

Small eFuse IC TCKE9 Series

Application Note

Overview

An eFuse IC is a protective IC that incorporates various functions for protecting electronic equipment, replacing conventional fuses and is also called an electronic fuse.

This document describes the basic use of the TCKE9 series, an eFuse IC that is compact, high-voltage resistant, and incorporates a wealth of protective functions such as short-circuit protection, overcurrent protection, overvoltage protection, thermal shutdown, inrush current protection, undervoltage lockout, and FLAG output.

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1. Introduction

Currently, fuses and poly switches (resettable fuses, poly fuses) are frequently used as safety components to prevent overheating and ignition in various electronic devices. Both devices use Joule heat generated by the flow of a current exceeding the rated current. In this document, these devices are referred to as “fuses”.

In the case of glass tube fuses and chip fuses, the circuit is protected, and the equipment is prevented from being damaged by interrupting or limiting the energization due to the sharp increase in the resistance value caused by the thermal expansion of the conductive polymer, which is caused by the melting of the built-in metal parts.

However, both have the disadvantages of low accuracy in operating current, large dispersion in interrupting current, and time-consuming protection due to the use of Joule heat.

Another disadvantage is that a conventional fuse is irreversibly destroyed once it triggers, requiring replacement of the fuse itself.

The eFuse IC (Electronic Fuse) solves the various disadvantages of conventional fuses described above by providing MOSFET de-energization. It can be used in the same way as conventional fuses. Additionally, it can have various protective functions other than overcurrent by taking advantage of its IC structure.

We have developed the TCKE9 series, a compact eFuse IC with high voltage resistance and abundant protective functions. The TCKE9 series includes built-in overcurrent protection (OCP), short-circuit protection, slew rate control (inrush current limiting), overvoltage clamping (OVC), and undervoltage lockout (UVLO) functions. Some of these functions have adjustable settings, which can be used to effectively protect circuits and equipment. The FLAG function or the quick discharge function can also be selected. *

This application note describes major characteristics, operations, usage, and applications of the TCKE9 series.

* Click here for FLAG, the quick Output Discharge feature, and supported products. →

[Click Here](#)

2. What is eFuse IC?

2.1. How to use eFuse IC

An eFuse IC uses a semiconductor switch to shut off the current, which was conventionally caused by the melting of an alloyed component. The built in MOSFET is controlled by the output signal of the detector that detects excessive current, and the current is limited or cut off. Figure 2.1 shows a block diagram when an eFuse IC is used to power a PMIC (Power Management IC).

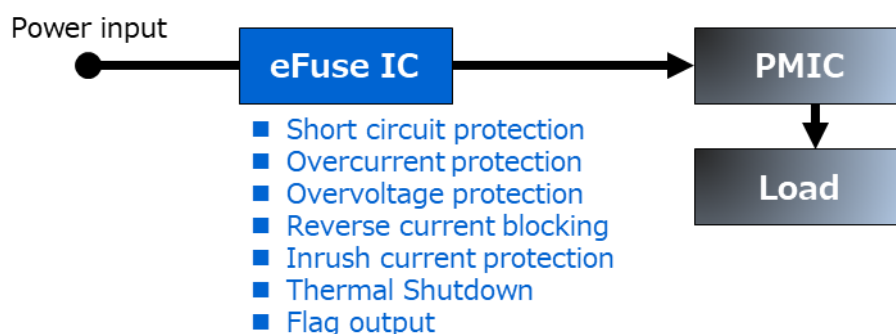


Figure 2.1 Examples of eFuse IC Use and Main Functions

In this instance, an eFuse IC is inserted in the PMIC power line instead of a conventional fuse. If an overcurrent flows due to an error in the PMIC itself or the circuit ahead of it, a current limit is applied to protect the circuit and prevent smoking and ignition of the equipment.

2.2. Advantages of using eFuse IC

By using an eFuse IC, the following advantages can be considered.

- **Reduction in maintenance costs and time due to no need for replacement**
In an eFuse IC, the built-in MOSFET is turned off to cut off the current, so it is not destroyed by a single overcurrent. If the MOSFET is turned on again, current flows as before to restore normal operation. Unlike conventional fuses, which are irreversibly destroyed, eFuse ICs can be used repeatedly, eliminating the need to replace parts and reducing maintenance costs and time.
- **High-precision current and voltage protection for robust performance**
The exact current limit cannot be determined because fuses previously utilize melting and thermal expansion are inaccurate. Therefore, there remains a risk of damage from selecting a fuse with a rated current that has a certain margin to avoid malfunction due to the current assumed for the load. On the other hand, an eFuse IC can protect against overcurrent with high accuracy. In addition, the TCKE9 series has configurable overcurrent protection and overvoltage protection functions to achieve robust protection against excessive current and voltage.
- **Improved reliability through high-speed protection**
In conventional fuses, it takes time for the temperature rise caused by Joule heat to reach the melting point of the fuse material, so there is a time lag between the occurrence of overcurrent and interruption. Overcurrent will continue to flow during this time. However, in an eFuse IC, the overcurrent can be cut off by turning off the switch almost at the same time as overcurrent is detected, greatly reducing the duration for which overcurrent flows. This reduces damage to the equipment and improves long-term reliability.
- **Cost reduction and miniaturization using one package for various protective functions**
An eFuse IC is an IC that, in addition to its overcurrent and short-circuit protection functions, can be packaged with a variety of other functions, such as overvoltage protection, inrush current protection (slew-rate control), thermal shutdown, and reverse current blocking, which are not available with conventional fuses. Compared to the function realization by combining discrete passive components and several ICs, the number of parts and workload required can be drastically reduced, along with reduced mounting area, contributing to cost reduction and miniaturization.

3. Example of an application circuit for the TCKE9 series

The TCKE9 series is an eFuse IC that operates on 2.7 V ~ 23 V or 3.0 V ~ 23 V and is adjustable in terms of current limit and V_{OUT} rising slew rate using external resistors and capacitors. The peripheral circuitry of the TCKE9 series is shown below.

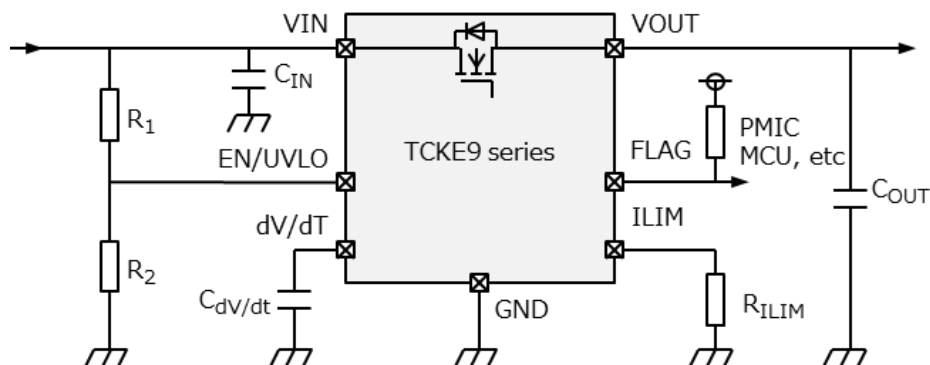


Figure 3.1 Example of an application circuit for the TCKE9 series

3.1. Precautions for peripheral circuits

If the short-circuit or overcurrent protection function is activated and the current suddenly decreases, high spike voltage may be generated due to the back electromotive force of the inductance components, such as the wires connected to TCKE9 series I/O pins. Examples of measures are shown below.

When designing the circuit board, design the patterns so that the wire lengths on the input side and output side of the TCKE9 series are as short as possible. Also, the GND wire area should be as wide as possible to reduce impedance.

The input capacitor C_{IN} suppresses the crest value against the positive spike voltage generated at the input. The spike voltage height V_{SPIKE} and C_{IN} capacitance are related as follows. Increasing C_{IN} can reduce the spike voltage.

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

| | | | |
|--------------------|---|---------------------------------------|-----|
| 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) |

Although 1 μF is recommended for C_{IN} in TCKE9 series. Be sure to check that V_{SPIKE} does not exceed the absolute maximum rating. If V_{IN} is high, the output-voltage V_{OUT} is high, and the current change during short-circuit or overcurrent protection is high. Therefore, V_{IN} or V_{OUT} may not be stable, resulting in unstable operation and IC corruption.

By connecting a TVS diode (ESD protective diode) or Zener diode to the input of TCKE9 series, this protects against ESD and transient overvoltage. If the negative spike voltage generated at the output exceeds the rating, a Schottky Barrier Diode (SBD) must be connected to prevent the output potential from dropping below GND. The SBD is effective not only for the TCKE9 series but also protects ICs and equipment connected as loads. Connect the SBD between the VOUT and GND pins of the TCKE9 series, with the GND pins as the anode. In this way, it is possible to further enhance the protection of the TCKE9 series. It is recommended to use a TVS diode or a Zener diode together with an SBD for TCKE9 series. Figure 3.2 shows an example of an application circuit.

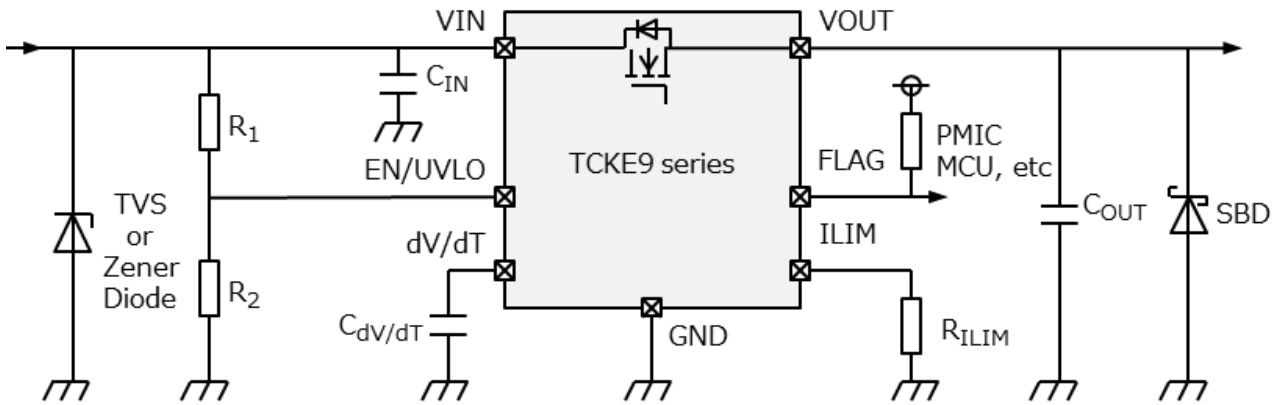


Figure 3.2 Example of an application circuit for the TCKE9 series with a TVS diode and an SBD

TCKE9 series can be paired with Zener diodes like the CUHZ series and Schottky Barrier Diodes like CUHS20S30. For the products and how to use them, refer to the link below.

For more information on Zener diode CUHZ series. → [Click Here](#)

For more information on Schottky barrier diode CUHS20S30 → [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 (IOUT_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 FLAG output is driven Low to signal an abnormal condition to a PMIC or an MCU. Connect an external pull-up resistor to the 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. Chapters 6 detail the functions of these pins and how to select external resistors.

4. Functions incorporated in the TCKE9 series

The TCKE9 series eFuse IC provides various protection features as shown in Table 4.1.

Table 4.1 Functions incorporated in the TCKE9 series

| | Overcurrent Protection | Short-circuit Protection | Overvoltage Protection | Thermal shutdown | Slew Rate control | Reverse current blocking | FLAG output | Discharge | Rapid output Discharge |
|-----------------|------------------------|---|------------------------|------------------|-------------------|--------------------------|---------------|-----------|------------------------|
| Availability | ✓ | ✓ | ✓ | ✓ | ✓ | - | See Table 4.2 | ✓ | See Table 4.2 |
| Programmability | ✓ | ✓ (Determined by the overcurrent protection threshold) | - | - | ✓ | - | - | - | ✓ |

Table 4.2 lists the types of the TCKE9 series.

The overvoltage clamp threshold, return operation types, FLAG function, and quick discharge function differ depending on the product.

Table 4.2 List of TCKE9 series by built-in functions

| Product name | Overvoltage clamp Threshold value | V _{EN/UVLO} Operation | Return operation type | FLAG function | Rapid output Discharge | Package |
|--------------|-----------------------------------|--------------------------------|-----------------------|---------------|------------------------|---------|
| TCKE903NA | 3.87 V (Typ.) | Active High | Auto-retry | Yes | None | WS0N8 |
| TCKE903NL | 3.87 V (Typ.) | Active High | Latched | Yes | None | |
| TCKE905ANA | 5.7 V (Typ.) | Active High | Auto-retry | Yes | None | |
| TCKE905NL | 5.7 V (Typ.) | Active High | Latched | Yes | None | |
| TCKE912NA | 13.7 V (Typ.) | Active High | Auto-retry | Yes | None | |
| TCKE912NL | 13.7 V (Typ.) | Active High | Latched | Yes | None | |
| TCKE920NA | 22.2 V (Typ.) | Active High | Auto-retry | Yes | None | |
| TCKE920NL | 22.2 V (Typ.) | Active High | Latched | Yes | None | |
| TCKE903QNA | 3.87 V (Typ.) | Active High | Auto-retry | None | Yes | |
| TCKE905QNA | 5.7 V (Typ.) | Active High | Auto-retry | None | Yes | |

5. Block diagram of the TCKE9 series

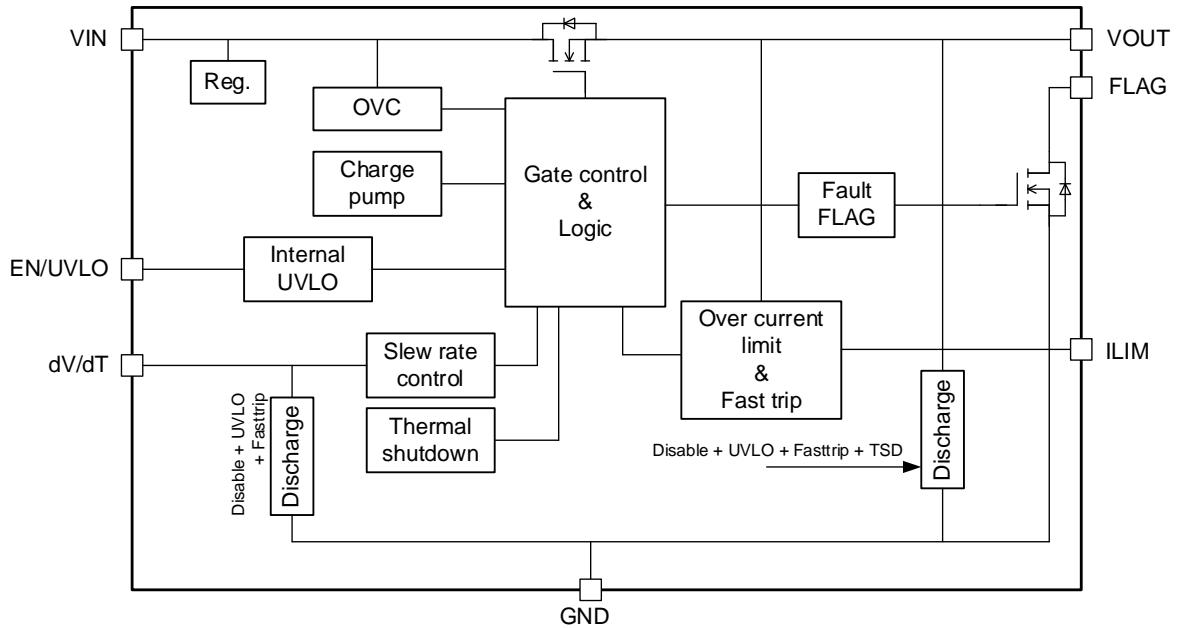


Figure 5.1 TCKE 9 xxNA/NL/ANA block diagram

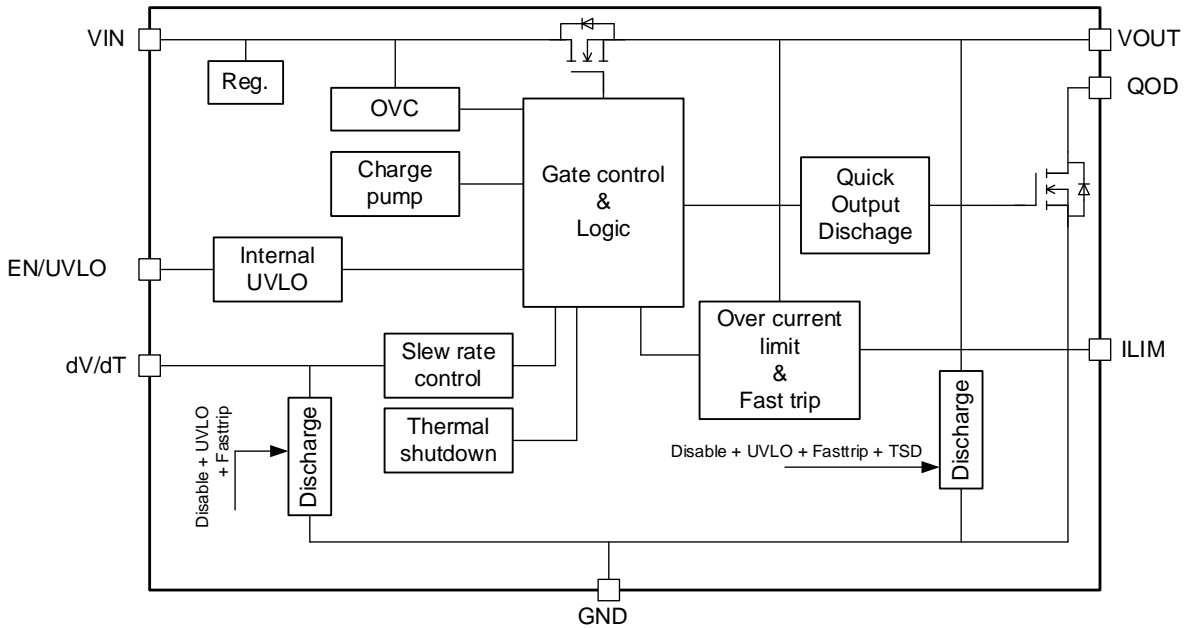


Figure 5.2 TCKE 9 xxQNA block diagram

Table 5.1 Pin Descriptions of TCKE9 series

| Pin name | Description of Pins |
|----------|---|
| VIN | Supply Input. Input to the power switch and the supply voltage for the device. |
| dV/dT | Rise time set input. A capacitor between dV/dT pin and GND sets the slew rate of VOUT when the device turns on. |
| EN/UVLO | This pin has two functions. One function turns on the output voltage of the internal MOSFET as an enable signal. Another function can be used as a UVLO trip point with external resistors. |
| ILIM | Current limit set input. A resistor between ILIM pin and GND sets the current limit. |
| GND | Ground. |
| FLAG | FLAG Open-Drain output pin. Fault event indicator which is pulled low when a fault is detected. |
| QOD | Quick output discharge pin when connected between VOUT and QOD directly or through external resistor. |
| VOUT | Output. Output of the power switch. |

6. Explanation of TCKE9 series Various circuits

6.1. Charge pump circuit

The charge pump circuit is a boost circuit for generating the gate drive voltage of the switching Nch MOSFET.

6.2. Operation of the Overvoltage Clamp circuit (OVC)

The overvoltage clamp circuit clamps the output voltage when a voltage equal to or greater than the preset input voltage is applied, preventing an overvoltage from being applied to the load. Fig. 6.1 shows an example of the TCKE9 series overvoltage protection operation. V_{OVC} , V_{CLAMP} voltage is set for each product.

Table 6.1 Overvoltage Clamp protection (OVC) properties listed in datasheet

$V_{IN} = 3.3\text{ V}$ (TCKE903), $V_{IN} = 5.0\text{ V}$ (TCKE905), $V_{IN} = 12\text{ V}$ (TCKE912), $V_{IN} = 20\text{ V}$ (TCKE920), $R_{LIM} = 487\ \Omega$

| Item | Symbol | Measurement condition | $T_a = 25\text{ }^\circ\text{C}$ | | | $T_a = -40\text{ to }125\text{ }^\circ\text{C}$ | | Unit |
|---|-------------|---|----------------------------------|-------|-----|---|-------|------|
| | | | Min | Typ. | Max | Min | Max | |
| Overvoltage clamping (OVC) threshold | V_{OVC} | TCKE903 TCKE905 TCKE912 TCKE920 $R_{OUT} = 10\text{ k}\Omega$ | - | 3.87 | - | 3.64 | 4.10 | V |
| | | | - | 5.7 | - | 5.4 | 6.0 | V |
| | | | - | 13.7 | - | 13.2 | 14.3 | V |
| | | | - | 22.2 | - | 21.0 | 23.3 | V |
| V_{OUT} voltage at overvoltage clamping | V_{CLAMP} | TCKE903 TCKE905 TCKE912 TCKE920 $I_{OUT} = 10\text{ mA}$ | - | 3.60 | - | 3.45 | 3.87 | V |
| | | | - | 5.55 | - | 5.20 | 5.80 | V |
| | | | - | 13.55 | - | 13.00 | 14.10 | V |
| | | | - | 22.1 | - | 21.0 | 22.8 | V |

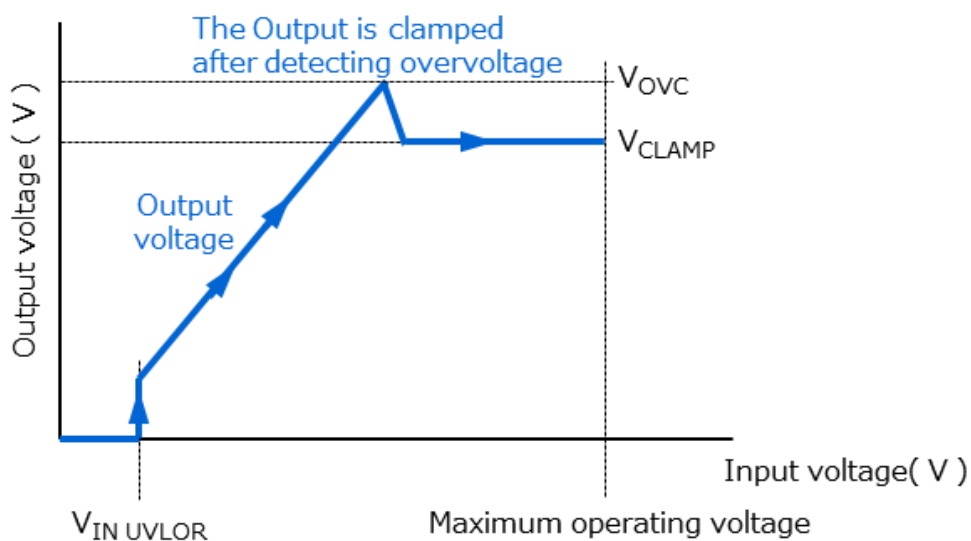


Figure 6.1 Example of Overvoltage Clamp (OVC) operation

6.3. Operation of the Undervoltage lockout (UVLO) circuit

When the input voltage V_{IN} drops below the minimum operating voltage of the subsequent IC or circuit connected to the output pin V_{OUT} , the undervoltage lockout circuit prevents the system from malfunctioning. When V_{IN} drops to the low-voltage protection threshold voltage, the output is turned off. When it rises to $V_{IN} \geq V_{IN_UVLOR}$, it starts operating as an IC. Hysteresis is set in the undervoltage lockout circuit. When V_{IN} drops below V_{IN_UVLOF} , the power is automatically disabled. Fig. 6.2 shows an example of TCKE9 series undervoltage lockout operation.

Table 6.2 UVLO specifications shown in the datasheet

$R_{LIM} = 487 \Omega$

| Item | Symbol | Measurement condition | $T_a = 25 \text{ }^\circ\text{C}$ | | | $T_a = -40 \text{ to } 125 \text{ }^\circ\text{C}$ | | Unit |
|---|------------------|--------------------------|-----------------------------------|------|-----|--|------|------|
| | | | Min | Typ. | Max | Min | Max | |
| VIN undervoltage lockout (UVLO) threshold | V_{IN_UVLOR1} | Rising, TCKE9xx series | - | 2.51 | - | 2.35 | 2.68 | V |
| | V_{IN_UVLOF1} | Falling, TCKE9xx series | - | 2.41 | - | 2.25 | 2.53 | V |
| | V_{IN_UVLOR2} | Rising, TCKE9xxQ series | - | 2.80 | - | 2.63 | 2.97 | V |
| | V_{IN_UVLOF2} | Falling, TCKE9xxQ series | - | 2.68 | - | 2.52 | 2.81 | V |

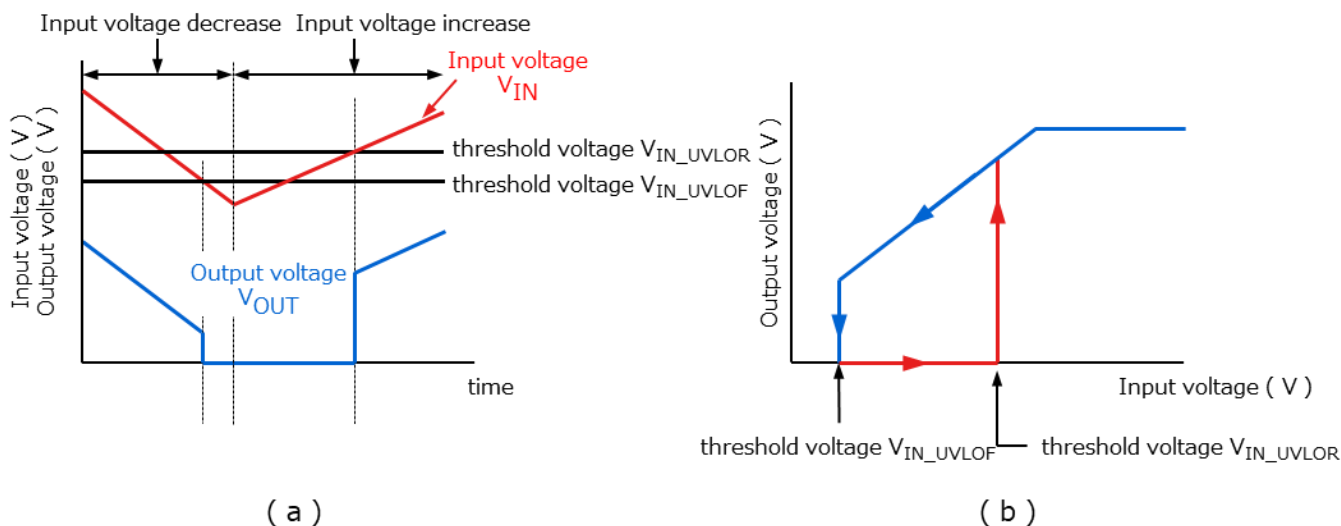


Figure 6.2 Example of an operation of the UVLO circuit

6.4. EN pin

TCKE9 series has an EN pin, which can be used to control the operation of TCKE9 series. In addition, an external resistor can be used to set the operating voltage of the undervoltage lockout (UVLO) to the optimal level.

Additionally, a window comparator is connected to the EN pin of the TCKE9 series. See Fig. 6.3. Since the window comparator has two thresholds, V_{REF_P} and V_{REF_N} , it can produce stable output as shown in Fig. 6.4(b) even if an unstable control signal is input with chattering or ringing superimposed on the mechanical switch. On the other hand, a normal inverter with one threshold at the input may cause the output to malfunction as shown in Fig. 6.4(a).

Note that EN pin is not pulled down in the TCKE9 series.

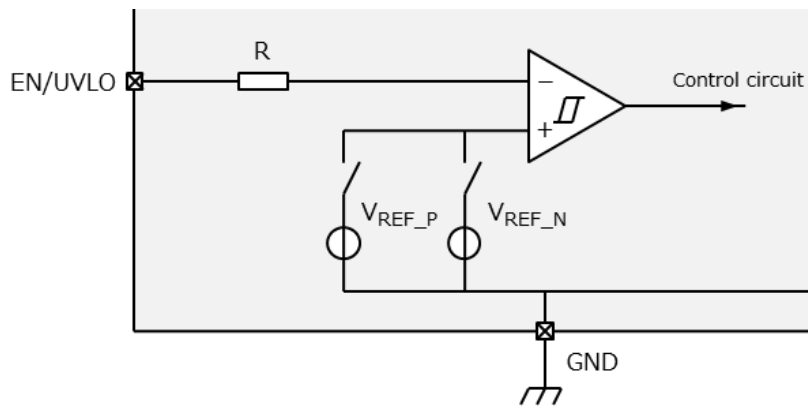


Figure 6.3 Equivalent circuit of the EN pin

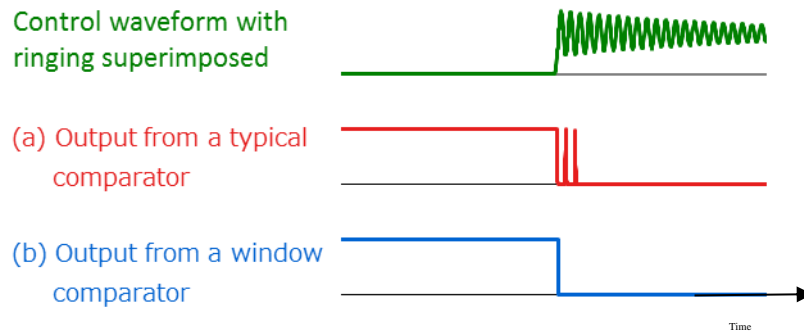


Figure 6.4 Outputs from a typical comparator and a window comparator

6.4.1. Sample Control Using EN Pin

The following shows how to control using the EN pin.

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

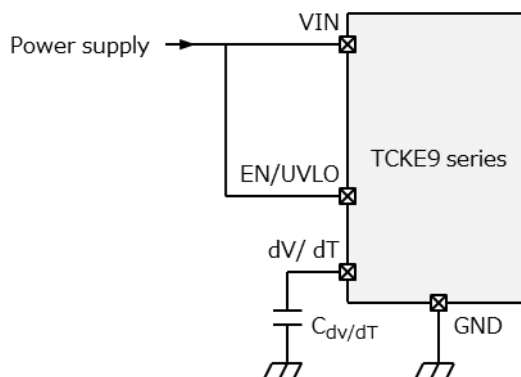


Figure 6.5 Example of the EN input connection (The EN input is connected directly to VIN.)

Connect the EN pin directly to the VIN pin (Fig. 6.5). In these cases, a pull-up resistor is not required for the TCKE9 series. The EN pin is designed to have the same withstand voltage as the VIN pin. The VIN pin and EN pin can be directly connected, contributing to a reduction in the number of parts.

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

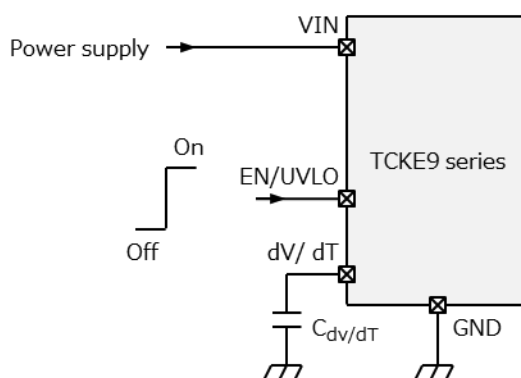


Figure 6.6 Example of the EN input connection (The EN input is controlled externally.)

Input an external control signal to the EN pin (Fig. 6.6). The on/off threshold voltage of the EN pin has hysteresis. Set the "H" level of the control signal to 1.2 V (Typ.) or higher, and the "L" level to 1.1 V (Typ.) or lower.

(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

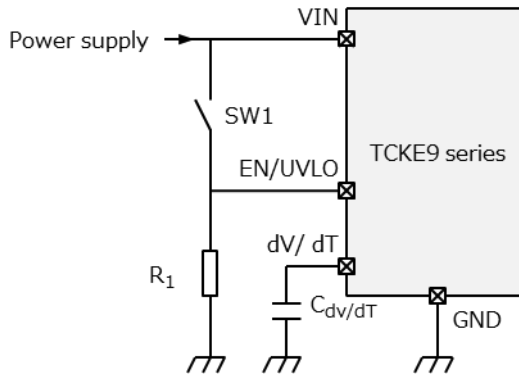


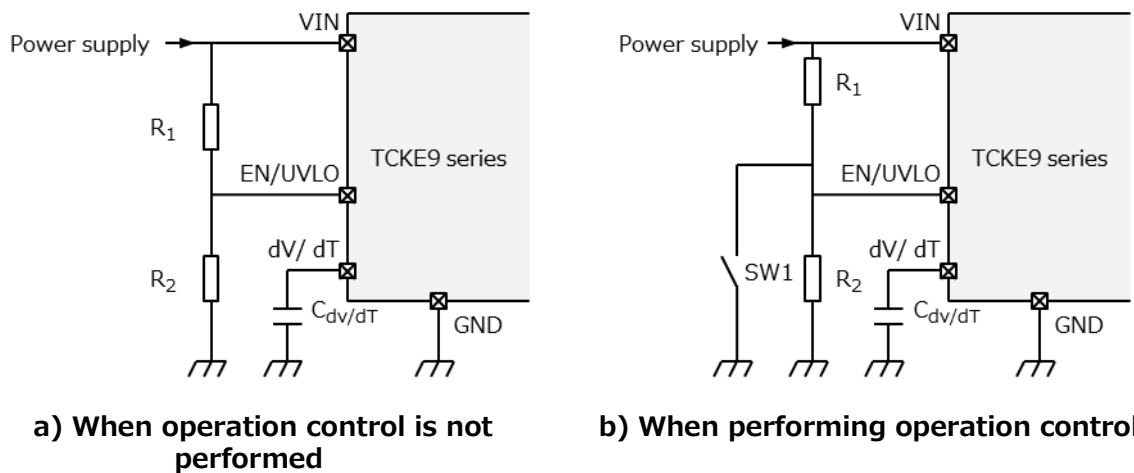
Figure 6.7 Connection Example of EN/UVLO pin (Connect by VIN and Switch)

A switch is provided at the direct connection to the VIN pin to enable operation control (Fig. 6.7).

A pull-down resistor is required to prevent the EN/UVLO pin from becoming open when SW1 is open. Design the pull-down resistor so that the EN/UVLO pin is not undefined. When SW1 is conducting, consider the current flowing through R_1 , and confirm with the actual device.

(4) When the UVLO trip threshold is programmed

Although there are specified UVLO for the incoming VIN, by adding an external resistor to the EN pin, it can be set to the desired operating voltage $V_{IN}/UVLO(\text{fall for preventing low-voltage malfunction})$, $V_{IN}/UVLO(\text{rise})$. An example circuit is shown in Figure 6.8.



a) When operation control is not performed

b) When performing operation control

Figure 6.8 Example of the EN input connection (VIN is divided with resistors.)

a) is for operation control without using the EN pin, and b) is for operation control. As shown in the diagram, by inputting the voltage divided by the input voltage V_{IN} using an external resistor to the EN/UVLO pin to perform operation control, operation can be stopped when V_{IN} drops. By appropriately selecting external resistors, the operating voltage of the UVLO circuit can be set to the desired value. It

cannot be set to a voltage lower than VIN UVLO voltage (VIN_UVLO). The equation (6-1) is used to calculate the set VIN/UVLO(fall) of the external resistor R1, R2 of EN/UVLO pin.

$$V_{IN/UVLO(fall)} = V_{ENUVF} \times \left(\frac{R_1 + R_2}{R_2} \right) \quad (6-1)$$

VIN/UVLO(fall) : UVLO trip threshold for falling VIN (V)

VENUVF : EN Threshold voltage, falling = 1.1 V (Typ.) (V)

As mentioned above, the control voltage of the EN pin has hysteresis. The voltage that starts when VIN rises varies. The startup-voltage VIN/UVLO(rise) at the rise can be calculated using equation (6-2).

$$V_{IN/UVLO(rise)} = V_{ENUVR} \times \left(\frac{R_1 + R_2}{R_2} \right) \quad (6-2)$$

VIN/UVLO(rise) : UVLO recovery threshold for rising VIN (V)

VENUVR : EN threshold voltage, rising = 1.2 V (Typ.) (V)

As shown in b) in Fig. 6.8, operation control can also be performed by connecting the switches in parallel with R2. In such cases, the TCKE9 series-series operation is stopped when SW1 is in continuity, contrary to the case in (3). In this case, R1 becomes the current limiting resistor. Pay attention to the selection of the resistor.

6.5. Operation of the Thermal Shutdown (TSD) circuit

The Thermal Shutdown (TSD) circuit turns off the output to protect IC when a large current continues to flow to the output, when an output is short-circuited, when an overvoltage is applied to the input, the ambient temperature rises rapidly and the junction temperature of TCKE9 series exceeds the TSD threshold temperature (T_{SD} :155 °C Typ.). In the TCKE9 series, when the thermal shutdown is activated, the output of the FLAG pin is turned off. At the same time, the output of FLAG pin changes from the "H" level to the "L" level. The thermal shutdown protection has hysteresis between detect temperature and recover temperature.

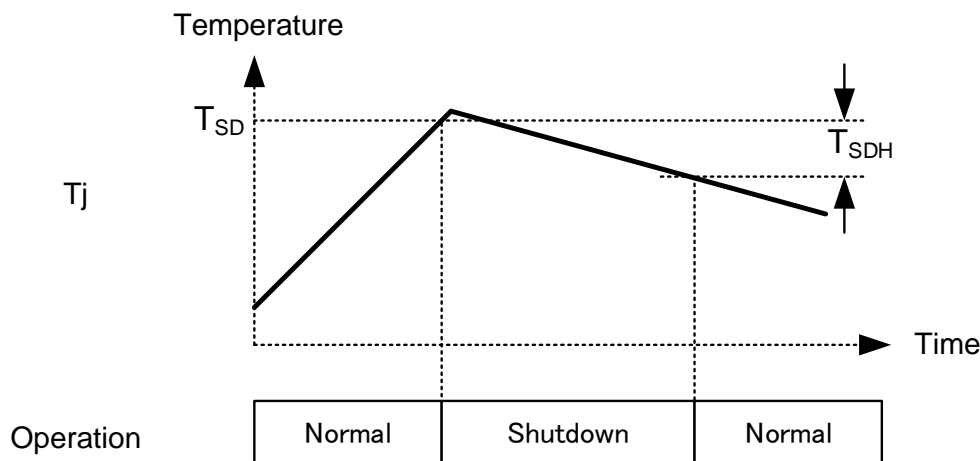


Figure 6.9 Thermal Shutdown circuit operation

6.5.1. Auto-retry type thermal shutdown

After going into a shutdown state due to thermal shutdown, the unit restarts after a certain period of time.

6.5.2. Latch type thermal shutdown

After the thermal shutdown function is operated and the device goes into a shutdown state, it must be restarted by a control signal on the EN/UVLO pin, etc. to recover. The protection operation continues until restarted.

6.5.3. Operating principle of thermal shutdown 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 6.10. When the TCKE9 series is operating normally, the forward voltage of the diode relative to V_{TSD} is high. Since the forward voltage of the diode has a temperature coefficient of about $-2 \text{ mV}/^\circ\text{C}$, when the junction temperature rises and the forward voltage falls below V_{TSD} , the comparator inverts and turns off the TCKE9 series output. At the same time, the FLAG pin output is inverted from the "H" level to the "L" level.

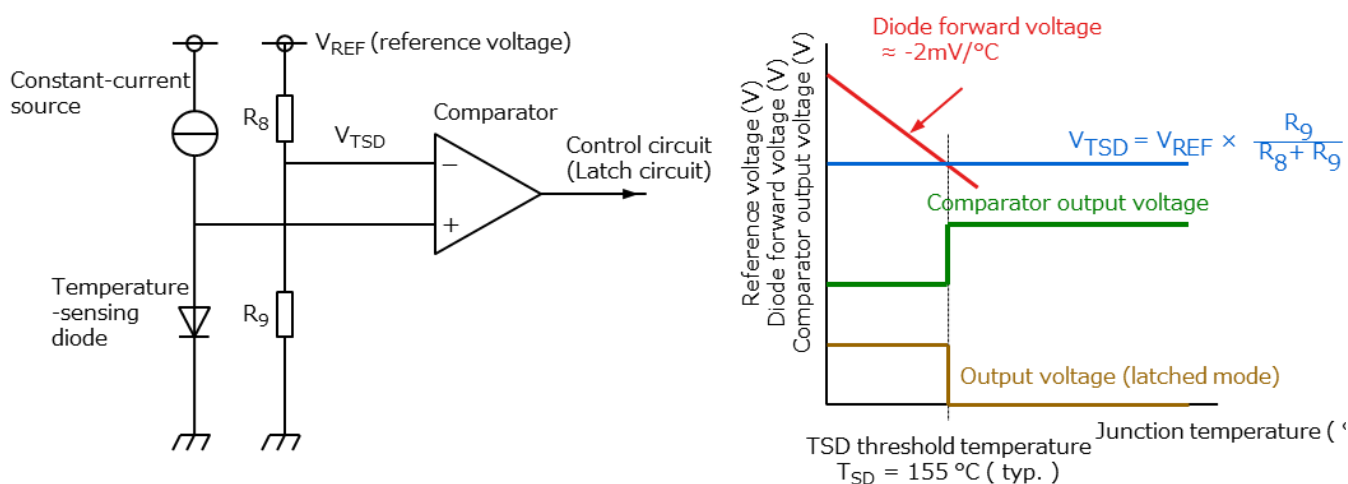


Figure 6.10 Thermal shutdown circuit and operation principle

Table 6.3 Thermal shutdown T_{SD} properties given in the datasheet

$V_{IN} = 3.3 \text{ V}$ (TCKE903), $V_{IN} = 5.0 \text{ V}$ (TCKE905), $V_{IN} = 12 \text{ V}$ (TCKE912), $V_{IN} = 20 \text{ V}$ (TCKE920), $R_{LIM} = 487 \Omega$

| Item | Symbol | Measurement condition | $T_a = 25^\circ\text{C}$ | | | $T_a = -40 \text{ to } 125^\circ\text{C}$ | | Unit |
|---|----------------|-----------------------|--------------------------|------|-----|---|-----|------------------|
| | | | Min | Typ. | Max | Min | Max | |
| Thermal shutdown threshold temperature | T_{SD} | T_j | - | 155 | - | - | - | $^\circ\text{C}$ |
| Thermal shutdown hysteresis temperature | T_{SDH} | T_j | - | 20 | - | - | - | $^\circ\text{C}$ |
| Thermal shutdown Auto-retry Interval time | $t_{TSD, RST}$ | - | - | 55 | - | - | - | ms |

6.6. Operation of the Overcurrent Limit (OCL)

The overcurrent protection circuit suppresses power dissipation when overcurrent flows to prevent degradation or breakage of IC and loads. When the output current reaches the output limit current I_{LIM} due to an error in the load or a short-circuit, the output current and the output voltage are lowered so that a current higher than I_{LIM} does not flow when an overcurrent is detected, and IC and the power consumed by the load are limited. In addition to the short-circuit protection circuit described later, it can be doubly protected against overcurrent, which greatly contributes to the prevention of firing and smoking. Fig. 6.11 shows the relation between output voltage and current in TCKE9 series output current limit operation.

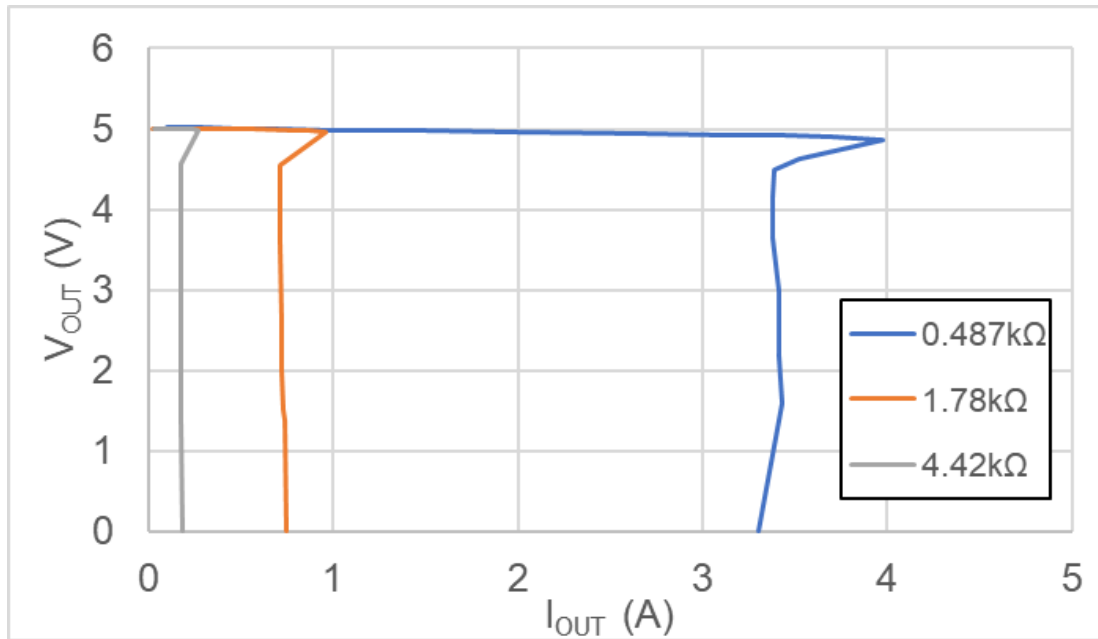


Figure 6.11 Output voltage vs. current characteristics in overcurrent limit operation

6.6.1. Overcurrent protection operation of the auto-retry type

When the output current value reaches the I_{LIM} and an overcurrent is detected, the current is limited so that no more current flows than the I_{LIM} . Currently, the output voltage decreases according to the relationship between output voltage and current. If the overcurrent is not resolved at this stage, the IC temperature rises, and if the temperature reaches the temperature for thermal shutdown, the output stops and the IC goes into shutdown state. For the auto-retry type, after a certain period, the operation restarts. However, if the overcurrent issue is not resolved, the current is limited once again, and this cycle repeats as follows: current limit \rightarrow temperature rise \rightarrow thermal shutdown \rightarrow shutdown \rightarrow temperature drop \rightarrow restart \rightarrow current limit.

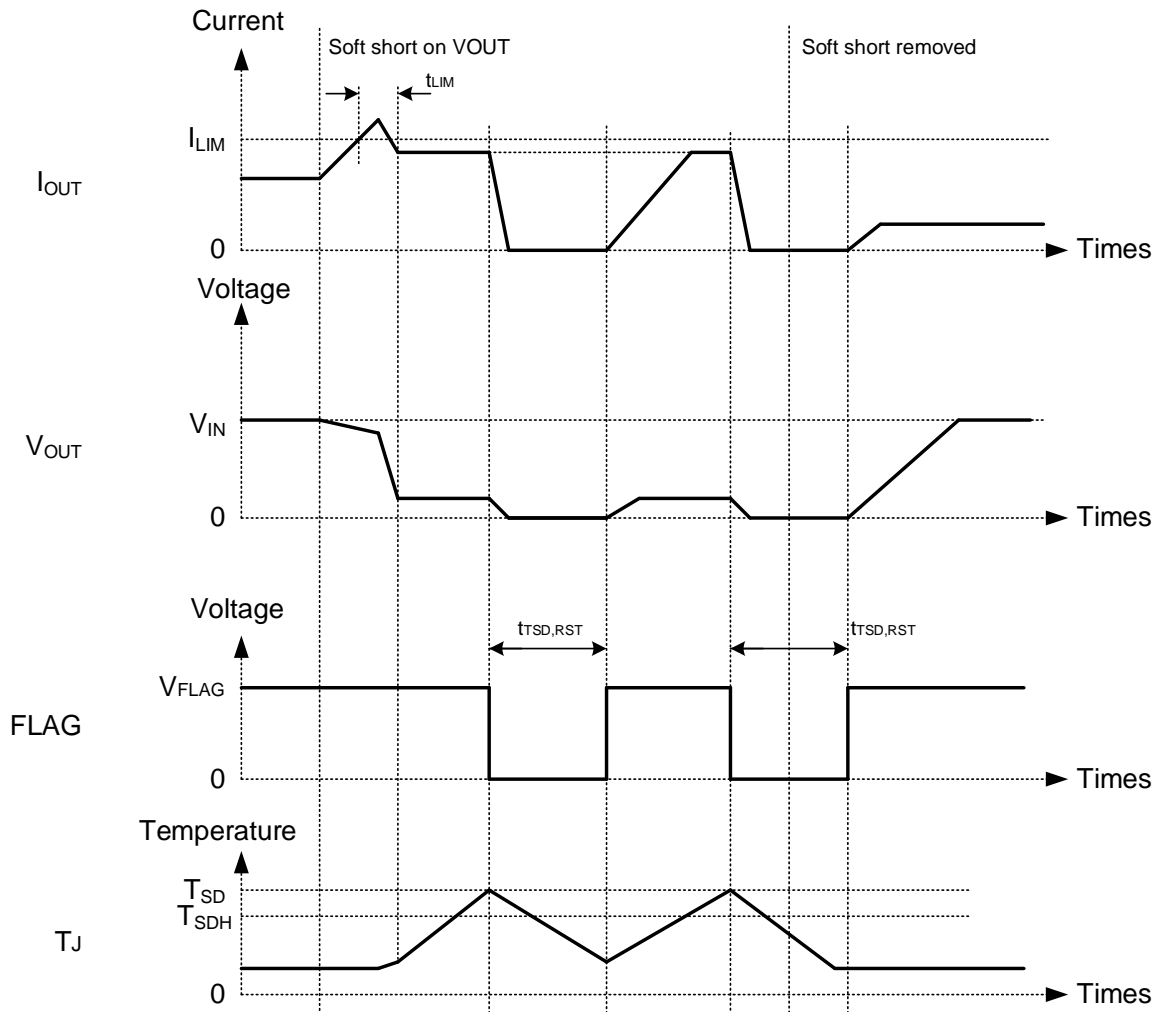


Figure 6.12 Timing chart of overcurrent protection operation (auto-retry type)

6.6.2. Latch-type overcurrent protection operation

Like the auto-retry type, When the output current value reaches the I_{LIM} and an overcurrent is detected, the current is limited so that no more current flows than the I_{LIM} . Currently, the output voltage decreases according to the relationship between output voltage and current. If the overcurrent is not resolved at this stage, the IC temperature rises, and if the temperature reaches the temperature for thermal shutdown, the output stops and the IC goes into shutdown state. In case of latch type, thermal shutdown operation is latched. To recover it, it must be restarted by a control signal on the EN/UVLO pin, etc. The protection operation continues until it is restarted.

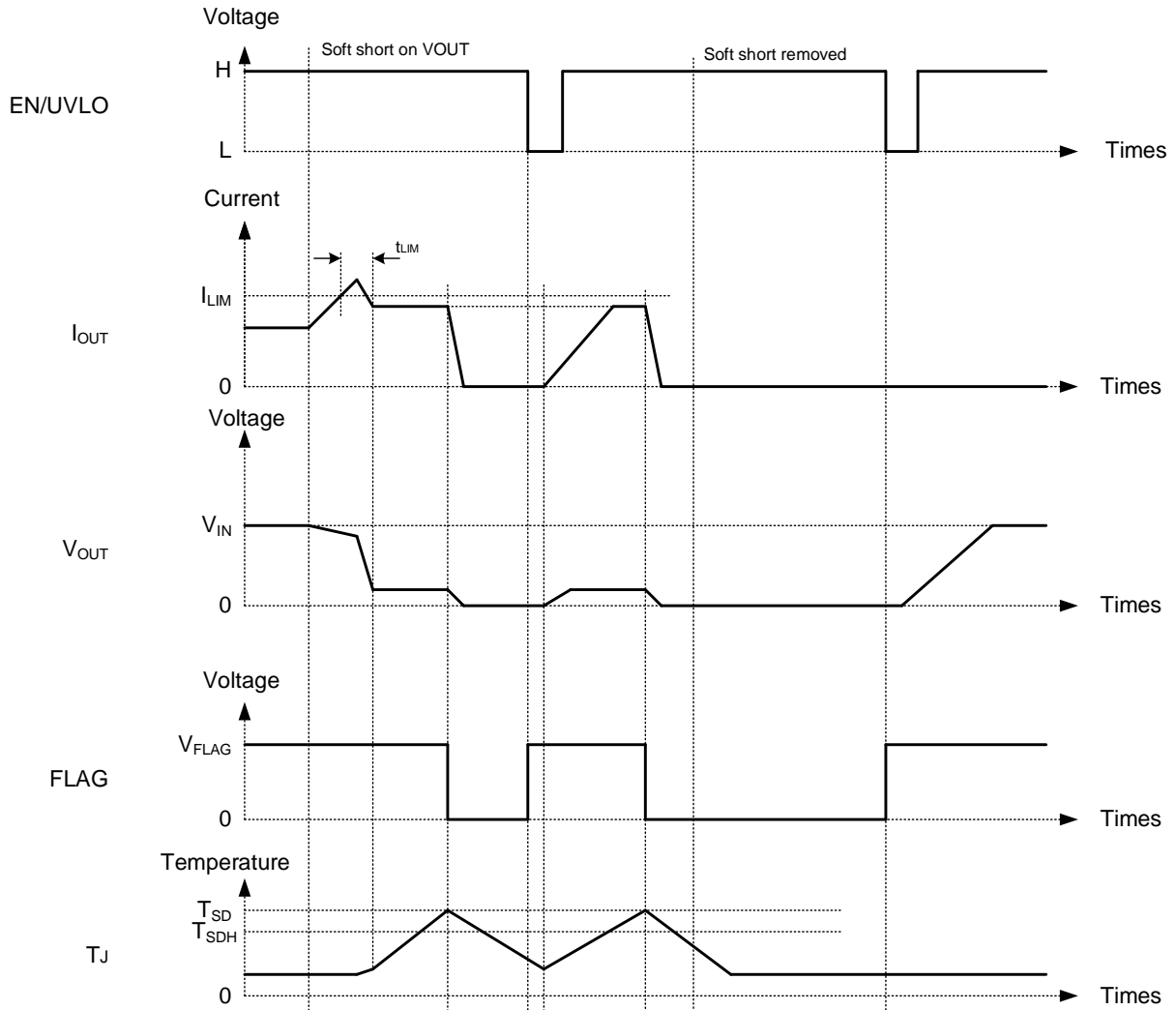


Figure 6.13 Timing chart of overcurrent protection operation (latch type)

6.6.3. Setting the overcurrent protection circuit

The output current limit I_{LIM} of the TCKE9 series is adjustable and can be set to the optimum limit current according to the application by selecting the external resistor R_{ILIM} of the ILIM pin. I_{LIM} can be obtained using equation (6-3). However, be sure to check the value on the actual machine when selecting the resistance.

$$R_{LIM} = \frac{1985}{I_{LIM} - 0.04} \quad (\Omega) \quad (6-3)$$

- I_{LIM} : Overcurrent limit value (A)
- R_{ILIM} : External resistor connected to ILIM pin (Ω)

Figure 6.14 and Figure 6.15 show the relationship between the peripheral circuit diagram of ILIM pin and I_{LIM} and R_{ILIM} .

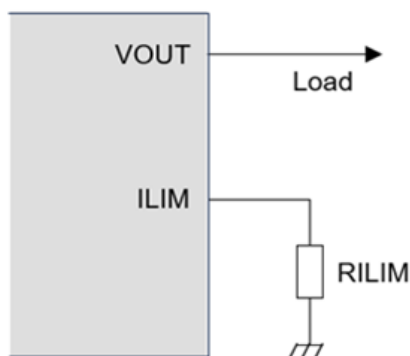


Figure 6.14 ILIM pin external circuit

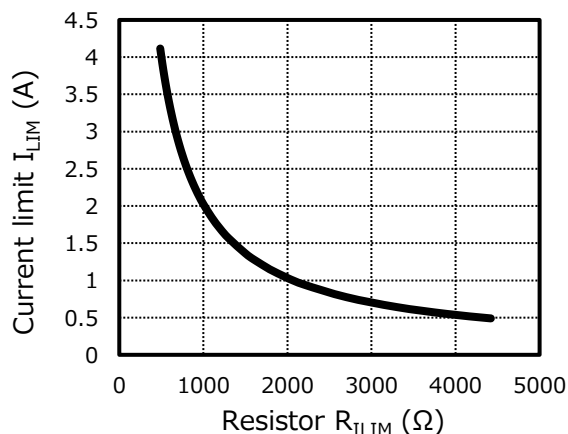


Figure 6.15 I_{LIM} - R_{ILIM} characteristics

Table 6.4 Overcurrent protection (OCL) characteristics in datasheet

$V_{IN} = 3.3$ V (TCKE903), $V_{IN} = 5.0$ V (TCKE905), $V_{IN} = 12$ V (TCKE912), $V_{IN} = 20$ V (TCKE920)

| Item | Symbol | Measurement condition | $T_a = 25$ °C | | | $T_a = -40$ to 125 °C | | Unit |
|-----------------------------|-----------|--------------------------|---------------|------|-----|-------------------------|------|------|
| | | | Min | Typ. | Max | Min | Max | |
| Output Limit Current (Note) | I_{LIM} | $R_{ILIM} = 487 \Omega$ | - | 4.09 | - | 3.40 | 4.68 | A |
| | | $R_{ILIM} = 1780 \Omega$ | - | 1.11 | - | 0.95 | 1.36 | A |
| | | $R_{ILIM} = 4420 \Omega$ | - | 0.49 | - | 0.33 | 0.65 | A |
| | | $R_{ILIM} = 0 \Omega$ | - | 2 | - | - | - | A |
| | | $R_{ILIM} = \text{Open}$ | - | 0 | - | - | - | A |

(Note): Guaranteed by design

6.7. Operation of short-circuit protection circuit

The short-circuit protection function (fast trip) prevents excessive current from flowing by stopping operation when the power supply line or load is short-circuited due to some kind of abnormality. If the output current is 1.6 times the current limit (I_{LIM}) for a very short term, the output is judged to be short-circuited, and this function operates.

6.7.1. Auto-retry type VOUT short-circuit protective operation

This function judges that VOUT is short-circuited and stops the output when the output current reaches 1.6 times the overcurrent limit current (I_{LIM}). The IC then starts operating with soft-start operation, but if the short-circuit continues, the IC temperature rises because the overcurrent limit current (OCL) operation continues. After that, the thermal shutdown function operates, and the IC goes into shutdown state. After a certain term, the IC starts operating again, but if the VOUT short-circuit has not been resolved, the current is limited again. Therefore, the recovery attempt is repeated by the following cycle.

Current limit → temperature rise → thermal shutdown → shutdown → temperature drop → restart → current limit

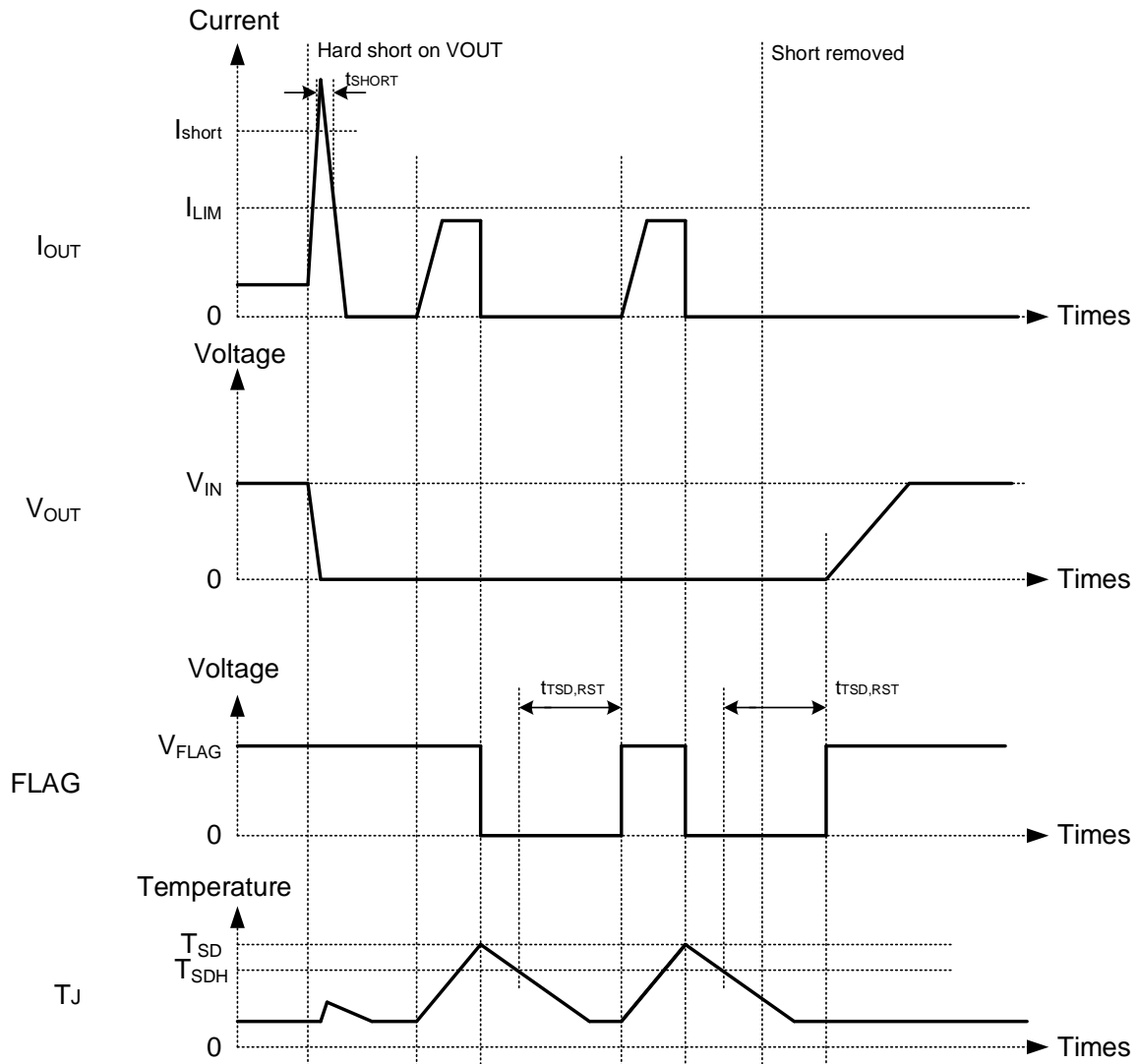


Figure 6.16 Example of short-circuit protection circuit and overcurrent protection operation

6.7.2. Latch-type VOUT short-circuit proof operation

Like the auto-retry type, this function judges that VOUT pin is short-circuited and stops output when the output current reaches 1.6 times the overcurrent limit current (I_{LIM}). The IC then starts operating with soft-start operation, but if the short-circuit continues, the IC temperature rises as the operation continues at the overcurrent limit current (OCL). After that, the thermal shutdown function operates, and the IC goes into shutdown state. To recover it, it must be restarted by a control signal on the EN/UVLO pin, etc. The protection operation continues until it is restarted.

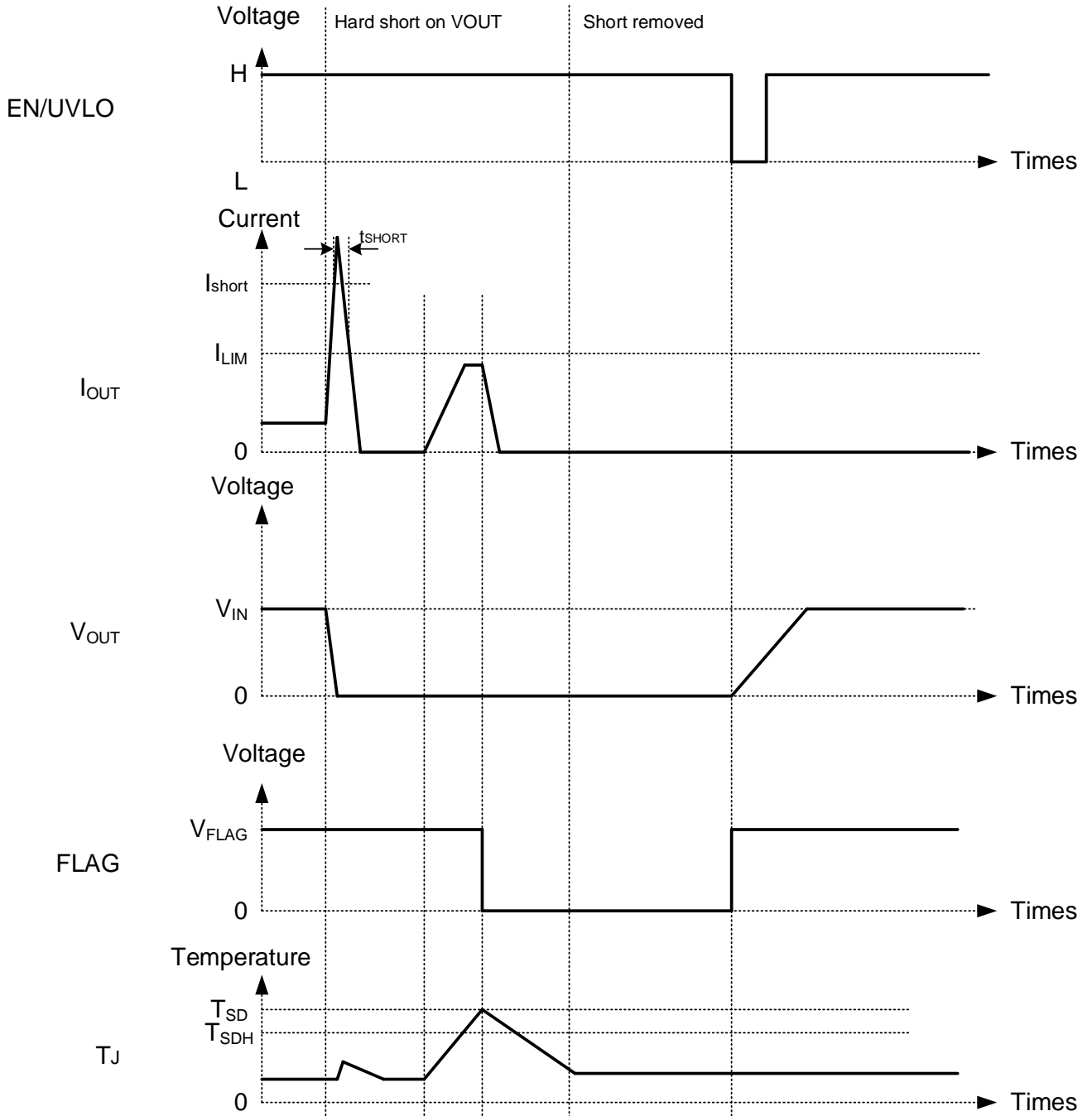


Figure 6.17 Example of short-circuit protection circuit and overcurrent protection operation

6.8. Operation of inrush current suppression circuit (Slew Rate Control)

6.8.1. Operation of inrush current suppression circuit

When the output is turned on, an inrush current flows to charge the capacitor connected to the load side. If this current is too large, the overcurrent protection circuit may operate, disabling the output rise, or the input voltage may undershoot or overshoot the output voltage. To prevent this, the inrush current suppression circuit controls the slew rate at the rising edge of the output voltage to limit the inrush current. Figure 6.18 shows the rise and inrush current of the output voltage when the inrush current is limited by this circuit.

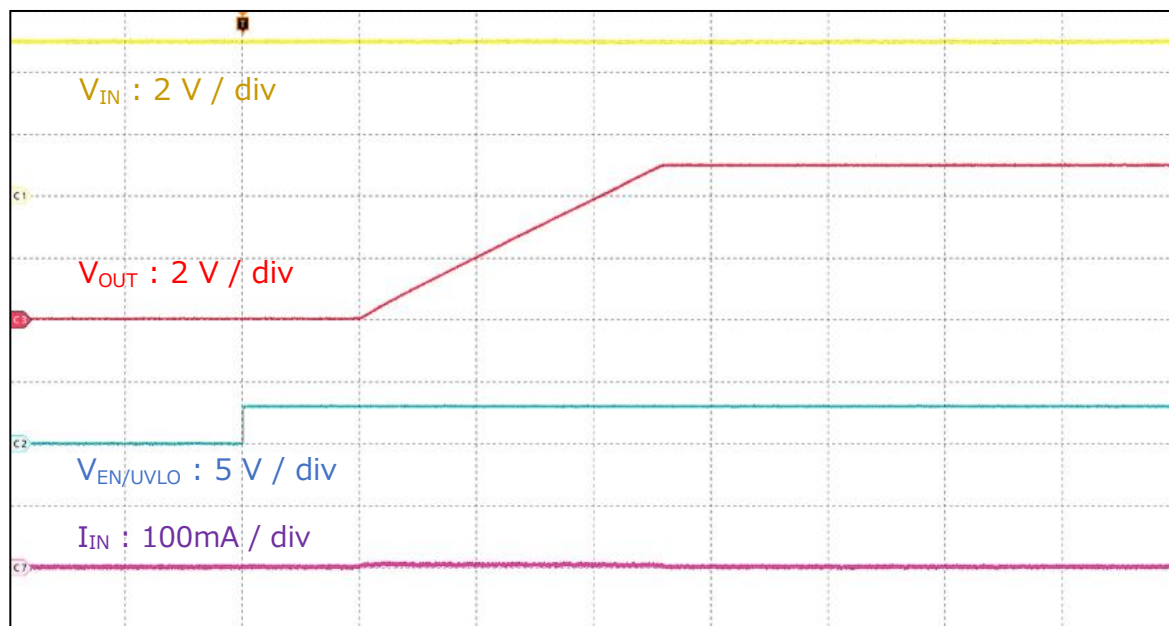


Figure 6.18 Operation waveform of inrush current suppression (slew rate control) circuit

6.8.2. Setting the Output-Voltage VOUT Rise Time (Slew Rate)

The slew-rate SR_{ON} of the output voltage in the TCKE9 series can be set appropriately by using an external capacitor connected to the dV/dT pin. The slew rate of the output voltage can be calculated as follows.

$$SR_{ON} = \frac{I_{INRUSH}}{C_{OUT}} \quad (6-4)$$

$$C_{dV/dT} = \frac{42000}{SR_{ON}} \quad (6-5)$$

| | | | |
|--------------|---|---|------------|
| SR_{ON} | : | Output voltage slew rate | (V/ms) |
| I_{INRUSH} | : | Inrush current | (mA) |
| C_{OUT} | : | Output capacitor | (μ F) |
| $C_{dV/dT}$ | : | External capacitor connected to dV/dT pin | (pF) |

Figure 6.19 and Figure 6.20 show dV/dT pin peripheral schematics and SR_{ON} - $C_{dV/dT}$ features.

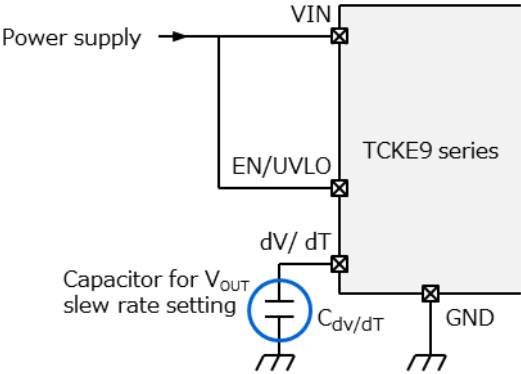


Figure 6.19 External Circuits around dV/dT pin

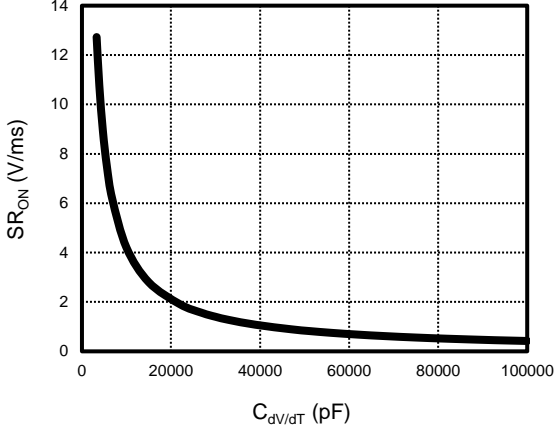


Figure 6.20 SR_{on} – C_{dv/dT} characteristics

6.9. FLAG circuit

The TCKE9xxNA/NL/ANA has a FLAG function. The FLAG circuit is a diagnostic circuit that changes the FLAG pin output from "H" to "L" when overvoltage protection, overcurrent protection, and short-circuit protection are activated, and outputs to the outside of the IC that an error has occurred. The FLAG pin has an open-drain structure. Use an external resistor to pull up the pin (Fig. 6.21).

Select a pull-up resistor considering the sink current (max. rating) of the FLAG pin (10 kΩ as a reference for the pull-up resistor). In addition, determine an appropriate resistance value after thoroughly evaluating with an actual device.

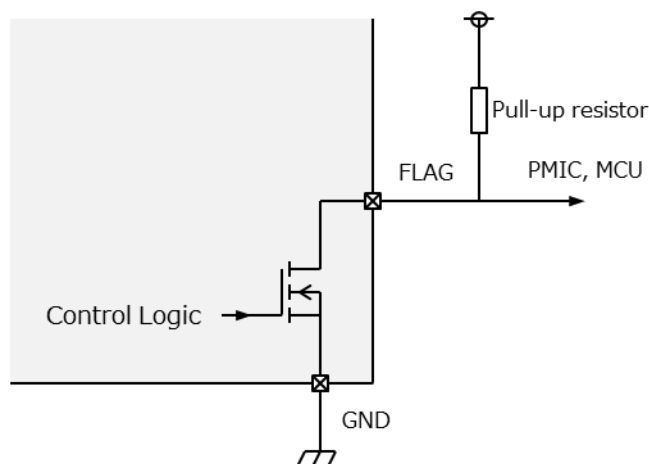


Figure 6.21 Equivalent circuit of the FLAG pin

Table 6.5 Target functions and operation timing of FLAG outputting

| Abnormal mode | FLAG power | Timing of FLAG Outputting Operation | IC operation |
|--------------------------|------------|---|---|
| Superheating | Yes | $T_j \geq T_{SD} 155 \text{ }^\circ\text{C}$ (Typ.) | Shutdown |
| Overvoltage | - | - | V_{OUT} voltage-clamp |
| Low voltage | - | - | Shutdown |
| Overcurrent | - | - | I_{OUT} Current Limit |
| Short-circuit | - | - | Shutdown |
| ILIM pin open | - | - | Shutdown |
| ILIM pin short-circuited | Yes | $I_{OUT} > 2 \text{ A}$ (Typ.) | $I_{OUT} > 2 \text{ A}$ (Typ.) shutdown |

6.10. Quick output discharge circuit

The TCKE9xxQNA discharges the capacitor when the IC is off. The QOD pin and VOUT pin are connected directly or through an external resistor. When the IC turns off, the MOSFET for discharging inside turns on and the output voltage is turned to 0 V. The discharge MOSFET initially operates in the saturated range and performs constant current discharge. After that, when this MOSFET enters the linear range, it becomes resistively discharged. Figure 6.23 shows the discharge waveform of the TCKE9xxQNA. When the QOD pin is OPEN, the output discharge duration is determined by the output capacitor and loads. When the QOD pin and VOUT pin are connected, the discharge function can be realized. The discharge time of the output voltage is determined by the output capacitor, the resistance (internal and external) of the discharge path, and the load.

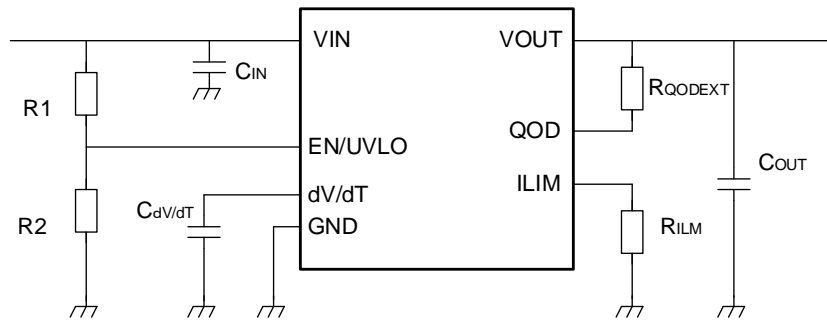
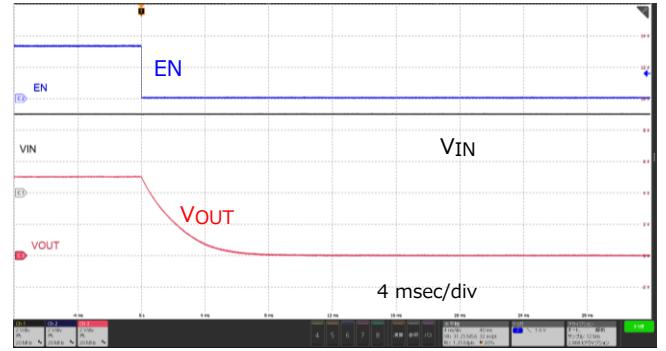
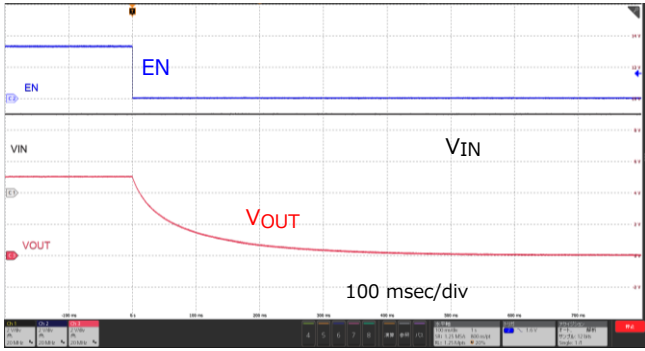


Figure 6.22 Typical circuit with QOD

$R_{QODEXT} = \text{OPEN}$
 $V_{IN} = 5.0 \text{ V}$, $EN = \text{H to L}$, $C_{OUT} = 100 \mu\text{F}$, $R_{OUT} = 1 \text{ k}\Omega$, $T_a = 25 \text{ }^\circ\text{C}$

$R_{QODEXT} = \text{Short}$
 $V_{IN} = 5.0 \text{ V}$, $EN = \text{H to L}$, $C_{OUT} = 100 \mu\text{F}$, $R_{OUT} = 1 \text{ k}\Omega$, $T_a = 25 \text{ }^\circ\text{C}$



$R_{QODEXT} = \text{OPEN}$
 $V_{IN} = 3.3 \text{ V}$, $EN = \text{H to L}$, $C_{OUT} = 100 \mu\text{F}$, $R_{OUT} = 1 \text{ k}\Omega$, $T_a = 25 \text{ }^\circ\text{C}$

$R_{QODEXT} = \text{Short}$
 $V_{IN} = 3.3 \text{ V}$, $EN = \text{H to L}$, $C_{OUT} = 100 \mu\text{F}$, $R_{OUT} = 1 \text{ k}\Omega$, $T_a = 25 \text{ }^\circ\text{C}$

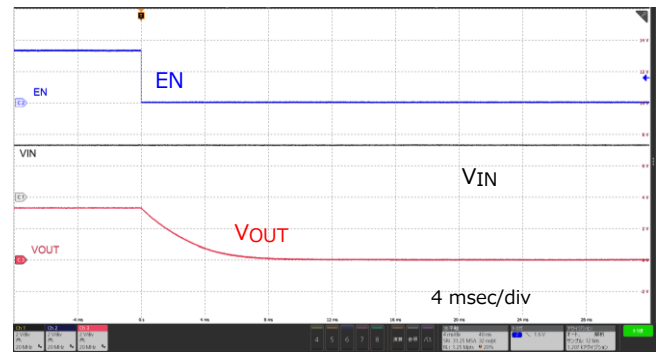
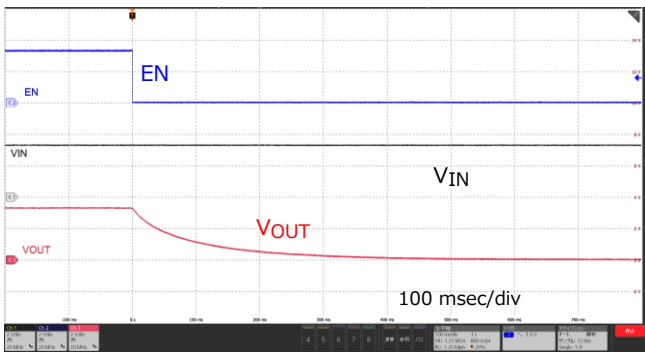


Figure 6.23 Discharge circuit operation waveform

7. Applications of TCKE9 series

The following are examples of applications

- Notebook PCs/ mobile devices

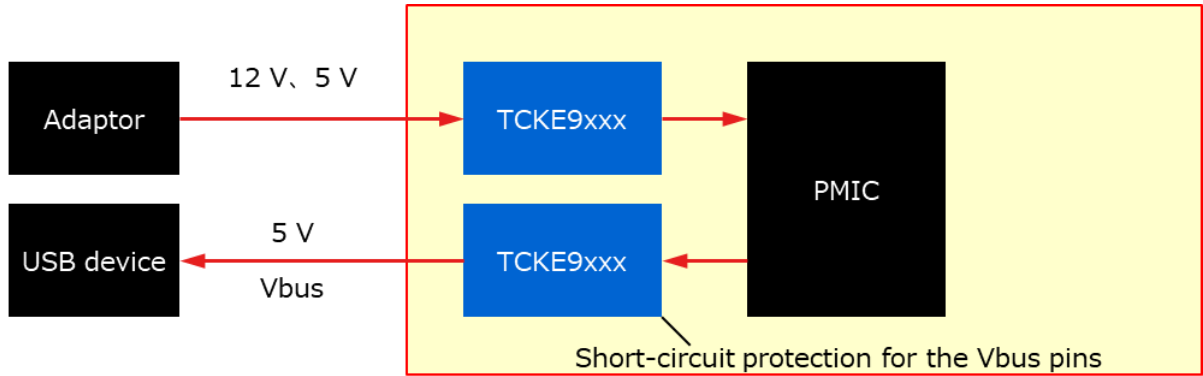


Figure 7.1 Applications for Laptop PCs/ Mobile Devices

- SSDs/ HDDs

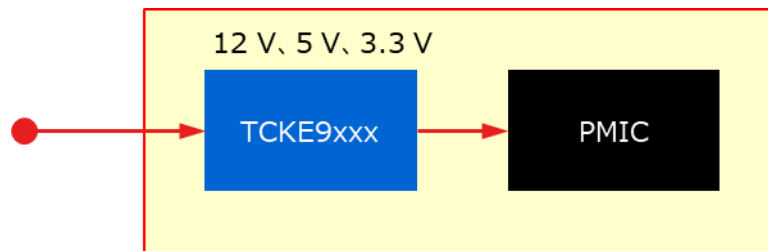


Figure 7.2 Applications to SSDs/ HDDs

- Servers

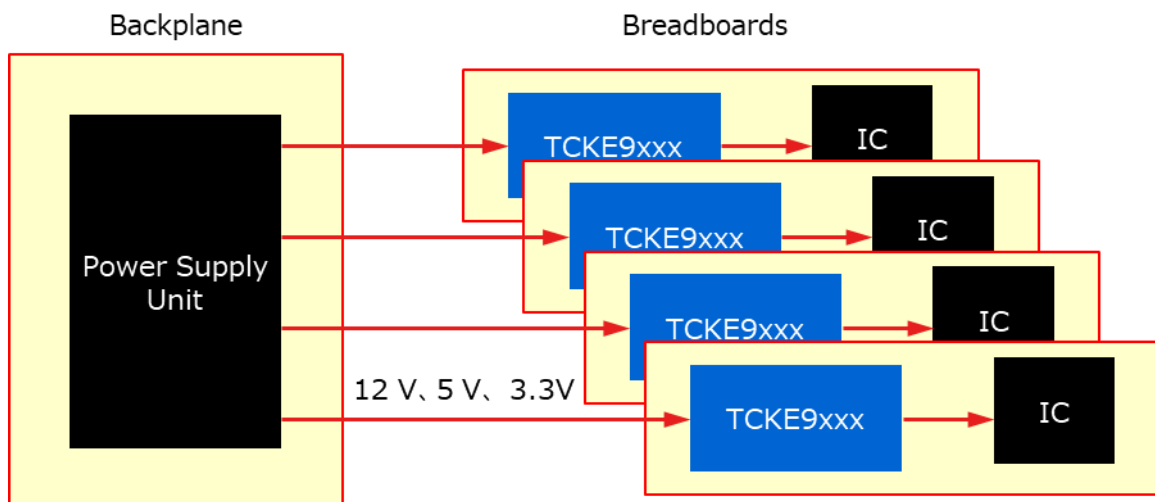


Figure 7.3 Applications to servers

- Wearables/IoT devices

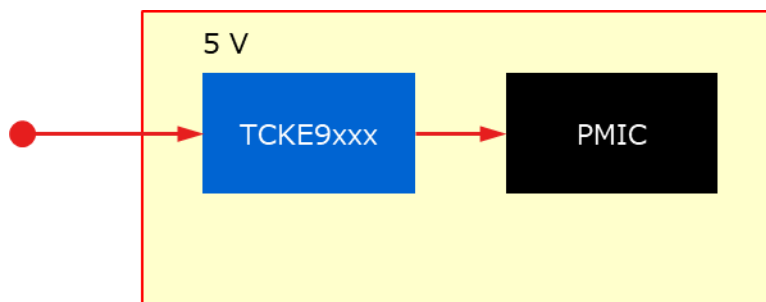


Figure 7.4 Application to wearables/IoT devices

8. Summary

The TCKE9 series not only interrupts large currents but also protects ICs and equipment from various possible abnormal conditions such as overvoltage and overheating. In addition, it offers convenient functions such as suppression of inrush current and prevention of malfunction at low voltage. These functions contribute to greatly improving the reliability of electronic equipment. Furthermore, if we consider using discrete components and other passive components to realize functions equivalent to those of the TCKE9 series, we would like you to understand that this will also be highly effective in downsizing equipment and reducing design/manufacturing costs. We hope you will be able to use the TCKE9 series. Refer to these documents to realize higher performance, smaller size, and lower total cost of the equipment. We intend to expand our lineup to include a wider range of selections to match the specifications of the equipment you are using, so we would like you to appreciate the reliability of our eFuse IC.

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