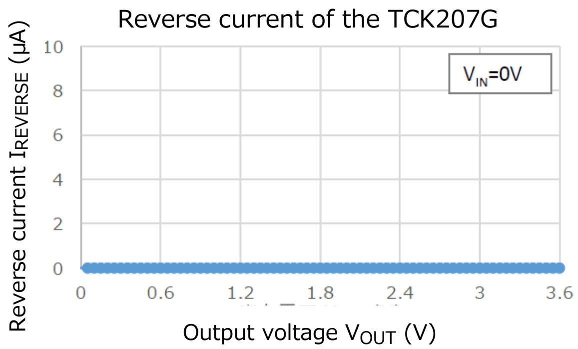

Figure 3.9 $I_{REVERSE}$ – V_{OUT} characteristics of the TCK207G

Load switch ICs with this type of reverse-current blocking circuit are useful as power multiplexers that select between two power supply paths to a single output as shown in Figure 3.10.

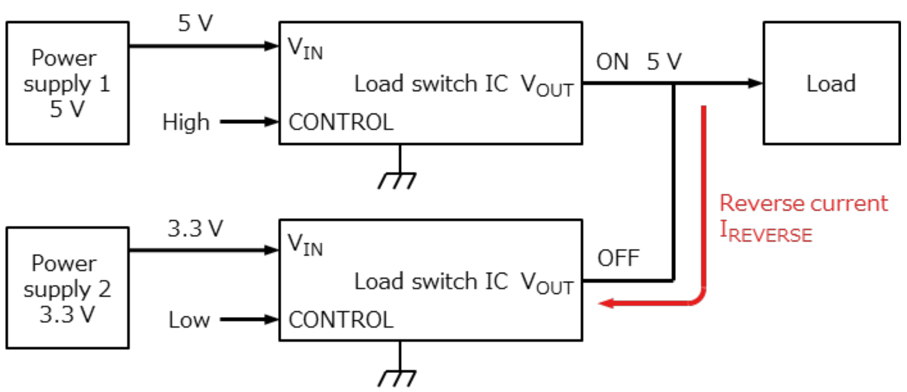

Figure 3.10 Example of a power multiplexer using load switch ICs that provide reverse-current blocking during turn-off

b) True reverse-current blocking

A true reverse-current blocking function prevents reverse current from flowing from the V_{OUT} terminal to the V_{IN} terminal 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). It is disabled when V_{OUT} becomes lower than V_{IN} by V_{RBR} (reverse blocking release voltage threshold). True reverse-current blocking is also called always-on reverse-current blocking.

Datasheet examples: TCK22946G, TCK22951G, TCK2065G, TCK1024G

Characteristics	Symbol	Test Condition	T_j = 25°C			T_j = -40 to 85°C		Unit
			Min	Typ.	Max	Min	Max	
Reverse blocking current	I_{RB}	V_{OUT} = 5.5 V, V_{IN} = 0 V RCB active	–	0.01	–	–	2	μA
Reverse blocking voltage threshold	V_{RB}	V_{OUT} - V_{IN}	–	35	–	–	–	mV
Reverse blocking release voltage threshold	V_{RBR}	V_{OUT} - V_{IN}	–	-15	–	–	–	mV

Figure 3.11 shows the operation of the true reverse-current blocking function. When V_{OUT} exceeds V_{IN}, reverse current ($I_{REVERSE}$) begins flowing. When V_{OUT} becomes higher than V_{IN} by V_{RB} (reverse blocking voltage threshold) at ①, reverse-current blocking is enabled to limit $I_{REVERSE}$. V_{IN} rises again while the reverse-current blocking circuit is active. When V_{IN} becomes higher than V_{OUT} by V_{RBR} (reverse blocking release voltage threshold) at ②, reverse-current blocking is disabled, causing output current (I_{OUT}) to begin flowing again. The maximum reverse current (I_{PEAK}) can be calculated as (3-1):

$$I_{PEAK} = \frac{V_{RB}}{R_{ON}} \tag{3-1}$$

I_{PEAK}: Maximum reverse current (A)

V_{RB}: Reverse blocking voltage threshold (V)

R_{ON}: Operating voltage of the load switch IC (V)

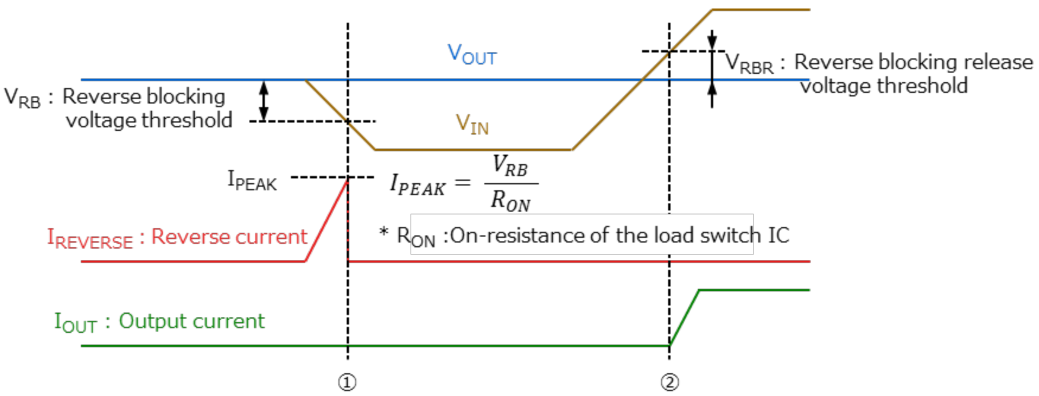

Figure 3.11 Operation of the true reverse-current blocking function

For your reference, Figure 3.12 shows the reverse-current characteristics of the TC111G 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 in the forward direction.

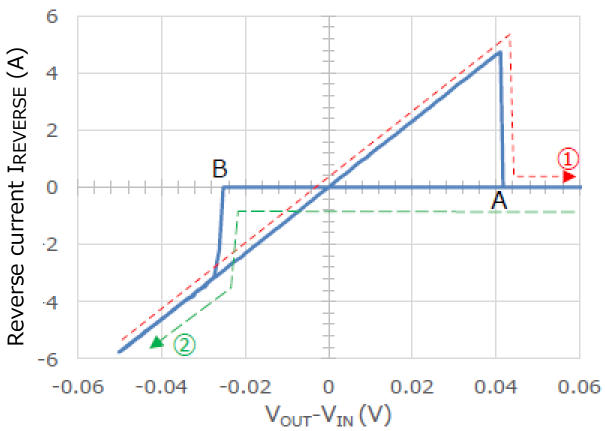

Figure 3.12 Example of $I_{REVERSE}$ vs. $V_{OUT} - V_{IN}$ characteristics

To perform a parametric search of load switch ICs incorporating a true reverse-current blocking circuit → Click Here

For a detailed description of the reverse-current blocking function, see “Overcurrent Protection and Reverse Current Blocking of the Load Switch IC.”

To download the application note “Overcurrent Protection and Reverse Current Blocking of the Load Switch IC” → Click Here

(5) Overcurrent protection circuit

The overcurrent protection (OCP) circuit is designed to limit the output current to protect the load switch IC and subsequent circuit in the event of a V_{OUT}-to-GND short-circuit or an overcurrent condition caused by load variations. The OCP circuit in Toshiba’s load switch ICs has foldback characteristics. Figure 3.13 shows the operation of overcurrent protection. In the event of an output short-circuit or other faulty condition, the output current (I_{OUT}) increases from Point A to Point B where it is equal to the specified output limited current (I_{CL}). When I_{OUT} reaches I_{CL}, the OCP circuit limits the increase in I_{OUT}, causing the output voltage (V_{OUT}) to drop to Point C. At this point, the foldback circuit causes both V_{OUT} and I_{OUT} to decrease. The current flowing at Point D when V_{OUT} = 0 V is called short-circuit current (I_{SC}).

Datasheet examples: TCK22946G, TCK22891G

Characteristics	Symbol	Test Condition	T_j = 25°C			T_j = -40 to 85°C		Unit
			Min	Typ.	Max	Min	Max	
Output limited current	I_{CL}	V_{IN} = 5.5 V	–	400	–	–	–	mA

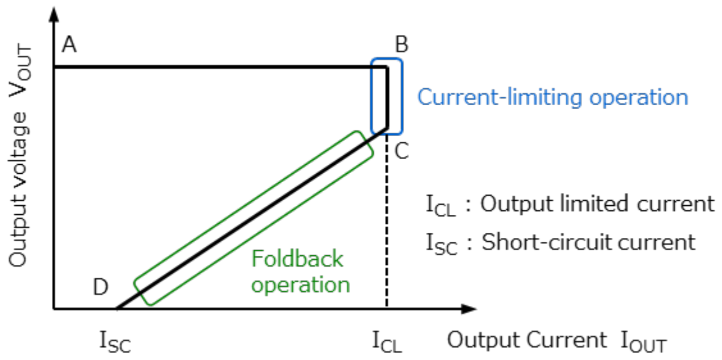

Figure 3.13 Operation of the OCP function

Toshiba provides load switch ICs incorporating an OCP circuit with a wide range of output limited current. Select load switch ICs with the optimal OCP function for your application.

To perform a parametric search of load switch ICs incorporating an OCP circuit → Click Here

For a detailed description of the OCP function, see “Overcurrent Protection and Reverse Current Blocking of the Load Switch IC.”

To download the application note “Overcurrent Protection and Reverse Current Blocking of the Load Switch IC” → Click Here

(6) Thermal shutdown circuit

A thermal shutdown (TSD) circuit protects a load switch IC by detecting the internal junction temperature. The TSD circuit turns off the load switch IC when the junction temperature reaches the internally set trip point because of a sharp increase in ambient temperature or self-heating caused by an overcurrent condition. When TSD is tripped, the load switch IC turns off its output to reduce power consumption, thereby reducing the junction temperature. When the junction temperature drops to the internally set recovery point, TSD is disabled to turn the IC back on. The TSD circuit has hysteresis, i.e., a difference between the junction temperature at which TSD is tripped to turn off the output and the junction temperature at which TSD is disabled.

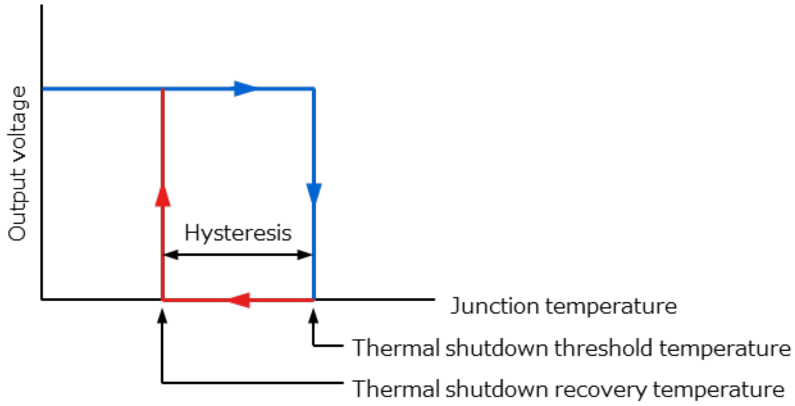

Figure 3.14 TSD operation

The junction temperature is detected by comparing a diode's forward voltage with a reference voltage that is hardly affected by temperature as shown in Figure 3.15. When a load switch IC is operating properly, the diode's forward voltage is higher than the reference voltage. The diode's forward voltage has a temperature coefficient of roughly -2 mV/°C. Therefore, when the junction temperature increases, the diode's forward voltage becomes lower than the reference voltage (V_{TSD}). This causes the comparator output to toggle, turning off the load switch IC. At this point, the reference voltage is switched to a higher level (V_{TSD_r}) via the comparator output signal. When the load switch IC turns off, its power consumption decreases considerably, causing the junction temperature to decrease. When the diode's forward voltage exceeds V_{TSD_r}, the output of the load switch IC turns back on automatically.

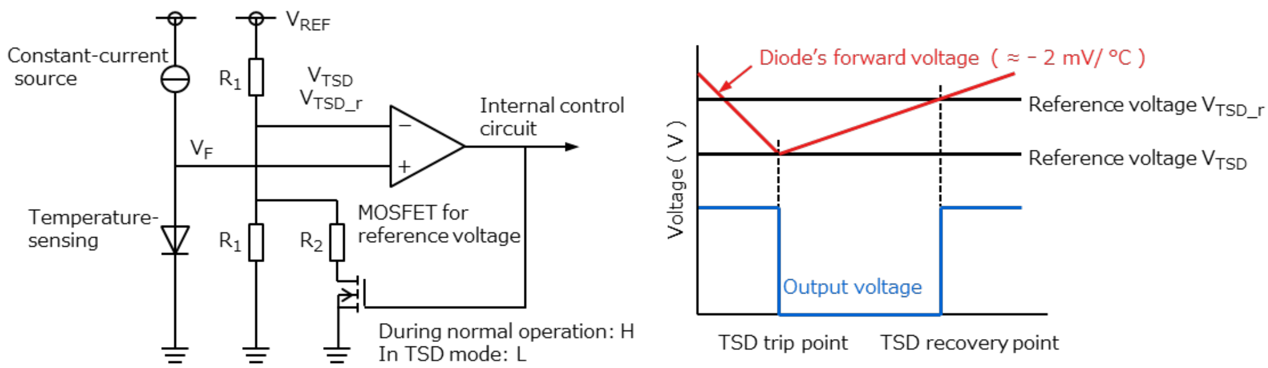

Figure 3.15 TSD circuit and its operation

To perform a parametric search of load switch ICs incorporating a TSD circuit → Click Here

(7) Undervoltage lockout circuit

If V_{IN} drops below the minimum operating voltage of the next-stage IC or circuitry connected to a load switch IC, a system malfunction might occur. When V_{IN} drops to V_{UVL_FA}, the undervoltage lockout (UVLO) circuit turns off the output of the load switch IC in order to prevent a system malfunction. The UVLO circuit has hysteresis. When V_{IN} rises back above the internally set recovery point while the CONTROL terminal remains at the High level, the output turns back on automatically. The UVLO function compares V_{IN} with the internal reference voltage as shown in Figure 3.16. When V_{IN} drops below reference voltage V_1, the comparator output toggles, turning off the output of the load switch IC. At this time, the N-channel MOSFET for reference voltage selection turns off, switching the reference voltage to a higher level (V_2). When V_{IN} rises back above V_2, the comparator output toggles again, turning the IC's output back on.

Datasheet examples: TCK301G, TCK302G, TCK303G, TCK304G, TCK305G

Characteristics	Symbol	Test Condition	T_j = 25°C			T_j = -40 to 85°C		Unit
			Min	Typ.	Max	Min	Max	
Undervoltage lockout (UVLO) rising threshold	V_{OVL_RI}	–	–	2.9	–	2.3	3.5	V
Undervoltage lockout (UVLO) falling threshold	V_{OVL_FA}	–	–	V_{UVL_RI} - 0.3	–	–	–	V

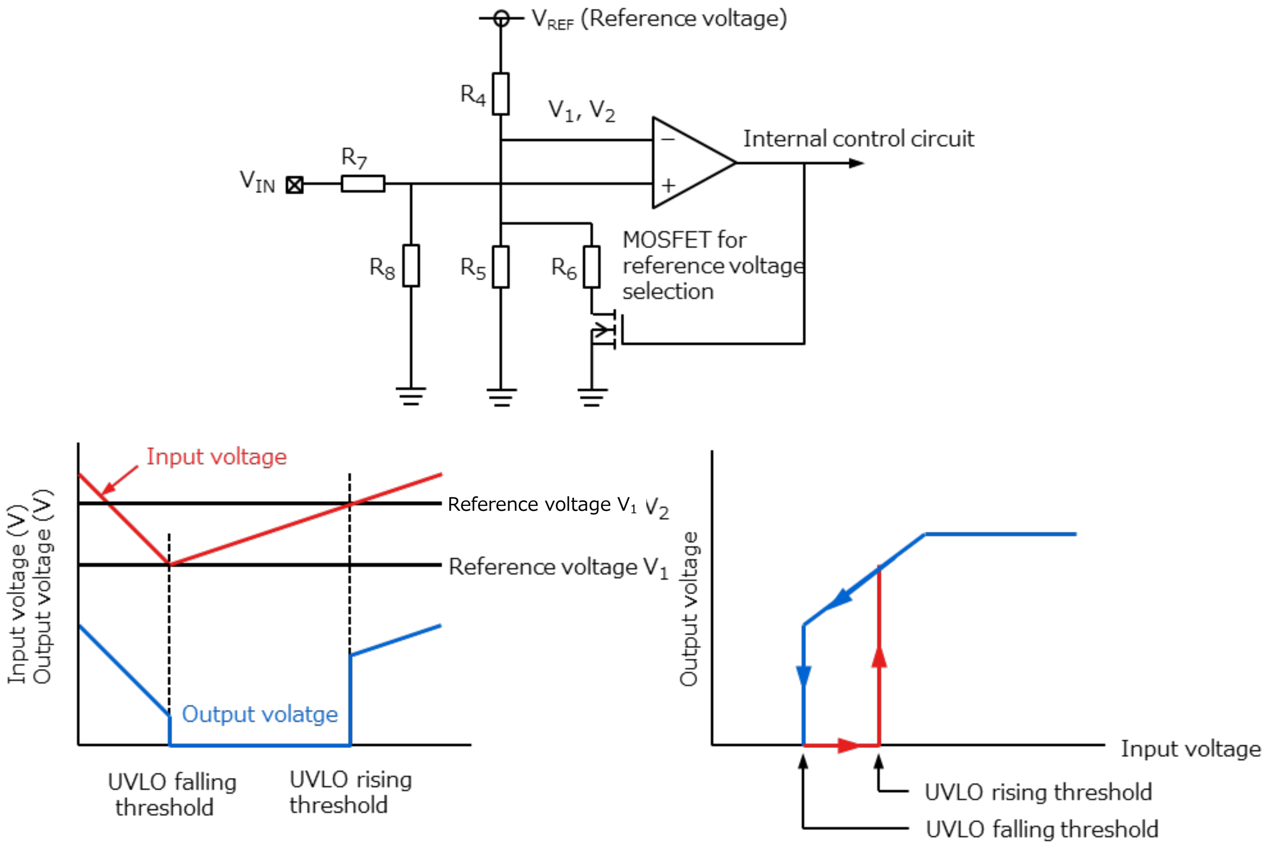

Figure 3.16 UVLO circuit and its operation

To perform a parametric search of load switch ICs incorporating an UVLO circuit → Click Here

(8) Overvoltage lockout circuit

When V_{IN} exceeds the overvoltage lockout (OVLO) rising threshold (V_{OLV_RI}), the OVLO circuit turns off the output of a load switch IC to protect the subsequent IC or circuitry. When V_{IN} drops below the OVLO falling voltage (V_{OLV_FA}) again, the output turns back on automatically. As is the case with the UVLO circuit, the OVLO circuit provides protection by comparing V_{IN} with the internal reference voltage.

Datasheet example: TCK301G

Characteristics	Symbol	Test Condition	T_j = 25°C			T_j = -40 to 85°C		Unit
			Min	Typ.	Max	Min	Max	
Overvoltage lockout (OVLO) rising threshold	V_{OVL_RI}	–	–	6.6	–	5.9	7.3	V
Overvoltage lockout (OVLO) falling threshold	V_{OVL_FA}	–	–	V_{OVL_RI} - 0.35	–	–	–	V

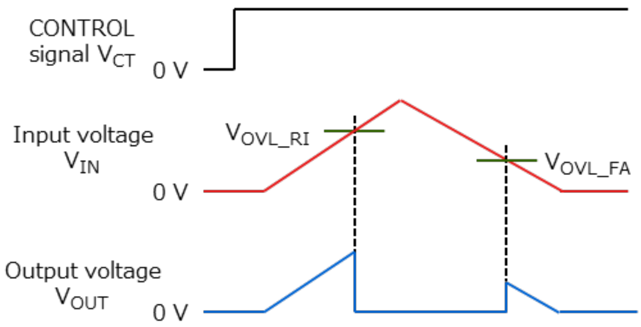

Figure 3.17 OVLO operation

To perform a parametric search of load switch ICs incorporating an OVLO circuit → Click Here

(9) Automatic output discharge circuit

When a load switch IC connected to a capacitive load turns off, the load remains charged. This makes it impossible for a system with multiple load switch ICs to set an appropriate power supply sequence. When a load switch IC turns off, the automatic output discharge circuit turns on an internal MOSFET connected between the V_{OUT} and GND terminals to discharge the load quickly. This circuit reduces the discharge time even when a large output capacitor is connected to a load switch IC, simplifying the setting of the system power sequence.

The discharge on-resistance (R_{SD}) shown in the datasheet is the on-resistance of the MOSFET for output load discharge.

Datasheet examples: TCK107AF, TCK108AF

Characteristics	Symbol	Test Condition	Min	Typ.	Max	Unit
Discharge on-resistance	R_{SD}	–	–	100	–	Ω

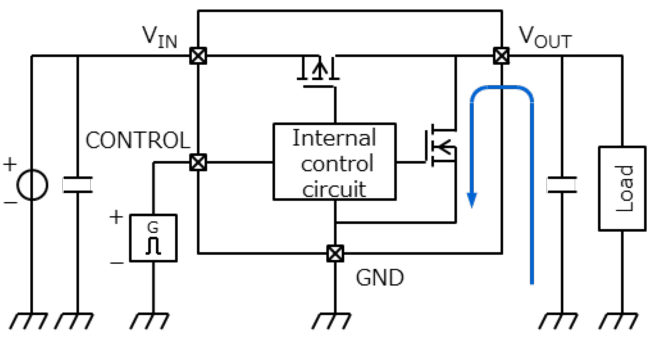

Figure 3.18 Automatic output discharge function

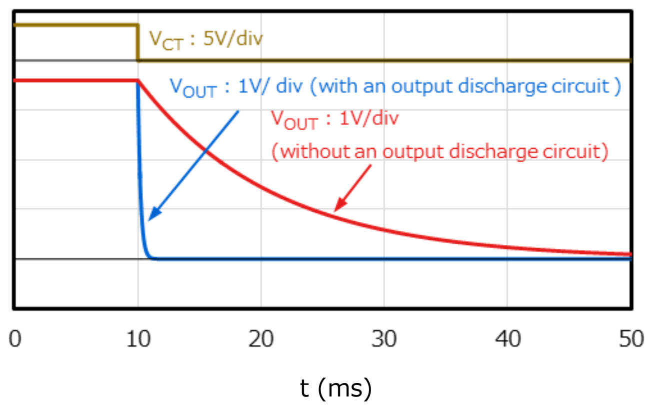

Figure 3.19 Output discharge waveforms

To perform a parametric search of load switch ICs incorporating an automatic output discharge circuit → Click Here

(10) FLAG circuit

When the UVLO, OVLO, or TSD circuit is tripped, the FLAG circuit causes the FLAG output terminal to change, for example, from Low to High, in order to warn of a system fault externally. The FLAG terminal has an open-drain configuration. Connect an external pull-up resistor to the FLAG terminal. The usage of the FLAG circuit differs from IC to IC. For details, see the datasheets for individual load switch ICs.

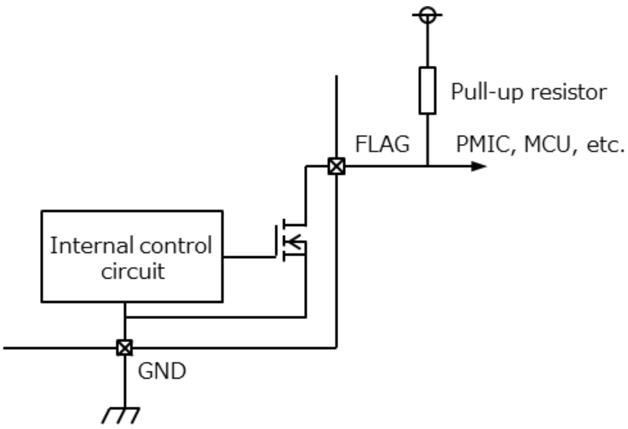

Figure 3.20 FLAG circuit

To perform a parametric search of load switch ICs incorporating a FLAG circuit → Click Here

(11) Input-tolerant circuit

The input-tolerant circuit prevents current from flowing from the CONTROL terminal to the V_{IN} terminal when the CONTROL terminal voltage (V_{CT}) exceeds V_{IN} or V_{IN} = 0 V. Use a load switch IC with the CONTROL terminal having an input-tolerant function if your application applies V_{IN} while the “on” signal is being applied to the CONTROL terminal. If the load switch IC does not incorporate the input-tolerant function, be sure to apply the CONTROL signal after V_{IN} rises to a stable level.

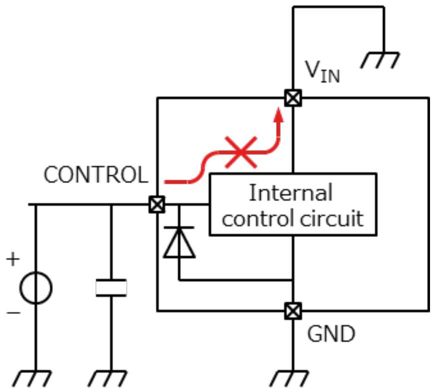

Figure 3.21 Input-tolerant function

(12) Pull-down circuit

Generally, load switch ICs incorporate a pull-down resistor between the CONTROL and GND terminals so that their internal circuitry remains stable in the event of the CONTROL terminal being open-circuited. Toshiba's load switch ICs contain an N-channel depletion MOSFET instead of a resistor as shown in Figure 3.22 in order to reduce control pull-down current (I_{CT}). This MOSFET maintains the current flowing between the CONTROL and GND terminals at almost a constant level as shown in Figure 3.23.

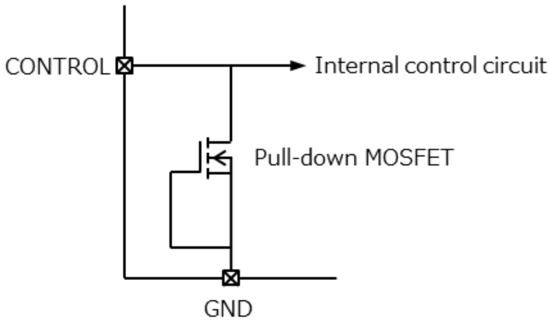

Figure 3.22 Pull-down circuit

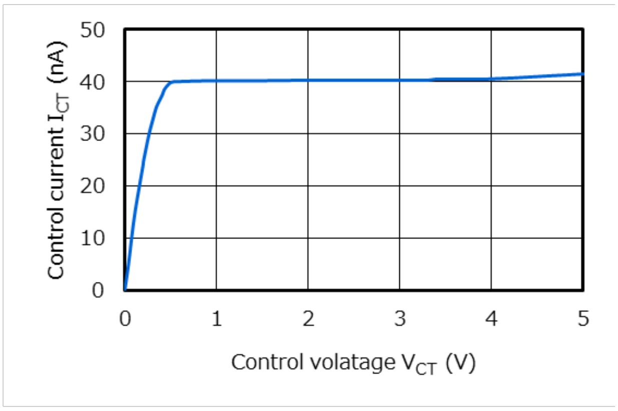

Figure 3.23 I_{CT} – V_{CT} curve

4. Calculating the power dissipation and junction temperature of a load switch IC

The power dissipation (P_D) of a load switch IC can be calculated as shown (4-1) below. The term $V_{IN} \times I_Q$ is negligible when it is much smaller than the term $I_{OUT}{}^2 \times R_{on}$.

$$P = I_{OUT}{}^2 \times R_{ON} + V_{IN} \times I_Q \quad \text{(W)} \qquad (4\text{-}1)$$

I_{OUT}:	Output current	(A)
R_{ON}:	On-resistance	(Ω)
V_{IN}:	Input voltage	(V)
I_Q:	On-state quiescent current	(A)

The maximum junction temperature ($T_{j(max)}$) can be calculated as (4-2):

$$T_{j(max)} = P \times R_{th(j-a)} + Ta$$

$$= P \times \frac{T_j - 25\ °C}{P_D} + Ta$$

$$= P \times \frac{150\ °C - 25\ °C}{P_D} + Ta \quad \text{(°C)} \qquad (4\text{-}2)$$

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}:	Thermal resistance	(°C/W)
T_j:	Maximum rated junction temperature	(°C)
T_a:	Ambient temperature	(°C)

5. Conclusion

This application note has discussed the basics of load switch ICs such as electrical characteristics and protection features shown in the datasheet. Load switch ICs are very effective for the power management of mobile and other electronic devices. Toshiba provides a wide range of load switch ICs, including low-on-resistance load switch ICs and those incorporating various protection features. We hope that you have found this application note useful in considering using Toshiba's load switch ICs.

To visit Toshiba's load switch IC web page → Click Here

6. Related Links

- ■Product Line Ups（Catalog） Click
- ■Product Line Ups（Detail） Click
- ■Product Line Ups（Parametric search） Click
- ■Stock check & Purchase Buy Online
- ■FAQ of Load Switch ICs Click
- ■Application Notes Click

7. RESTRICTIONS ON PRODUCT USE

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as "TOSHIBA".
Hardware, software and systems described in this document are collectively referred to as "Product".

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**
- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**

Toshiba Electronic Devices & Storage Corporation
https://toshiba.semicon-storage.com/