# TCKE712BNL eFuse IC with Flag Output and Reverse-Current Protection

# Application Note

## Outline

An eFuse IC (also known as an electronic fuse) incorporates various functions for protecting electronic devices and serves as a replacement for a conventional fuse.
This application note describes the TCKE712BNL, an eFuse IC with various protection functions and a flag output function, which is a diagnostic function that signals an abnormal condition externally. This application note discusses its basic usage and functions, including short-circuit protection, overcurrent protection, overvoltage protection, thermal shutdown, inrush current limiting, reverse-current blocking during turn-off, undervoltage lockout, and the $\overline{\text{FLAG}}$ output.
Since the TCKE712BNL can be turned on and off via an external signal, it can also be used as a load switch IC.

# Table of Contents

# List of Figures

# List of Tables

# 1. Introduction

At present, fuses and polyswitches (also known as resettable fuses and polyfuses) are widely used to protect electronic devices from overheating and fire hazards. Both fuses and polyswitches are tripped by Joule heat generated by current exceeding their ratings. In this application note, they are referred to as conventional fuses.
There are two types of conventional fuses for the protection of electronic circuits and an overall system. In the case of glass tube and chip current fuses, excessive current causes their internal metal strip to melt, interrupting the current. In the case of polyswitches, the heat generated by current causes their internal conductive polymer to expand; the resulting increase in resistance substantially limits the current.
However, conventional fuses exhibit substantial variations with respect to the interrupting rating. Another downside of conventional fuses is that they take a long time to blow because of their dependence on Joule heat.
In addition, a fuse that relies on a metal melting process must be replaced once it blows.
To overcome these disadvantages of conventional fuses, eFuse ICs use a MOSFET to interrupt current. While usable in the same way as conventional fuses, eFuse ICs can be designed with various protection functions other than overcurrent protection.
The TCKE712BNL, Toshiba's new versatile eFuse IC, also incorporates a flag output function, a diagnostic function that signals an abnormal condition externally. The TCKE712BNL provides overcurrent protection (OCP), short-circuit protection, inrush current limiting (slew rate control), overvoltage protection (OVP), and undervoltage lockout (UVLO). Furthermore, the protection thresholds are programmable. With thermal shutdown (TSD) and reverse-current blocking during turn-off, the TCKE712BNL further simplifies circuit and system protection.
This application note describes major characteristics, operations, usage, and applications of the TCKE712BNL.

* Click here for a detailed description of the flag output and the conditions that cause it to change.

→ Click Here

# 2. What is an eFuse IC?

## 2.1. Usage of an eFuse IC

Whereas conventional fuses rely on the melting of an alloy part, an eFuse IC uses a semiconductor switch to interrupt current. When an internal current sensor detects excessive current, an internal MOSFET is turned off via its output signal to interrupt the current. Figure 2.1 shows an example of a block diagram in which power is supplied to a power management IC (PMIC) via an eFuse IC.

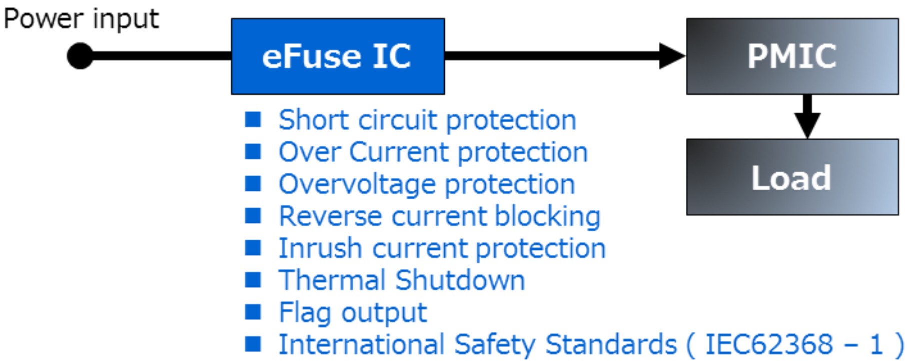



**Figure 2.1 Application example of an eFuse IC**

In this example, an eFuse IC is used instead of a conventional fuse along the power supply line. In the event of excessive current because of a failure of the PMIC or the load, this eFuse IC interrupts the current to protect the circuit, thereby protecting a system from fuming and fire hazards.

## 2.2. Benefits of using an eFuse IC

The eFuse IC provides the following benefits:

- Reduction in the cost and time required for maintenance because of no need for fuse replacement
  Since the eFuse IC interrupts current by turning off an internal MOSFET, it is not destroyed by a single overcurrent event. Therefore, when the MOSFET turns back on again, the eFuse IC returns to normal operation. Unlike conventional fuses that rely on an irreversible melting process, the eFuse IC can be used repeatedly. It eliminates the need for replacement, reducing the cost and time required for maintenance and repairing.

- Robust system protection because of accurate overcurrent and overvoltage detection
  Conventional fuses rely on either a melting or thermal expansion process. Since they do not provide current interruption at exactly the desired ampere level, it is necessary to select fuses with a current rating sufficiently higher than the expected load current. Therefore, some risk remains that they might fail to protect the circuit from destruction. In contrast, eFuse ICs provide protection against overcurrent with high accuracy. The TCKE712BNL allows the setting of its overcurrent and overvoltage protection functions, providing robust protection against current and voltage.

- Enhanced reliability due to high-speed protection operation
  In the case of conventional fuses, it takes some time for the temperature of the internal fuse strip to reach its melting point. Therefore, there is a time lag from the occurrence of an overcurrent condition to the interruption of current. Excessive current continues flowing during this time lag. In contrast, eFuse ICs can switch off the current flow almost immediately upon detection of an overcurrent condition, considerably reducing the time during which a system under protection is exposed to excessive current. Because of reduced damage to the circuit, eFuse ICs help enhance long-term system reliability.

- Cost and size reduction due to single-chip implementation of various protection functions
  In addition to overcurrent and short-circuit protection, an eFuse IC allows various functions to be integrated on the same chip that cannot be realized with conventional fuses, including overvoltage protection, inrush current limiting (slew rate control), thermal

shutdown, and reverse-current blocking. Therefore, an eFuse IC helps reduce the number of parts and the amount of workload required, compared with the case of implementing the same functions using multiple discrete passive components and ICs, and thus reduce the system cost and size.

- Simplified system design because of compliance with international safety standards
  It requires a long time to test fuses to ensure their compliance with internationally recognized safety standards. IEC 62368-1 applies to a wide range of commercial and industrial information and communication and audio/visual equipment. IEC 62368-1 requires that power supply be immediately interrupted in a reliable manner in the event of any abnormal condition. Toshiba obtained certification for IC current limiters stipulated in Section G.9 of IEC 62368-1. Since this certification makes it possible to omit some system tests stipulated in this safety standard, it helps reduce the time and effort required for system design.

Table 2.1 compares Toshiba's TCKE712BNL and conventional fuses.

**Table 2.1 Comparison between an eFuse IC (TCKE712BNL) and conventional fuses**

| | Glass tube fuses | Chip current fuses | Polyswitches (resettable fuses) | Toshiba TCKE712BNL |
|---|---|---|---|---|
| Size | 3 mm × 10 mm or larger | 1 mm × 0.5 mm or larger | 1 mm × 0.5 mm or larger | 3 mm × 3 mm (WSON10) |
| Repeated use | No | No | Yes | Yes |
| Overcurrent protection | N/A (Rated current) | N/A (Rated current) | N/A (I trip) | 0.5 to 3.6 A (Programmable via external resistors) |
| Overvoltage protection (Clamp voltage) | N/A | N/A | N/A | A (Programmable via external resistors) |
| Short-circuit protection speed | ✓ (Because of heat-induced melting) | ✓ (Because of heat-induced melting) | ✓ (Because of a heat-induced change in a physical property) | ✓✓✓ (High speed because of electrical detection: 320 ns typical) |
| Thermal shutdown | N/A | N/A | N/A | A |
| Flag output function | N/A | N/A | N/A | A |
| Reverse-current blocking at turn-off | N/A | N/A | N/A | A (integrated on-chip) |

* ✓ Slow (on the order of milliseconds) ✓✓✓ Fast (less than a microsecond)

Chip current fuses and polyswitches are becoming progressively smaller. However, when protection features available with an eFuse IC are externally added to these fuses using multiple components, the total footprint considerably exceeds the size of a conventional fuse. Although conventional fuses compare favorably with eFuse ICs in some respects, eFuse ICs provide greater benefits as shown in Table 2.1.

# 3. Example of an application circuit for the TCKE712BNL

Figure 3.1 shows an example of an application circuit for the TCKE712BNL.

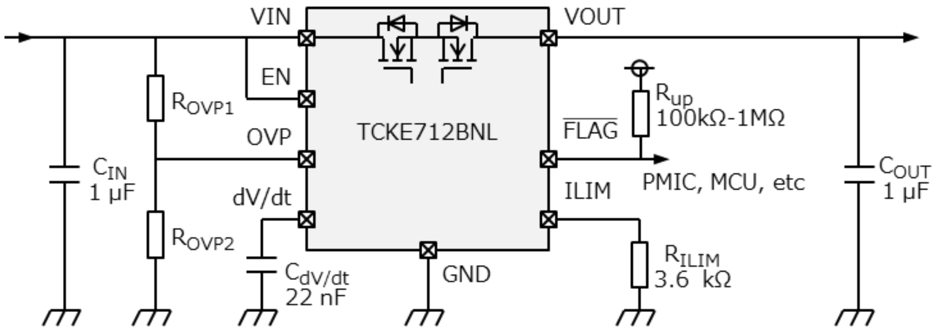



**Figure 3.1 Example of an application circuit for the TCKE712BNL**

A power supply is connected to the VIN input. During normal operation, the VOUT voltage is almost equal to the VIN voltage.

In the event of a sharp decrease in current due to a short-circuit or overcurrent, the back-EMF induced by the inductance of the board traces connected to the input and output pins of the TCKE712BNL causes high-voltage spikes, which might degrade or permanently damage the TCKE712BNL. In that event, a positive voltage spike appears on the input side while a negative voltage spike appears on the output side.

Create a board design in such a manner as to minimize the lengths of the traces on the input and output sides of the TCKE712BNL. Also, maximize the width of the GND trace in order to reduce its impedance.

The input capacitor, $C_{IN}$, helps reduce the peak of the positive spike voltage that appears on the input side. The peak spike voltage ($V_{SPIKE}$) and the value of the input capacitor ($C_{IN}$) have the following relationship. This equation indicates that increasing $C_{IN}$ helps reduce the spike voltage.

$$V_{SPIKE} = V_{IN} + I_{OUT} \times \sqrt{\frac{L_{IN}}{C_{IN}}} \qquad (3\text{-}1)$$

| | | |
|---|---|---|
| $V_{SPIKE}$: | Peak spike voltage | (V) |
| $V_{IN}$: | Input voltage during normal operation | (V) |
| $I_{OUT}$: | Output current | (A) |
| $L_{IN}$: | Effective inductance of the input pin | (H) |
| $C_{IN}$: | Value of the input capacitor | (F) |

In the case of the TCKE712BNL, a 1-μF capacitor is recommended as $C_{IN}$. However, be sure to perform a board evaluation to determine that $V_{SPIKE}$ does not exceed the maximum rated input voltage. The TCKE712BNL can be protected from electrostatic discharge (ESD) by connecting a transient-voltage-suppression (TVS) diode (also known as an ESD protection diode) on the input side. Connecting a Schottky barrier diode (SBD) on the output side prevents the output voltage from dropping considerably below GND because of a negative spike. This SBD helps protect not only the TCKE712BNL but also the load IC and a system. Connect an SBD between the VOUT and GND pins with the anode pointing toward GND. It is recommended to enhance the protection capability of the TCKE712BNL by connecting a TVS diode and an SBD as described above. Figure 3.2 shows an example of an application circuit.

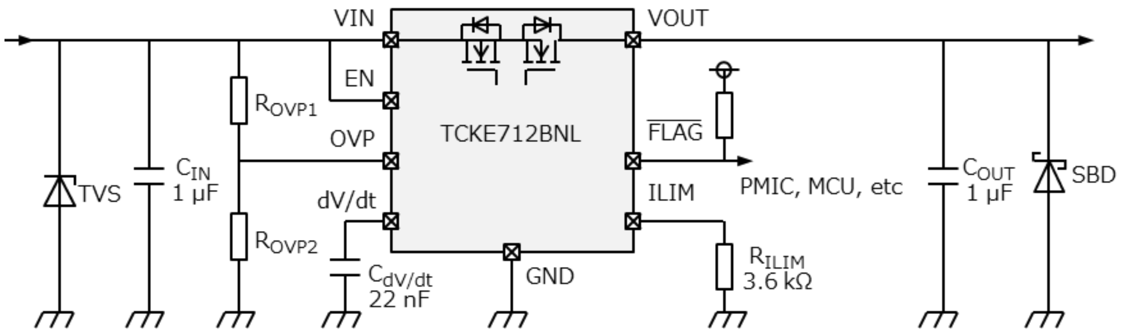



**Figure 3.2 Example of an application circuit for the TCKE712BNL with a TVS diode and an SBD**

In the case of this example, it is recommended to use the DF2S23P2CTC TVS diode and the CUHS20S30 SBD. For details of these diodes and how to select and use the TVS diode, visit the following links:

For details of the DF2S23P2CTC TVS diode → Click Here

For details of the CUHS20S30 Schottky barrier diode → Click Here

For application notes about the basics of TVS (ESD protection) diodes → Click Here

How should I select TVS (ESD protection) diodes according to the voltage level of a signal line to be protected? (FAQ)

→ Click Here

How to select TVS (ESD protection) diodes (FAQ) → Click Here

Board design considerations for TVS (ESD protection) diodes (FAQ) → Click Here

The resistor connected to the ILIM input sets the current limit ($I_{OUT\_CL}$) for overcurrent protection. In the above example, the current limit is set to roughly 1.7 A. The capacitor connected to the dV/dT input is used to adjust the slew rate to limit inrush current. In the event of overcurrent protection, thermal shutdown, or overvoltage protection being tripped, the $\overline{\text{FLAG}}$ output is driven Low to signal an abnormal condition to a PMIC or an MCU. Connect an external pull-up resistor to the $\overline{\text{FLAG}}$ output since it has an open-drain configuration. The EN input is used to turn on and off the internal MOSFET. An external resistor connected to the EN input determines the threshold voltage of the undervoltage lockout circuit. A resistor connected to the OVP input determines the voltage at which overvoltage protection is tripped.
Chapters 6 and 7 detail the functions of these pins and how to select external resistors.

# 4. Functions incorporated in the TCKE712BNL

The TCKE712BNL eFuse IC provides various protection features as shown in Table 4.1.

**Table 4.1 Functions incorporated in the TCKE712BNL**

| | Overcurrent protection | Short-circuit protection | Overvoltage protection | Thermal shutdown | Slew rate control | Reverse-current blocking | Flag output |
|---|---|---|---|---|---|---|---|
| Availability | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ (When the output is off) | ✓ |
| Programmability | ✓ | ✓ (Determined by the overcurrent protection threshold) | ✓ | – | ✓ | – | – |

# 5. Block diagram of the TCKE712BNL

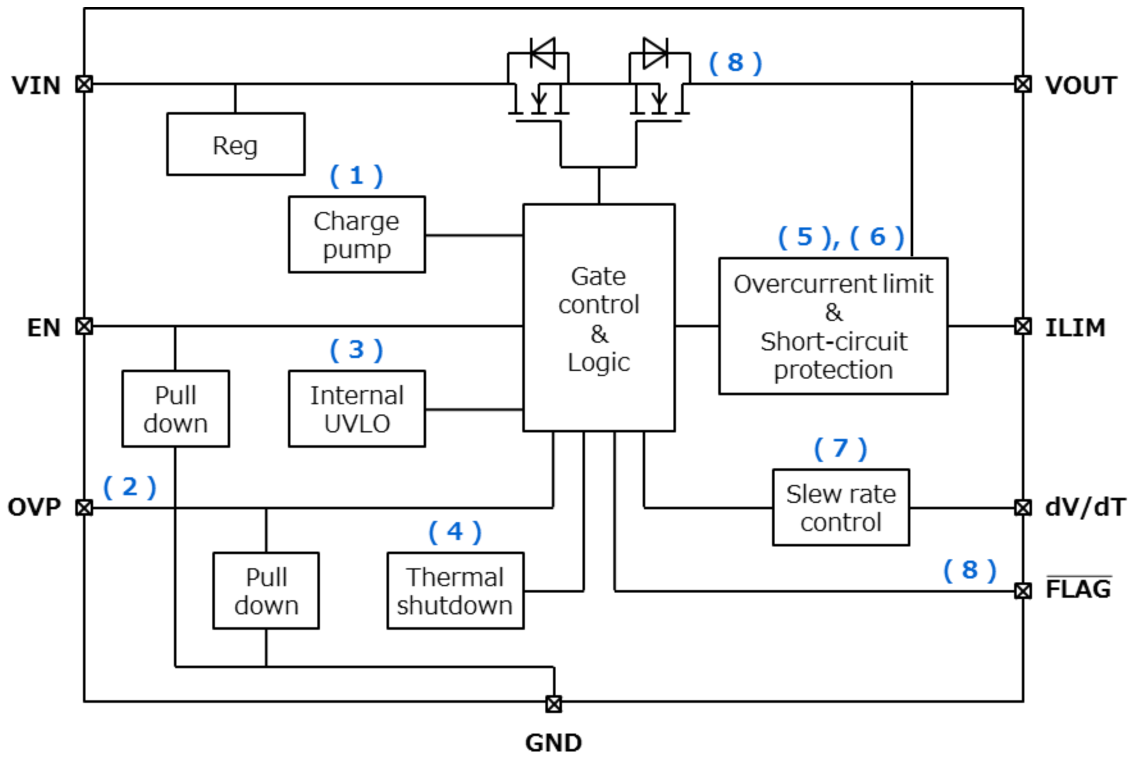



**Figure 5.1 Block diagram of the TCKE712BNL**

**Table 5.1 Pin description of the TCKE712BNL**

| Pin Name | Description |
|---|---|
| VIN | Supply input. |
| dV/dT | Adjusts the rise time of the VOUT output. The rise time is determined by the value of the capacitor connected between the dV/dT and GND pins. |
| EN | Enable pin |
| ILIM | Sets the overcurrent protection threshold. The current limit is determined by the value of the resistor connected between the ILIM and GND pins. |
| GND | Ground pin |
| OVP | Adjusts the overvoltage protection (OVP) threshold. The threshold voltage is determined by the values of the resistors connected to the OVP pin. |
| $\overline{\text{FLAG}}$ | Flag output that externally signals an abnormal condition of the IC such as overcurrent, short-circuit, and thermal shutdown conditions. Connect an external pull-up resistor to this output since it has an open-drain configuration. |
| VOUT | Output voltage |

# 6. Circuits incorporated in the TCKE712BNL

## 6.1. Charge pump [Figure 5.1(1)]

A charge pump is a voltage booster that generates a voltage for the gate drive of an N-channel MOSFET that acts as a switch.

## 6.2. Overvoltage protection circuit [Figure 5.1(2)]

### 6.2.1. Operation of the overvoltage protection (OVP) circuit

When voltage higher than a threshold ($V_{OVPR}$) is applied to the VIN input, the OVP circuit turns off and latches the output voltage to prevent excessive voltage from being applied to a load. At the same time, the $\overline{\text{FLAG}}$ output is driven Low and latched Low. Figure 6.2 shows an example of the OVP operation of the TCKE712BNL. The OVP circuit releases the latch when the EN input is set Low.

**Table 6.1 $V_{OVPR}$ specification shown in the datasheet**

$V_{IN}$ = 12 V, $R_{LIM}$ =3.6 kΩ

| Characteristic | Symbol | Test Conditions | $T_a$ = 25 °C | | | $T_a$ = -40 to 85°C | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | Min | Typ. | Max | Min | Max | |
| Overvoltage protection threshold | $V_{OVPR}$ | – | – | 1.2 | – | 1.14 | 1.26 | V |

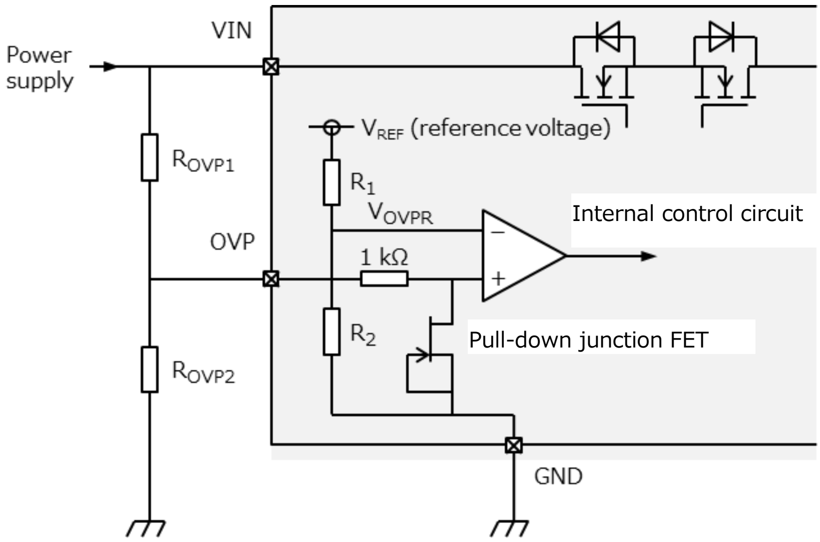



**Figure 6.1 OVP circuit**

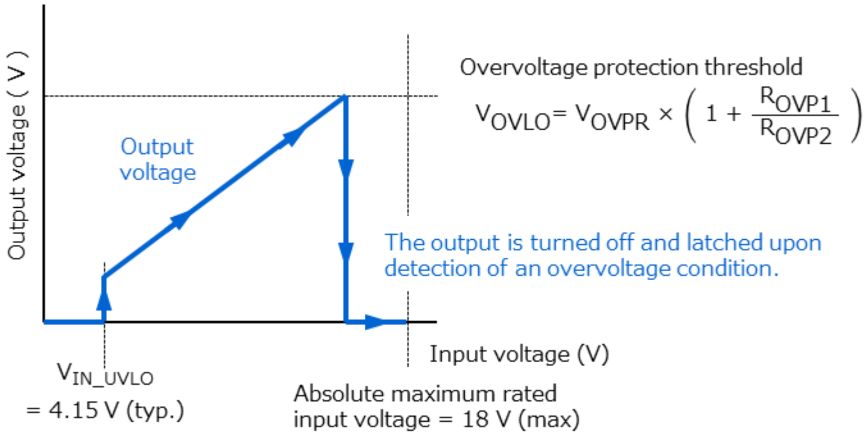



**Figure 6.2 Example of an OVP operation**

Figure 6.1 shows the OVP circuit. It compares the voltage at the OVP input ($V_{OVP}$) and the reference voltage of an internal comparator ($V_{OVPR}$). When $V_{OVP}$ exceeds $V_{OVPR}$, the comparator output toggles Low, turning off the MOSFET switch and latching its output, as shown in Figure 6.3.

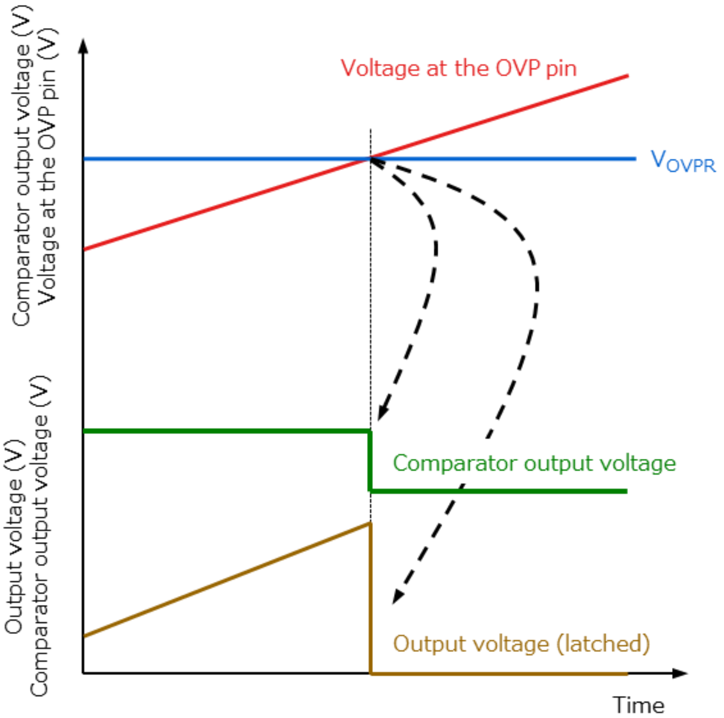



**Figure 6.3 Example of overvoltage detection by the OVP circuit**

A pull-down junction FET equivalent to an $R_{OVP}$ of 22 MΩ (typical) is internally connected between the OVP and GND pins so that the internal circuit does not become unstable when the OVP pin is open.

**Table 6.2 $R_{OVP}$ specification of the OVP pull-down resistor shown in the datasheet**

$V_{IN}$ = 12 V, $R_{LIM}$ =3.6 kΩ

| Characteristic | Symbol | Test Conditions | $T_a$ = 25 °C | | | $T_a$ = -40 to 85°C | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | Min | Typ. | Max | Min | Max | |
| OVP pull-down resistor | $R_{OVP}$ | $V_{OVP}$ = 1.2 V | – | 22 | – | 11 | 60 | MΩ |

### 6.2.2. Setting the OVP trip voltage

The TCKE712BNL allows the OVP trip voltage to be programmed via two resistors, $R_{OVP1}$ and $R_{OVP2}$, as shown in Figure 6.1. The OVP trip voltage can be calculated as follows. Be sure to perform a board evaluation to select resistors with appropriate values.

$$V_{OVP} = V_{OVPR} \times \left(1 + \frac{R_{OVP1}}{R_{OVP2}}\right) \quad \text{(V)} \qquad (6\text{-}1)$$

| | | |
|---|---|---|
| $V_{OVP}$: | OVP trip voltage | (V) |
| $V_{OVPR}$: | Comparator reference voltage | (V) |
| $R_{OVP1}$, $R_{OVP2}$: | External resistors for setting the OVP trip voltage | (Ω) |

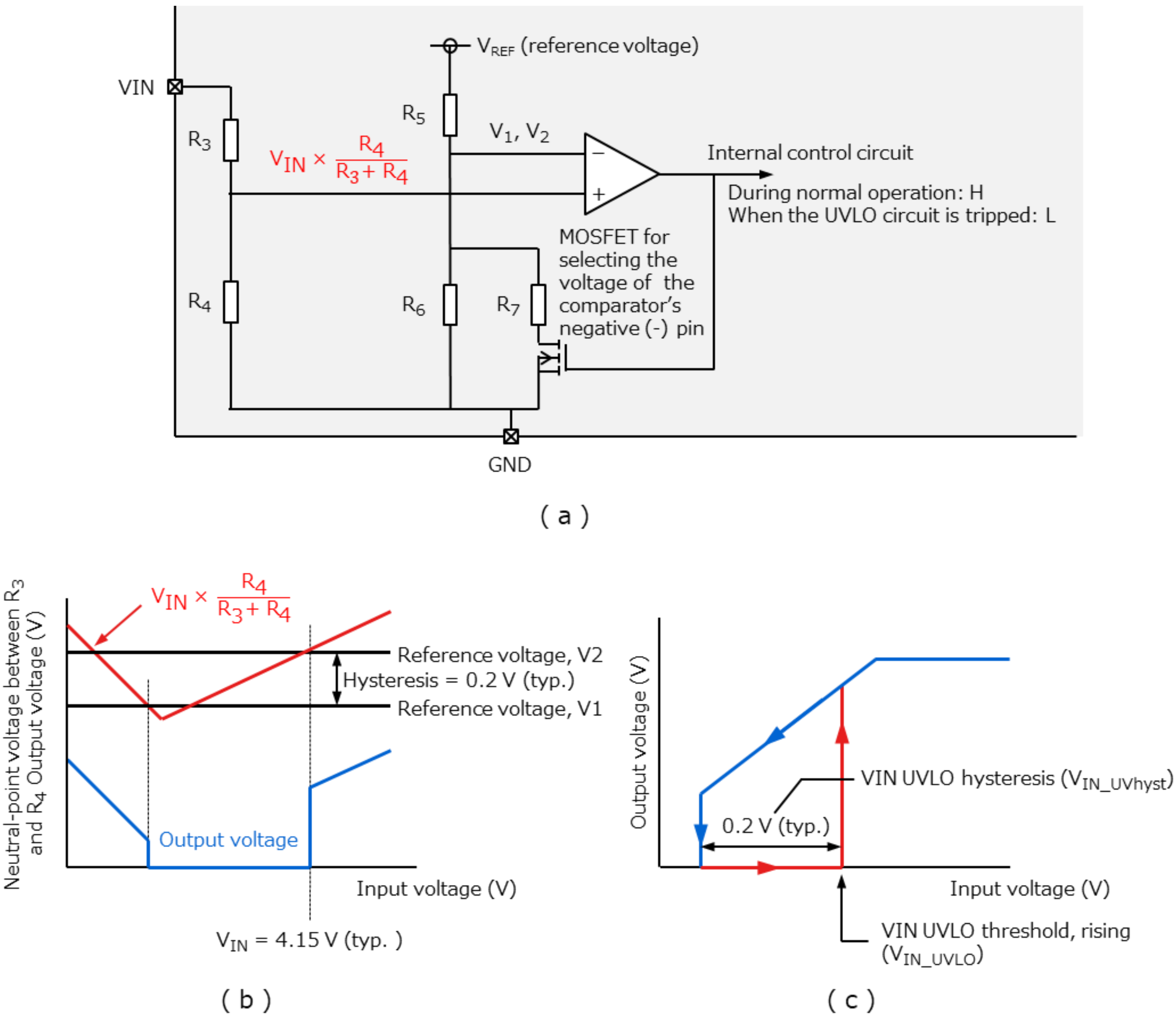
## 6.3. Undervoltage lockout (UVLO) circuit [Figure 5.1(3)]

The UVLO circuit is designed to prevent a system malfunction in the event of the input voltage ($V_{IN}$) dropping below the minimum operating voltage of the IC or circuitry connected to the VOUT output. When $V_{IN}$ drops to the UVLO threshold, VOUT is turned off. When $V_{IN}$ rises and reaches 4.15 V typical, the TCKE712BNL enters into normal operation. The UVLO circuit has hysteresis. When $V_{IN}$ rises by more than $V_{IN\_UVhyst}$ after the UVLO circuit is tripped, VOUT is automatically turned back on. The UVLO circuit compares a voltage derived by dividing $V_{IN}$ with resistors against an internal reference voltage as shown in Figure 6.4 (a). When $V_{IN}$ drops below $V_1$, the comparator output toggles, turning off VOUT. At the same time, the N-channel MOSFET for reference voltage selection turns on, switching the reference voltage to $V_2$. When $V_{IN}$ rises back above $V_2$, the comparator output toggles again, turning VOUT back on.

### Table 6.3 UVLO specifications shown in the datasheet

$V_{IN}$ = 12 V, $R_{LIM}$ =3.6 kΩ

| Characteristic | Symbol | Test Conditions | $T_a$ = 25 °C | | | $T_a$ = -40 to 85°C | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | Min | Typ. | Max | Min | Max | |
| VIN undervoltage lockout (UVLO) threshold, rising | $V_{IN\_UVLO}$ | — | – | 4.15 | – | 4.00 | 4.4 | V |
| VIN undervoltage lockout (UVLO) hysteresis | $V_{IN\_UVhyst}$ | – | – | 0.2 | – | – | – | V |




### Figure 6.4 Example of an operation of the UVLO circuit

## 6.4. Thermal shutdown circuit [Figure 5.1(4)]

The thermal shutdown (TSD) circuit turns off VOUT to protect the TCKE712BNL when its junction temperature rises above the TSD threshold ($T_{SD}$) of 134°C typical as a result of excessive current flowing through VOUT or a sharp increase in ambient temperature. In the event of TSD being tripped, the TCKE712BNL turns off and latches VOUT, and the $\overline{\text{FLAG}}$ pin is driven Low and latched Low. A Low on the EN input takes VOUT out of the latched mode. Figure 6.5 shows an example of an operation of the TCKE712BNL

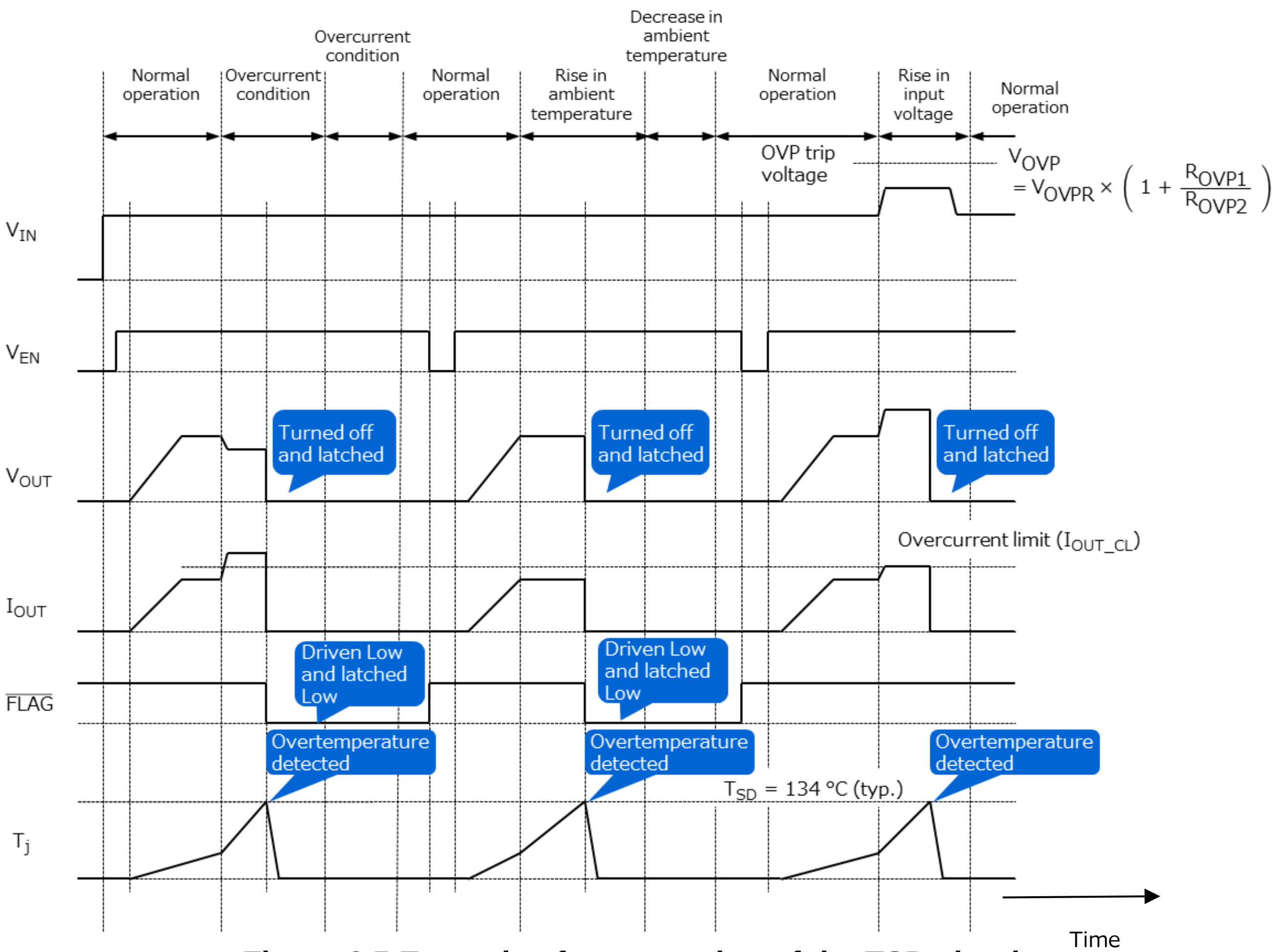



**Figure 6.5 Example of an operation of the TSD circuit**

The junction temperature is detected by comparing a voltage derived from dividing a reference voltage ($V_{REF}$), which changes little with temperature, with $R_8$ and $R_9$ against the forward voltage of a diode, as shown in Figure 6.6. While the TCKE712BNL is operating properly, the diode forward voltage is higher than $V_{TSD}$. The diode forward voltage decreases by -2 mV per Celsius degree rise in temperature. When the diode forward voltage drops below $V_{TSD}$ as a result of an increase in junction temperature, the comparator output toggles, turning off the VOUT output of the TCKE712BNL. At the same time, the $\overline{\text{FLAG}}$ output toggles from High to Low. Setting the EN input Low takes the VOUT output out of the latched mode. However, unless the cause of the increase in junction temperature is removed, TSD is tripped again, turning off the VOUT and $\overline{\text{FLAG}}$ outputs and placing VOUT in the latched mode.

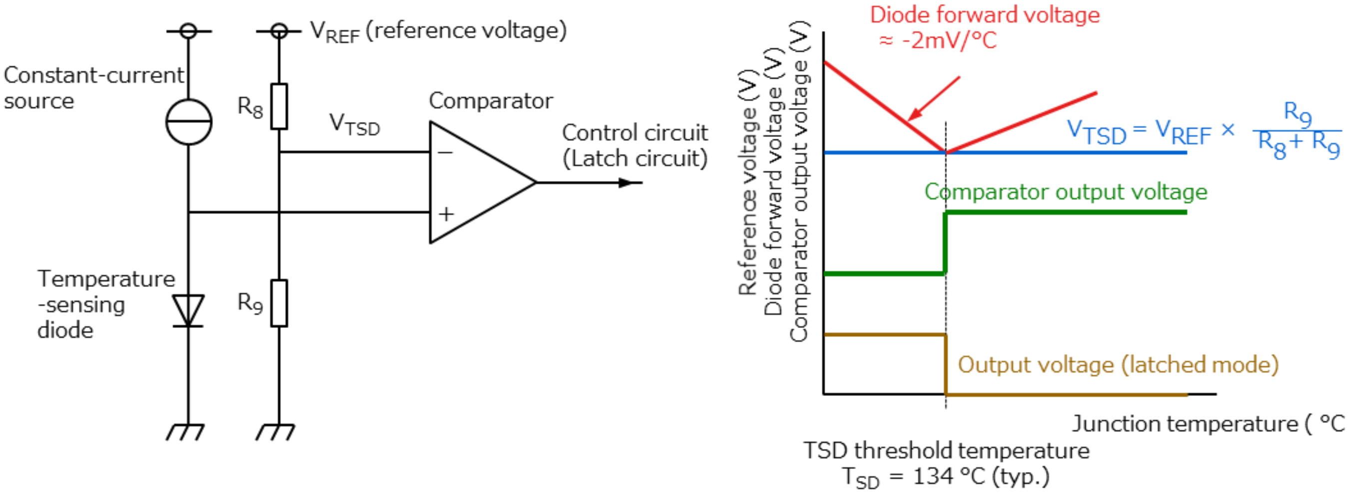



**Figure 6.6 TSD circuit and its principle of operation**

**Table 6.4 $T_{SD}$ specification shown in the datasheet**

$V_{IN}$ = 12 V, $R_{LIM}$ =3.6 kΩ

| Characteristic | Symbol | Test Conditions | $T_a$ = 25 °C | | | $T_a$ = -40 to 85°C | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | Min | Typ. | Max | Min | Max | |
| Thermal shutdown threshold temperature | $T_{SD}$ | $T_j$ | – | 134 | – | – | – | °C |

# 6.5. Overcurrent protection circuit [Figure 5.1(5)]

## 6.5.1. Operation of the overcurrent protection circuit

In the event of an overcurrent condition, the overcurrent protection (OCP) circuit reduces power consumption to protect the TCKE712BNL and the load from degradation and permanent damage. When the output current reaches the overcurrent limit ($I_{OUT\_CL}$) because of an abnormal load condition or a short-circuit, the OCP circuit clamps the output current at $I_{OUT\_CL}$ for a period of $t_{FLAGblank}$ (5.5 ms typical), then turns off the output and latches it. At the same time, the $\overline{FLAG}$ output toggles from High to Low. Even during the period of $t_{FLAGblank}$, VOUT is turned off and latched if the junction temperature rises steeply to the TSD trip threshold, tripping thermal shutdown. The OCP circuit and the short-circuit protection circuit described later provide double protection against overcurrent, greatly contributing to the prevention of fuming and fire hazards. Figure 6.7 shows the timing diagram of the output current limiting operation of the TCKE712BNL.

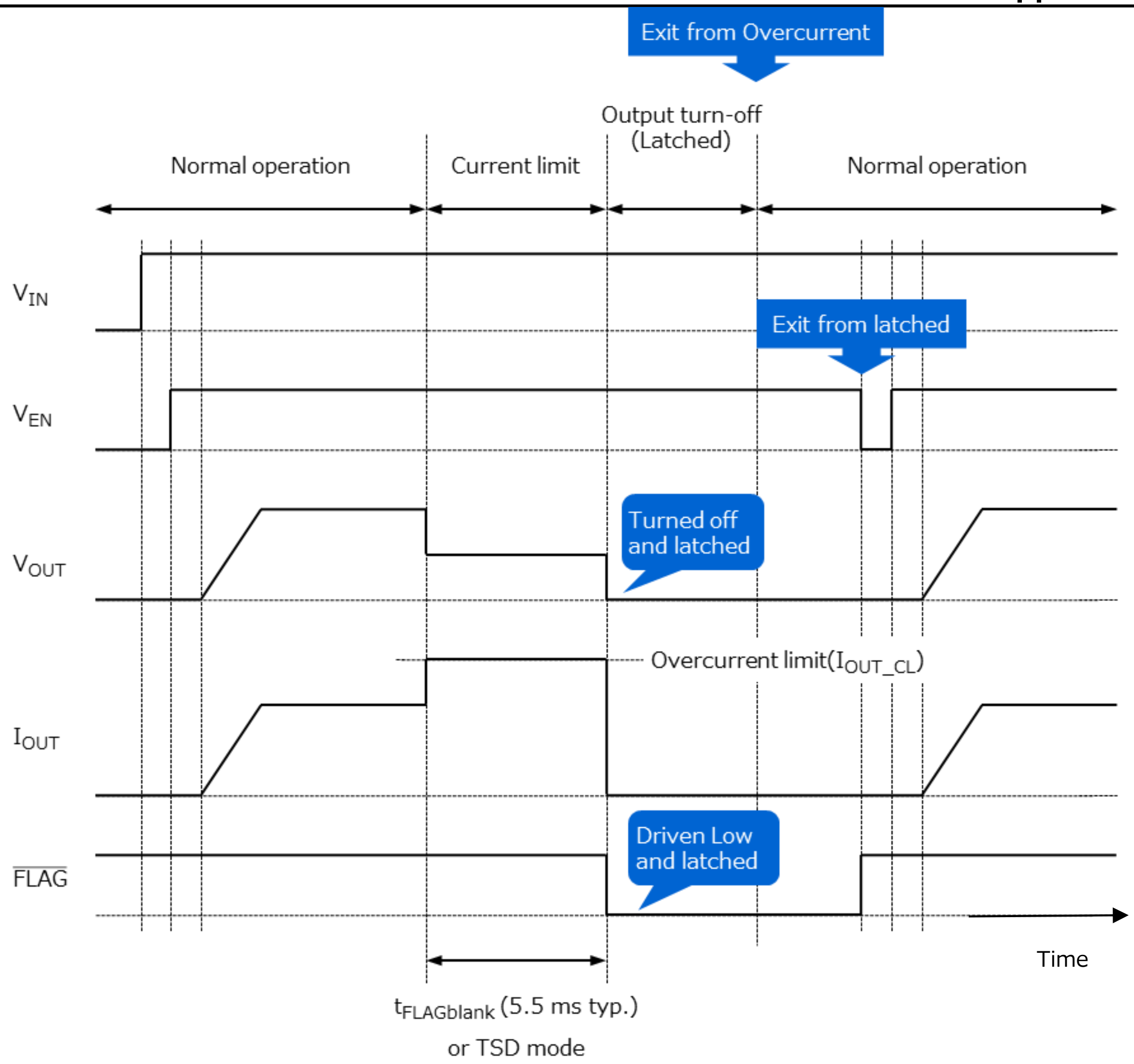



**Figure 6.7 Example of an OCP operation**

**Table 6.5 $t_{FLAGblank}$ specification shown in the datasheet**

$V_{IN}$ = 12 V, $R_{LIM}$ =3.6 kΩ, $R_{LOAD}$ = 12 Ω, $C_{IN}$ = $C_{OUT}$ = 1 μF

| Characteristic | Symbol | Test Conditions | $T_a$ = -40 to 85 °C | | | Unit |
|---|---|---|---|---|---|---|
| | | | Min | Typ. | Max | |
| Overcurrent flag-blanking time / overcurrent switch-off delay | $t_{FLAGblank}$ | Period from when an overcurrent condition is detected to when $V_{FLAG}$ is driven Low (Note) | 3.3 | 5.5 | – | ms |

Note: Guaranteed by design

If short output pulses occur five times during a period of $t_{OCP\_COUNT}$ (176 ms typical) with a pulse width of less than $t_{FLAGblank}$ per pulse, the TCKE712BNL regards them as being caused by an abnormal system condition. In this case, VOUT is turned off, and $\overline{FLAG}$ is driven Low and latched Low.

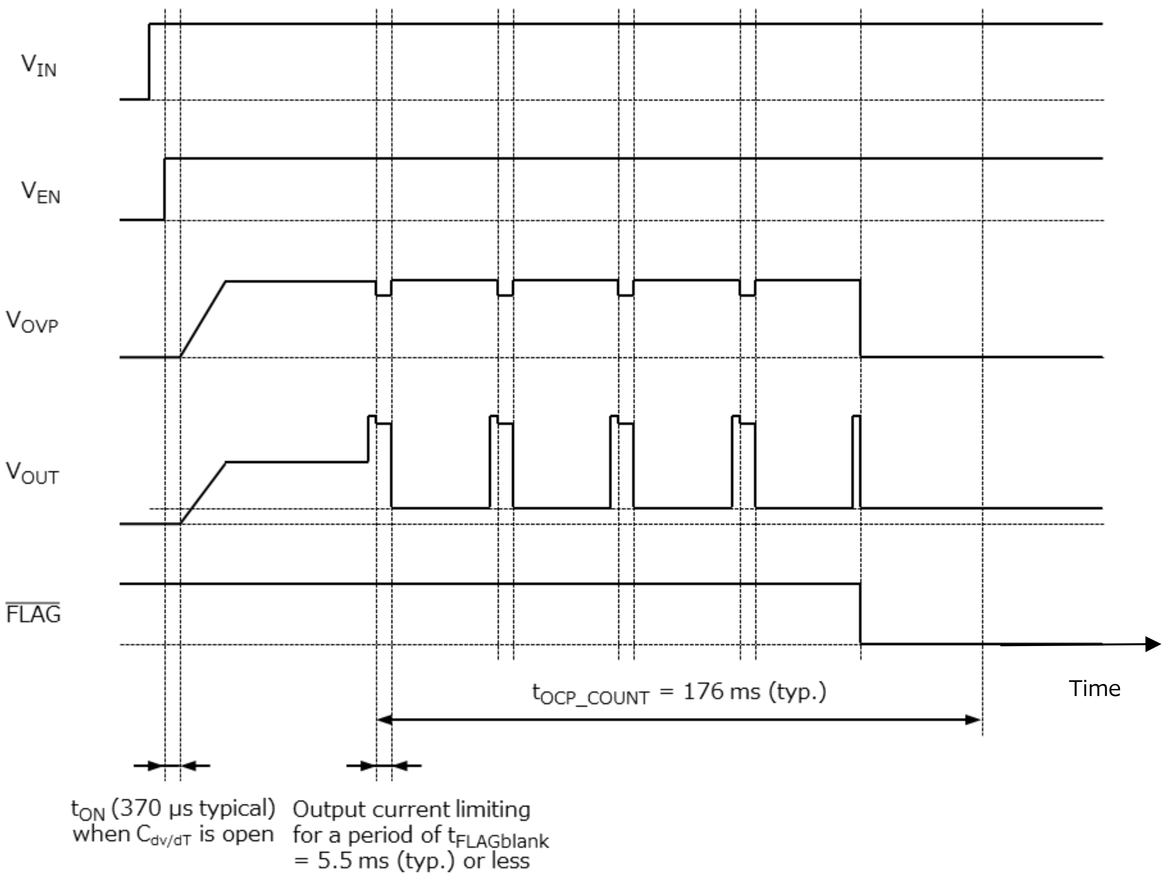



**Figure 6.8 Example of an OCP operation in the event of a repetitive pulsed overcurrent condition**

**Table 6.6 $t_{OCP\_COUNT}$ specification(<5ms) shown in the datasheet**

$V_{IN}$ = 12 V, $R_{LIM}$ =3.6 kΩ, $R_{LOAD}$ = 12 Ω, $C_{IN}$ = $C_{OUT}$ = 1 μF

| Characteristic | Symbol | Test Conditions | $T_a$ = -40 to 85 °C | | | Unit |
|---|---|---|---|---|---|---|
| | | | Min | Typ. | Max | |
| Duration(<5ms) during which overcurrent pulses are counted | $t_{OCP\_COUNT}$ | – (Note) | – | 176 | – | ms |

Note: Guaranteed by design

### 6.5.2. Setting the overcurrent protection circuit

The TCKE712BNL allows the programming of the overcurrent limit ($I_{OUT\_CL}$) via an external resistor ($R_{ILIM}$) connected to the ILIM pin. $I_{OUT\_CL}$ can be calculated as follows. However, be sure to perform a board evaluation when selecting a resistor since theoretical and measured results differ slightly at a current of less than 1 A.

$$I_{OUT\_CL} = \frac{6200}{R_{ILIM}} \quad (A) \qquad (6\text{-}2)$$

| | | |
|---|---|---|
| $I_{OUT\_CL}$: | Overcurrent limit | (A) |
| $R_{ILIM}$: | Value of the external resistor connected to the ILIM input | (Ω) |

Figure 6.9 shows a resistor connected to the ILIM input, and Figure 6.10 shows the $I_{OUT\_CL}$–vs-$R_{ILIM}$ curve.

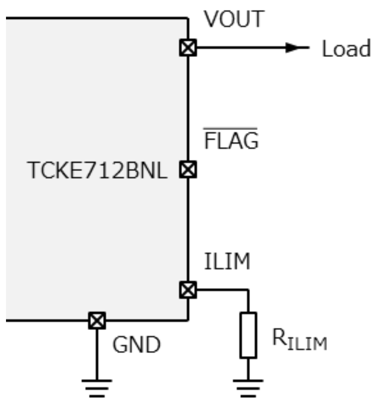



**Figure 6.9 Resistor connected to the ILIM input**

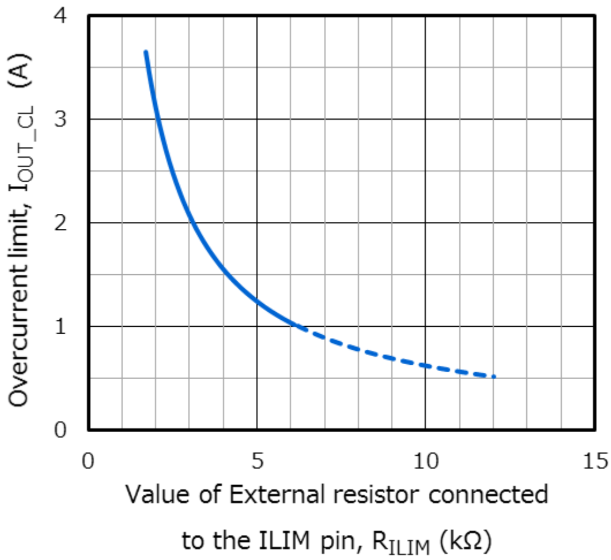



**Figure 6.10 Example of the $I_{OUT\_CL}$ – $R_{ILIM}$ curve**

## 6.6. Short-circuit protection circuit [Figure 5.1(6)]

The short-circuit protection circuit shuts down the TCKE712BNL in the event of the output line or the load being short-circuited for some reason in order to prevent excessive current from flowing.

If output current exceeds 2.5 times (typical) the overcurrent limit ($I_{OUT\_CL}$) instantaneously, the TCKE712BNL regards it as being a short-circuit condition. The TCKE712BNL incorporates an ultra-fast short-circuit protection circuit (called a Fast Trip circuit), which trips short-circuit protection in 320 ns typical from the detection of a short-circuit condition as shown in Figure 6.11.

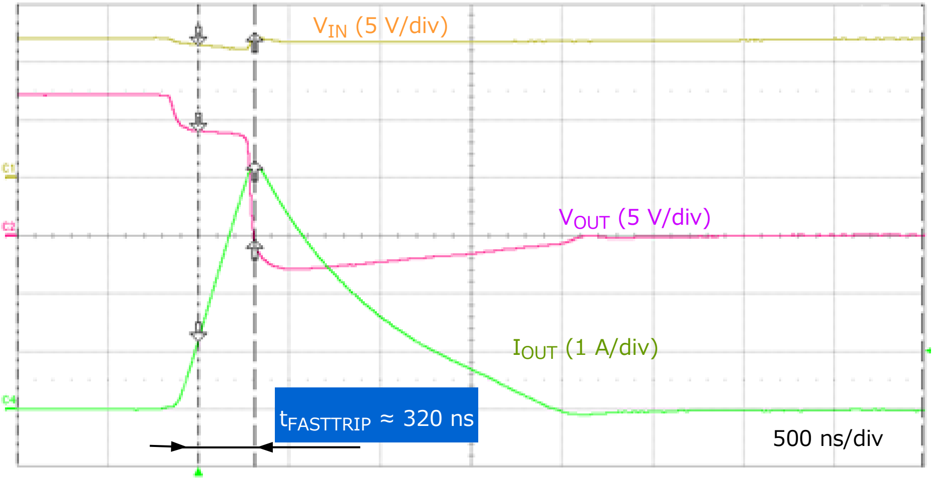



**Figure 6.11 Output voltage and current waveforms during a Fast Trip operation**

After the short-circuit protection circuit is tripped, the TCKE712BNL returns to normal operation automatically. However, if the short-circuit condition persists, the short-circuit protection circuit is tripped again at the output current value determined by the overcurrent limit ($I_{OUT\_CL}$). In this case, VOUT is turned off, and $\overline{\text{FLAG}}$ is driven Low and latched Low either after a period of $t_{FLAGblank}$ (5.5 ms typical) or when thermal shutdown (TSD) is tripped during this period.

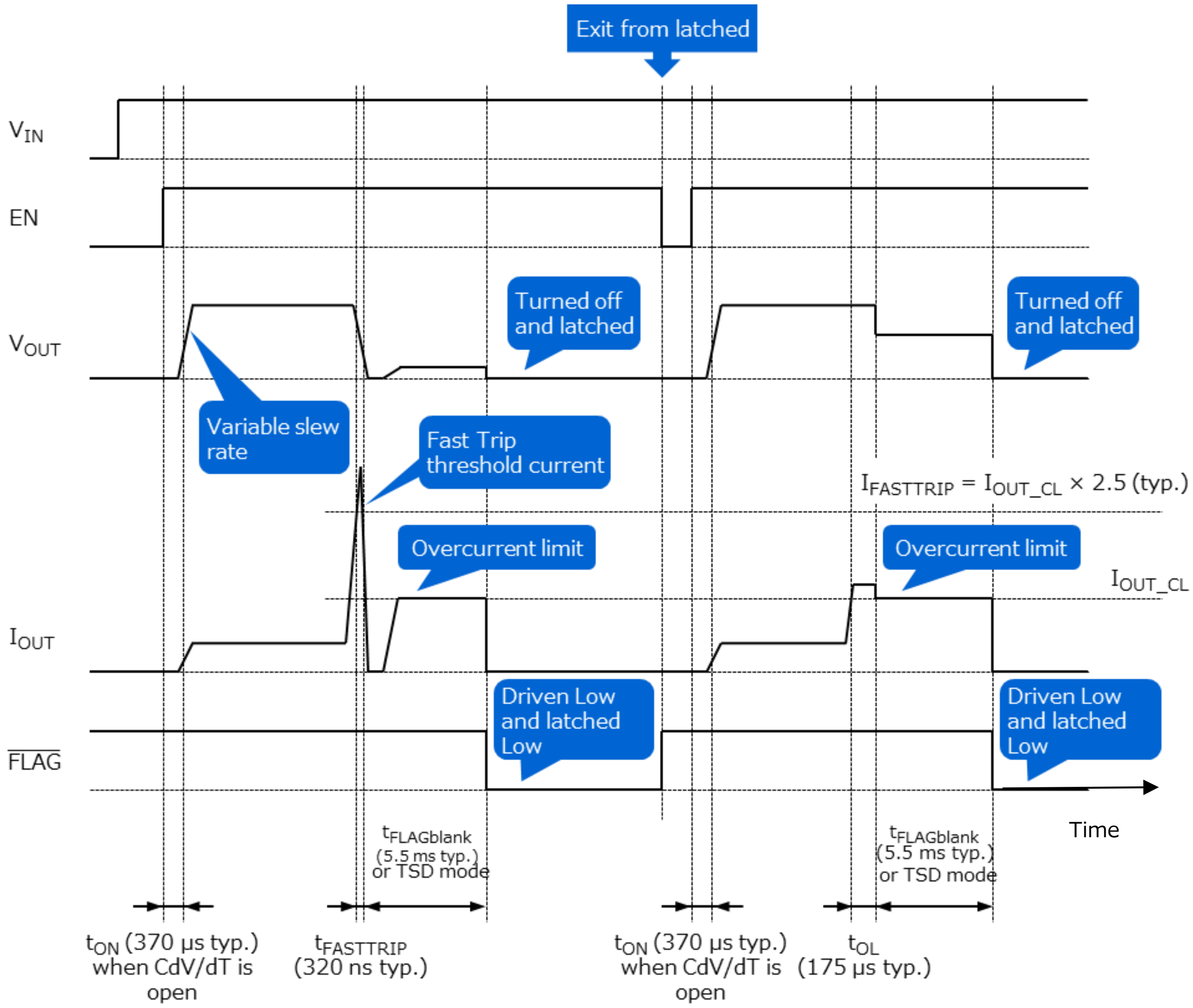



**Figure 6.12 Example of short-circuit protection and thermal shutdown operations**

# 6.7. Inrush current limiting (slew rate control) circuit [Figure 5.1(7)]

## 6.7.1. Operation of the inrush current limiting circuit

When VOUT is turned on, inrush current flows, charging the capacitor on the load side. Excessive inrush current might trip the overcurrent protection circuit, causing VOUT to become unable to rise or producing VIN undershoot and VOUT overshoot. To prevent these situations, the inrush current limiting circuit controls the rising slew rate of the VOUT voltage. Figure 6.13 shows the rising VOUT voltage and inrush current when the inrush current is limited.

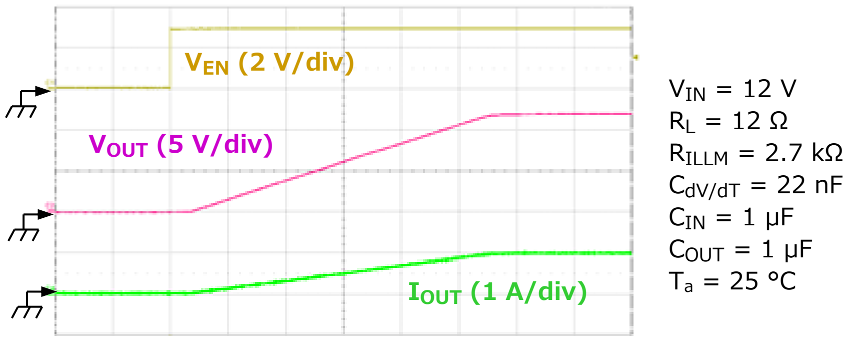



**Figure 6.13 Waveforms of the inrush current limiting (slew rate control) circuit**

## 6.7.2. Setting the rise time (slew rate) of the VOUT voltage

The TCKE712BNL allows the rising slew rate ($t_{dV/dT}$) of the VOUT voltage to be programmed via an external capacitor connected to the dV/dT pin. The rise time can be calculated as follows:

$$t_{dV/dT}(s) = 18 \times 10^{3} \times V_{IN} \times C_{dV/dT} + 4 \times 10^{-4} \qquad (6\text{-}3)$$

| | | |
|---|---|---|
| $V_{IN}$: | Input voltage | (V) |
| $C_{dv/dT}$: | Value of the external capacitor connected to the dV/dT input | (F) |

Figure 6.14 shows a capacitor connected to the dV/dT input, and Figure 6.15 shows the $t_{dV/dT}$ - $C_{dV/dT}$ characteristics.

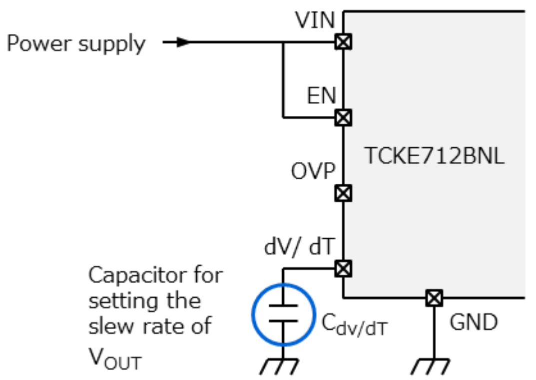



**Figure 6.14 Capacitor connected to the dV/dT input**

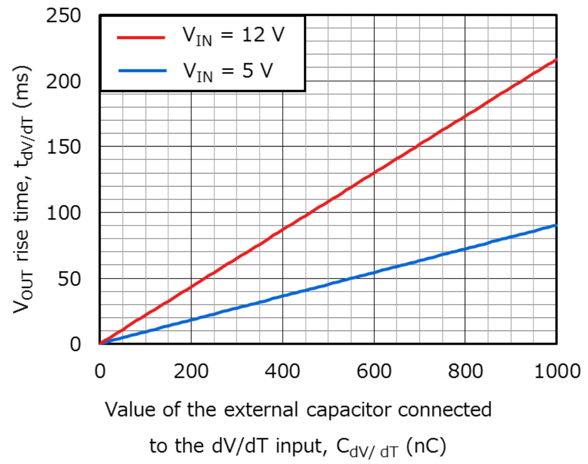



**Figure 6.15 $t_{dV/dT}$ - $C_{dV/dT}$ characteristics**

## 6.8. Reverse-current blocking circuit [Figure 5.1(8)]

When the TCKE712BNL is disabled by turning off the input voltage ($V_{IN}$) or setting the EN input to an inactive state, $V_{OUT}$ becomes higher than $V_{IN}$. The reverse-current blocking circuit prevents current from flowing in the reverse direction from the VOUT pin to the VIN pin when $V_{OUT}$ > $V_{IN}$. The TCKE712BNL incorporates a back-to-back reverse-current blocking circuit. This means that two N-channel MOSFETs are connected back-to-back in a common-source configuration as shown in Figure 6.16. Reverse current is blocked when both these MOSFETs are turned off simultaneously at the turn-off of VOUT.

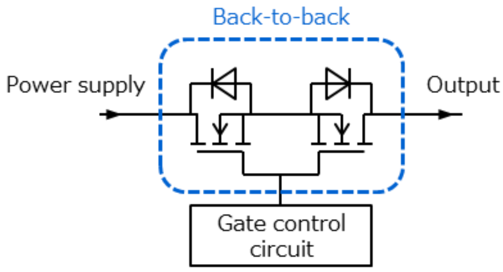



**Figure 6.16 Back-to-back reverse-current blocking circuit**

## 6.9. FLAG circuit

The FLAG circuit is a diagnostic circuit that toggles the $\overline{\text{FLAG}}$ output from High to Low to signal an abnormal condition externally in the event of overvoltage, overcurrent, or short-circuit protection being tripped. The $\overline{\text{FLAG}}$ output has an open-drain configuration. Connect an external pull-up resistor to the $\overline{\text{FLAG}}$ pin.
Select a pull-up resistor, taking the maximum rated sink current of the $\overline{\text{FLAG}}$ pin into consideration. As a guide, the value of the pull-up resistor should be 100 kΩ to 1 MΩ. Be sure to perform a board evaluation to select an appropriate resistor.

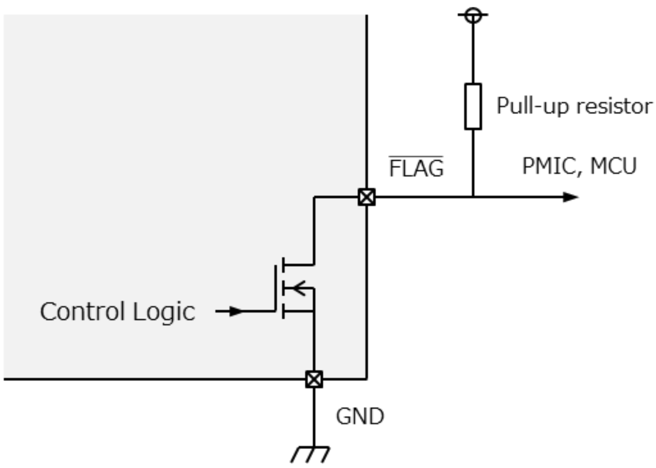



**Figure 6.17 Equivalent circuit of the $\overline{\text{FLAG}}$ pin**

**Table 6.7 Indications and timing of the $\overline{\text{FLAG}}$ output**

| Indication | $\overline{\text{FLAG}}$ output timing | Reference |
|---|---|---|
| **Overvoltage protection (OVP)** | When $V_{IN} \geq V_{OVLO}$ | Figure 6.4 |
| **Thermal shutdown (TSD)** | When $T_{SD} \geq 134°C$ (typ.) | $T_{SD}$: TSD threshold temperature (Figure 6.5 and Figure 6.6.) |
| **Overcurrent protection (OCP)** | 1. When output current is equal to or higher than $I_{OUT\_CL}$ for a period of $t_{FALblank}$ (5.5 ms) or longer. | $I_{OUT\_CL}$: Overcurrent limit (Figure 6.7) |
| | 2. After five overcurrent pulses (< 5 ms) during $t_{OCP\_COUNT}$ | $t_{OCP\_COUNT}$: Overcurrent flag-blanking time (Figure 6.8) |
| | 3. After TSD is tripped | (Figure 6.13) |

## 6.10. EN pin

The TCKE712BNL can be enabled and disabled via the EN input. It also allows the undervoltage lockout (UVLO) trip voltage to be programmed via an external resistor.
A window comparator is connected to the EN input as shown in Figure 6.18. Since a window comparator determines whether an input is between two threshold voltages, $V_{REP\_P}$ and $V_{REF\_N}$, it provides a stable output even in the presence of mechanical chatter and ringing on the EN input as shown in Figure 6.19(b). In contrast, a typical comparator with a single threshold voltage might produce a false output as shown in Figure 6.19(a).

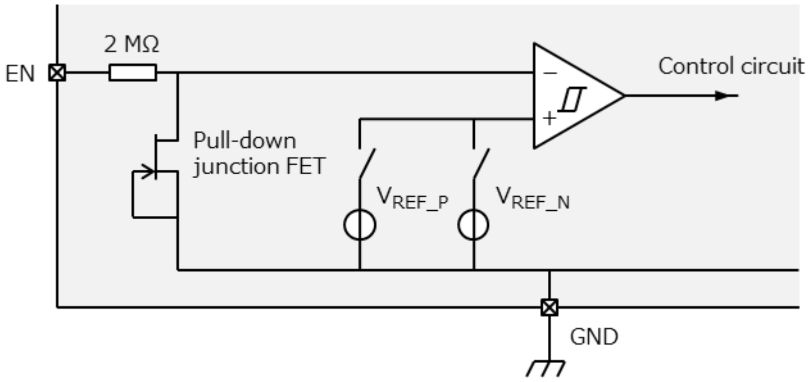



**Figure 6.18 Equivalent circuit of the EN pin**

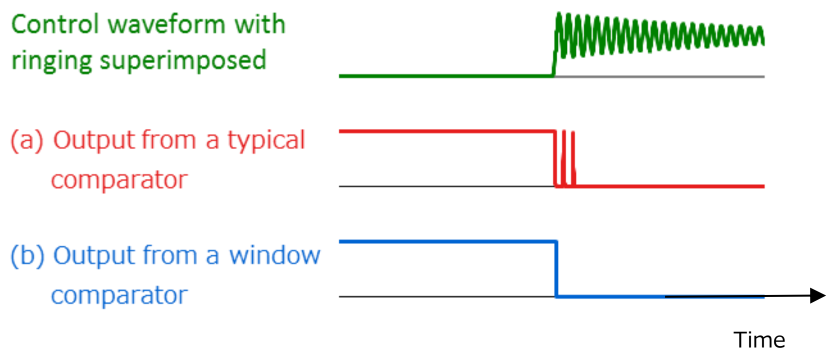



**Figure 6.19 Outputs from a typical comparator and a window comparator**

The TCK712BNL incorporates a pull-down junction FET with a typical $R_{EN}$ of 20 MΩ between the EN and GND pins so that its internal circuitry does not become unstable even when the EN pin becomes open.

**Table 6.8 EN pull-down resistor specification shown in the datasheet**

$V_{IN}$ = 12 V, $R_{LIM}$ =3.6 kΩ

| Characteristic | Symbol | Test Conditions | $T_a$ = 25 °C | | | $T_a$ = -40 to 85°C | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | Min | Typ. | Max | Min | Max | |
| EN pull-down resistor | $R_{EN}$ | $V_{EN}$ = 1.1 V | – | 20 | – | 10 | 55 | MΩ |

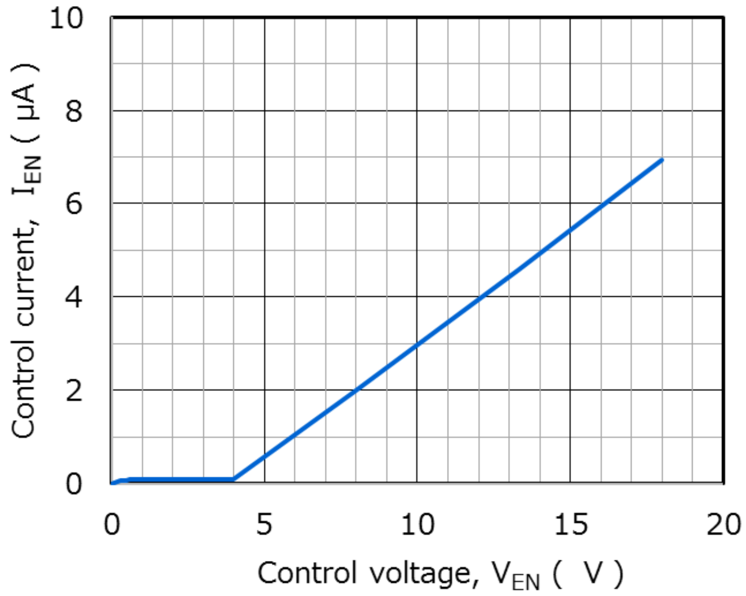



**Figure 6.20 $I_{EN}$ - $V_{EN}$ characteristics (shown only as a guide)**

# 7. Examples of controlling the TCKE712BNL via the EN input

This section shows several examples of how to control the TCKE712BNL via the EN input.

(1) When the UVLO trip voltage is left unchanged and the EN control is not used

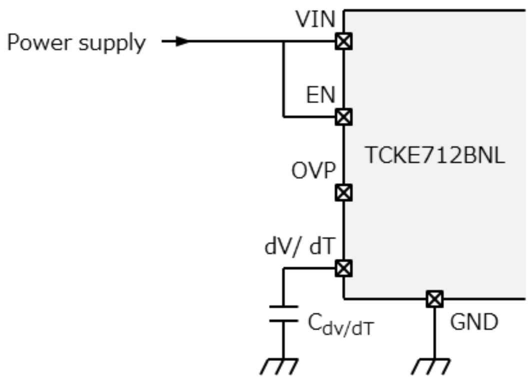



**Figure 7.1 Example of the EN input connection (The EN input is connected directly to VIN.)**

The EN input is designed to tolerate up to 18 V. Therefore, connect the EN input directly to the VIN input without a pull-up resistor(Figure 7.1). This helps reduce the number of external parts required.

(2) When the UVLO trip voltage is left unchanged and the EN input is externally controlled

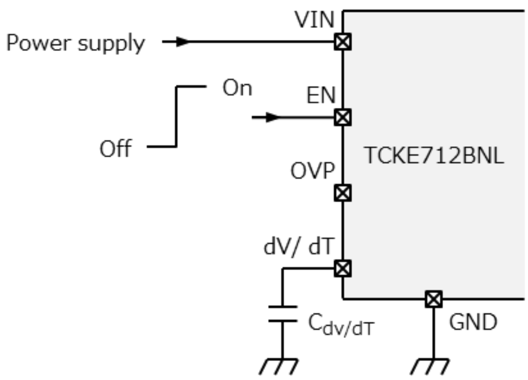



**Figure 7.2 Example of the EN input connection (The EN input is controlled externally.)**

An external control signal can be applied directly to the EN input(Figure 7.2). The on/off threshold of the EN input has hysteresis. The control signal must be 1.1 V or higher (typical) when High and 0.95 V or lower (typical) when Low.

(3)When the UVLO trip voltage is left unchanged and the EN input is controlled using a short-circuit switch connected to the VIN input(Figure 7.3)

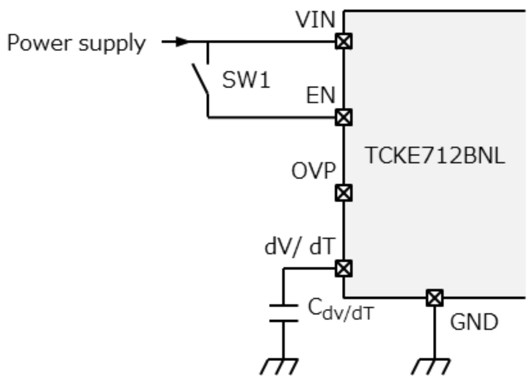
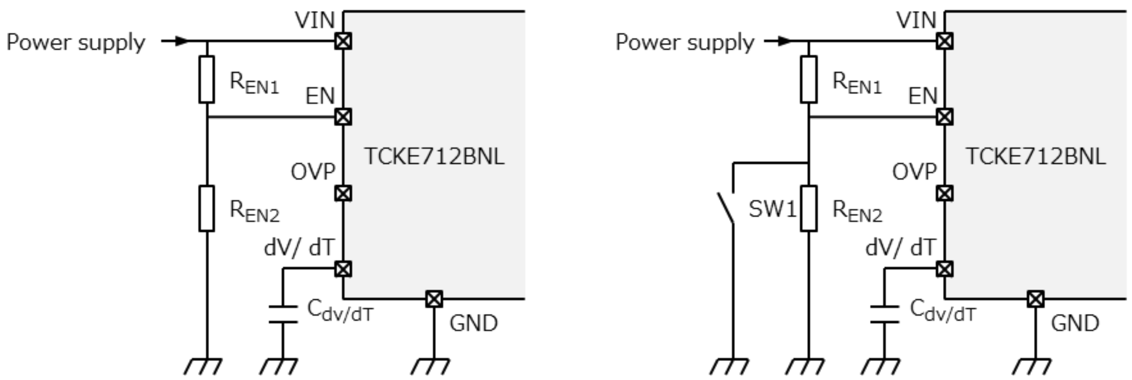



**Figure 7.3 Example of the EN input connection (The EN input is connected to the VIN input via a switch.)**

In this example, the EN input is controlled via a switch connected to the VIN input.

(4)When the UVLO trip threshold is programmed
The UVLO trip threshold can be programmed via external resistors connected to the EN input. Figure 7.4 shows two circuit examples.




a) When the EN input is not enabled and disabled

b) When the EN input is enabled and disabled

**Figure 7.4 Example of the EN input connection ($V_{IN}$ is divided with resistors.)**

The circuit of Figure 7.4(a) does not allow the EN input to be enabled and disabled whereas the circuit of Figure 7.4(b) allows the EN input to be controlled via a switch. In these examples, a voltage derived by dividing $V_{IN}$ with external resistors is applied to the EN input. Therefore, the TCKE712BNL is disabled in the event of undervoltage on $V_{IN}$. The UVLO trip voltage can be set to the optimal value by selecting appropriate resistors. The UVLO trip voltage must be 4.15 V or higher. The UVLO trip voltage ($V_{IN\_UVLO(fall)}$) can be calculated as follows from the values of the external resistors ($R_{EN1}$ and $R_{EN2}$) connected to the EN input. A pull-down resistor is internally connected between the EN and GND pins. Since this pull-down resistor has a value of 22 MΩ, this equation regards the EN pin as being open.

$$V_{IN\_UVLO(fall)} = V_{ENF} \times \left(1 + \frac{R_{EN1}}{R_{EN2}}\right) \quad (7\text{-}1)$$

| | | |
|---|---|---|
| $V_{IN\_UVLO(fall)}$: | UVLO trip threshold for falling $V_{IN}$ | (V) |
| $V_{ENF}$: | EN threshold voltage, rising = 0.95 V typical | (V) |

The on/off threshold of the EN input has hysteresis, as described above. The UVLO recovery threshold for rising $V_{IN}$ ($V_{IN\_UVLO(rise)}$) differs from the UVLO trip threshold and is calculated as follows:

$$V_{IN\_UVLO(rise)} = V_{ENR} \times \left(1 + \frac{R_{EN1}}{R_{EN2}}\right) \quad (7\text{-}2)$$

| | | |
|---|---|---|
| $V_{IN\_UVLO(rise)}$: | UVLO recovery threshold for rising $V_{IN}$ | (V) |
| $V_{ENR}$: | EN threshold voltage, falling = 1.1 V typical | (V) |

The EN input can be controlled by connecting a switch in parallel with $R_{EN2}$ as shown in Figure 7.4(b). Contrary to the example shown in (3), the circuit of Figure 7.4(b) disables the TCKE712BNL when SW1 is closed. At this time, $R_{EN1}$ acts as a current-limiting resistor. Therefore, care should be exercised when selecting its value.

# 8. TCKE712BNL application examples

This section shows several application examples for the TCKE712BNL.

- Notebook PCs and mobile devices

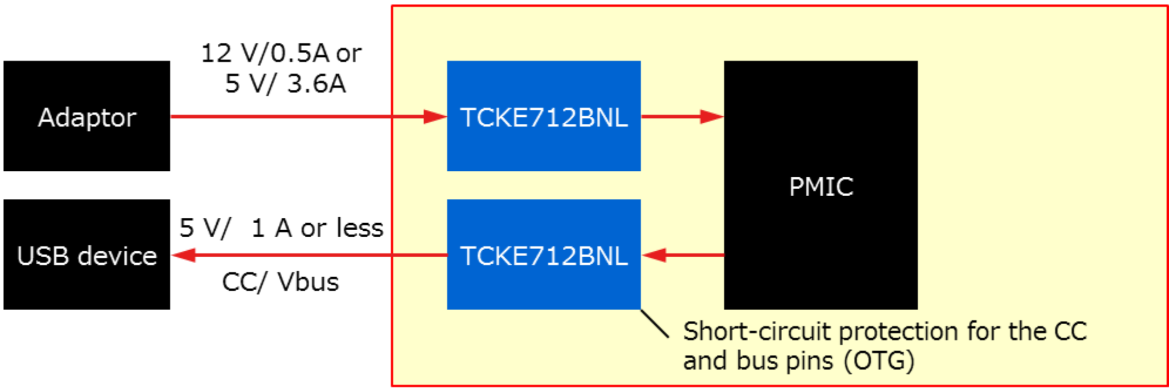



**Figure 8.1 Application to notebook PCs and mobile devices**

- SSDs and HDDs

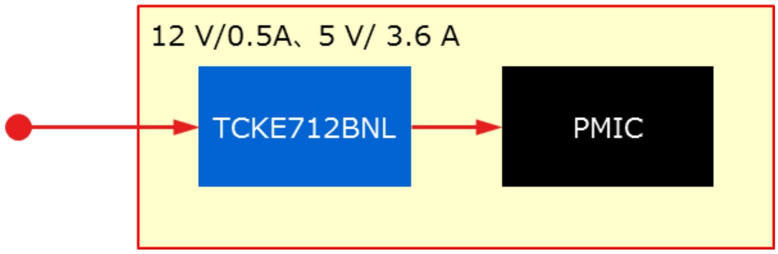



**Figure 8.2 Application to SSDs and HDDs**

- Servers

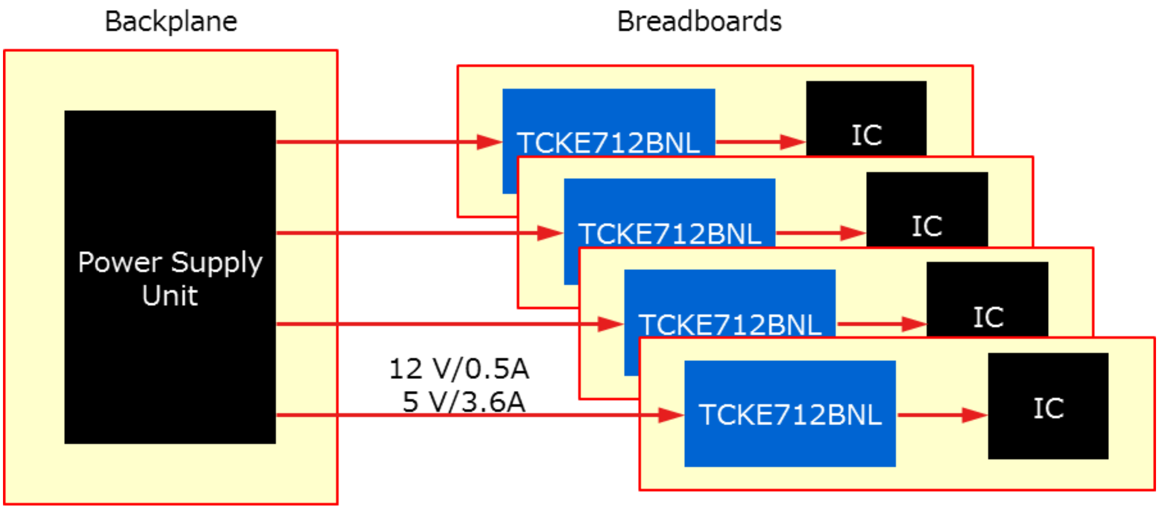



**Figure 8.3 Application to servers**

- Wearable and IoT devices

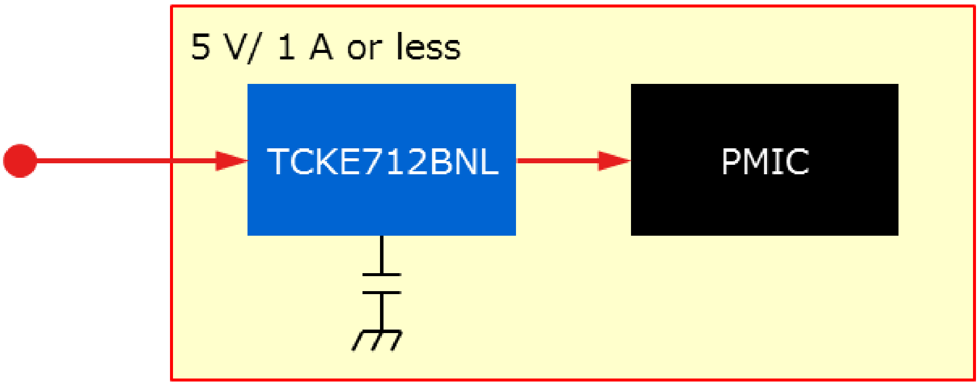



**Figure 8.4 Application to wearable and IoT devices**

- USB devices (example of using the TCKE712BNL as a power multiplexer)

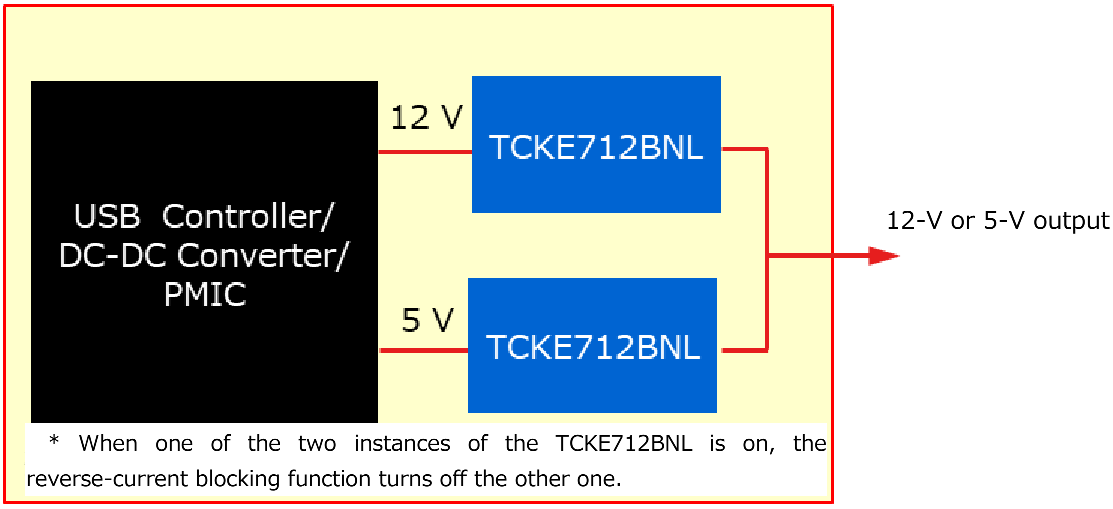



**Figure 8. 5 Using two instances of the TCKE712BNL as a power multiplexer for a USB device**

# 9. Conclusion

This application note has described the usage and various protection functions of the TCKE712BNL. The TCKE712BNL not only interrupts excessive current but also protects ICs and an overall system from overvoltage, overheating, and other abnormal conditions. It also provides other useful functions such as inrush current limiting and undervoltage lockout. These functions contribute to greatly enhancing the reliability of electronic devices. Furthermore, the TCKE712BNL helps reduce system size and cut design and manufacturing costs, as compared with the case of implementing the same functions using discrete passive components and other parts. We hope that you have found this application note useful for enhancing the performance, reducing the size, and cutting the total costs of your system applications. We will continually add more eFuse ICs to our product portfolio to expand the range of your choices. We hope you will select Toshiba's eFuse ICs.

To visit a web page on eFuse ICs → Click Here

To perform a parametric search of eFuse ICs → Click Here

To visit an FAQ web page on eFuse ICs → Click Here

To purchase eFuse ICs → Click Here

■Company names, product names, and service names may be trademarks of their respective companies.

# 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/