# Over Temperature Detection IC Thermoflagger™ Application Circuit (TCTH021AE version)

# Design Guide

## RD225-DGUIDE-02

Toshiba Electronic Devices & Storage Corporation

# Table of Contents

# 1. Introduction

This Design Guide describes the reference design (hereafter referred to as the Design) of the Over Temperature Detection Circuit using the Over Temperature Detection IC Thermoflagger™. This design has a simple configuration which detects the rise of temperature above the set alert temperature.

This design uses an Over Temperature Detection IC Thermoflagger™ TCTH021AE. MOSFETs SSM3K35MFV and SSM3J35AMFV are also used to drive LEDs.

# 2. Components Used

## 2.1. Over Temperature Detection IC Thermoflagger™ TCTH021AE

This design uses the over temperature detection IC Thermoflagger™ TCTH021AE. TCTH021AE is used in conjunction with a PTC thermistor whose resistance changes with temperature.

TCTH021AE detects the change in resistance of PTC thermistor placed at the position where over temperature is desired to be detected, and it outputs FLAG signal when over temperature is detected i.e., when thermistor's temperature rises above its set alert temperature. Thus, helping in detecting over temperature in an electronic equipment. By connecting multiple PTC thermistors in series, over temperature can be detected at multiple points. Its package is the small-size industry standard SOT-553 (our package name: ESV) and it achieves a low current consumption of 11.3 μA (Typical). Thermoflagger™ can be used to easily configure the over temperature detection system of the entire electronic equipment, and it contributes to miniaturization and low power dissipation.

The features of TCTH021AE are as follows.

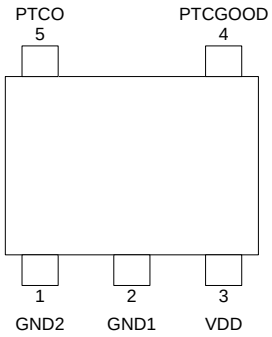
### Features

- PTCO output current $I_{PTCO}$ = 10 μA (Typ.)
- High PTCO output current accuracy ±8 % ($V_{DD}$ = 3.3 V, 25 °C)
- Low current consumption $I_{DD}$ = 11.3 μA (Typ.)
- FLAG signal output (PTCGOOD): Push-pull type
- Standard package ESV (SOT-553) (1.6 mm x 1.6 mm x 0.55 mm)

### Application Equipment

- Mobile equipment (e.g. Notebook PC)
- Home appliance
- Industry equipment, etc.

### External View and Pin Arrangement (Top View)



### 2.1.1. Operation

Fig. 2.1 and Fig. 2.2 show the internal circuit diagram of Thermoflagger™ TCTH021AE during normal temperature and over temperature respectively. The internal circuit sections listed below are also shown in the following figures.

(1) Push-pull Output Section
(2) Comparator Section
(3) Reference Voltage (0.5 V) Section
(4) Constant Current Source (10 μA) Section

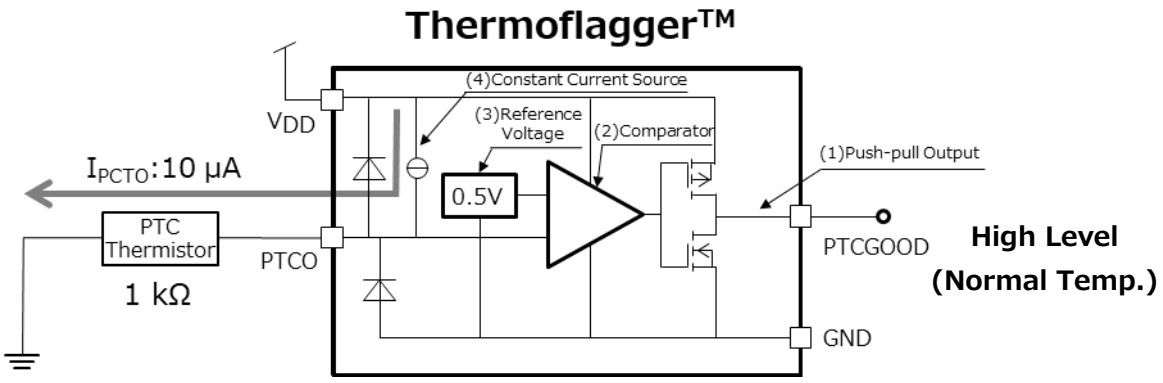



**Fig. 2.1 Internal Circuit Diagram (During Normal Temperature)**

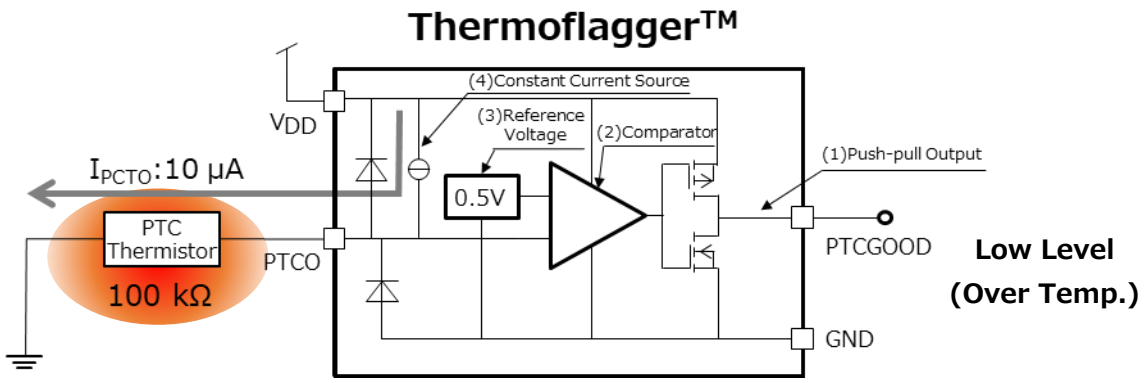



**Fig. 2.2 Internal Circuit Diagram (During Over Temperature)**

The over temperature detection IC Thermoflagger™ TCTH021AE detects over temperature and is used by connecting a PTC thermistor to PTCO pin. A constant current of 10 μA (Typ.) $I_{PTCO}$ flows from PTCO pin to PTC thermistor. Thus:

Voltage of PTCO pin = (resistance of PTC thermistor) x 10 μA  … (1)

PTC thermistor has the property that its resistance rises rapidly when the temperature exceeds a certain temperature. TCTH021AE detects the over temperature when the voltage at PTCO pin (sensing voltage) becomes more than 0.5 V (Typ.) detection voltage ($V_{DET}$) which is the reference voltage of the internal comparator. And this happens when the resistance of PTC thermistor becomes 50 kΩ (Typ.) or more, since the current flowing through the thermistor is always 10 μA

($I_{PTCO}$). TCTH021AE outputs FLAG signal from PTCGOOD pin according to the voltage at PTCO pin. When a voltage equal to or greater than the detection voltage $V_{DET}$ appears on PTCO pin, over temperature is detected, and "Low" output is generated. When the voltage is lower than $V_{DET}$, a "High" output is generated.

Therefore, when the resistance of PTC thermistor at normal temperature is 1 kΩ, (Fig. 2.1) PTCO pin voltage is approximately 10 mV from equation (1), FLAG signal becomes "High". And when the temperature rises and the resistance of PTC thermistor becomes 100 kΩ (Fig. 2.2), the voltage at PTCO pin becomes 1 V and FLAG signal becomes "Low".

## 2.2. N-ch MOSFET SSM3K35MFV

This design uses N-ch MOSFET SSM3K35MFV in LED drive circuit. The features of SSM3K35MFV are as follows.

**Features**

- Compact package (VESM, SOT-723:1.2 x 1.2 x 0.5 mm)
- Low on-resistance $R_{DS(ON)}$ = 8.0 Ω (Max.) @$V_{GS}$ = 1.5 V
  $R_{DS(ON)}$ = 4.0 Ω (Max.) @$V_{GS}$ = 2.5 V

## 2.3. P-ch MOSFET SSM3J35AMFV

This design uses P-ch MOSFET SSM3J35AMFV in LED drive circuit. The features of SSM3J35AMFV are as follows.

**Features**

- Compact package (VESM, SOT-723:1.2 x 1.2 x 0.5 mm)
- Low on-resistance $R_{DS(ON)}$ = 4.0 Ω (Max.) @$V_{GS}$ =-1.5 V
  $R_{DS(ON)}$ = 2.1 Ω (Max.) @$V_{GS}$ =-2.5 V

# 3. Specifications and Block Diagram

## 3.1. Specifications

Table 3.1 lists the main specifications of this circuit, and Fig. 3.1 shows the block diagram.

**Table 3.1 Circuit Specifications**

| Circuit Name | Thermoflagger™ | Onboard Sensor | Power Supply | Operation |
|---|---|---|---|---|
| AE1 | TCTH021AE (Push-pull type) | PTC thermistor | USB Type-C® | Red LED turns ON if the temperature of either PTC thermistor exceeds its alert temperature. |

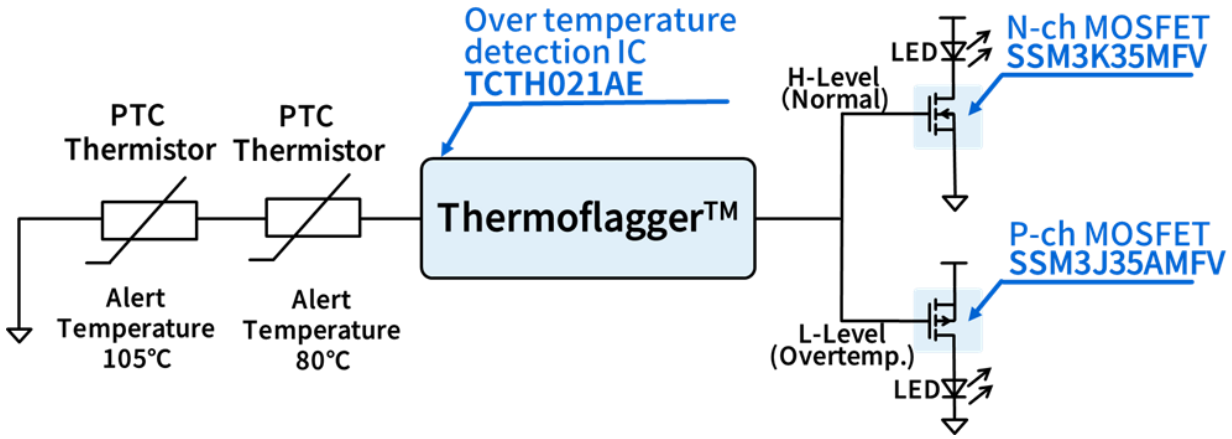



**Fig. 3.1 Block Diagram**

# 4. Circuit Design

## 4.1. Circuit Diagram

Fig. 4.1 shows the circuit diagram.

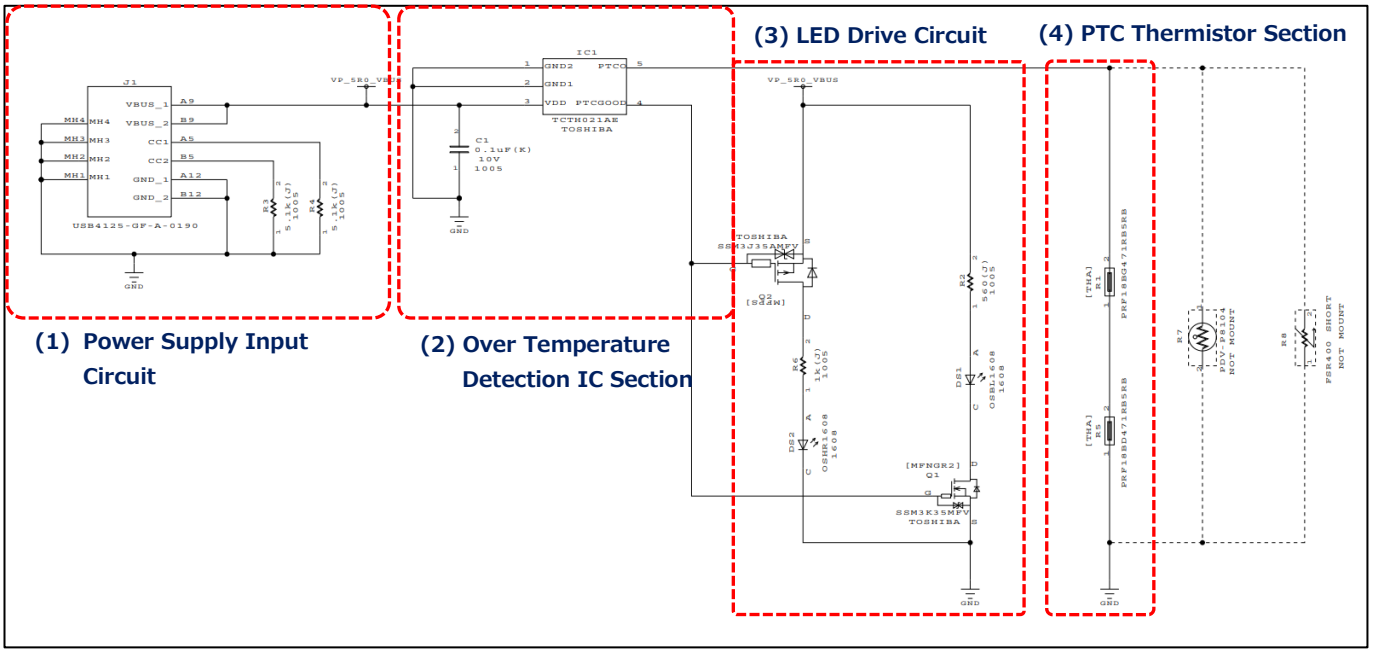



**Fig. 4.1 Schematic**

### 4.1.1. PTC Thermistor Section

In this design, a circuit to detect over temperature abnormality is designed which in this design is the rise of temperature above approximately 80 °C and approximately 105 °C. In this design, over temperature detection happens when the resistance value between PTCO pin and GND becomes 50 kΩ or more. So, two thermistors with different resistance-temperature characteristics are connected in series between PTCO and GND in order to detect different temperatures which are approximately 80 °C and 105 °C. The resistance of PTC thermistor PRF18BG471RB5RB (R1, Murata) and PRF18BD471RB5RB (R5, Murata) becomes 50 kΩ at approximately 80 °C and 105 °C respectively.

Fig. 4.2 and Fig. 4.3 shows the thermal characteristic of PTC thermistor PRF18BG471RB5RB and PRF18BD471RB5RB respectively. PTC thermistors have the property that their resistance increases rapidly as the temperature rises. From these figures it can be seen that PRF18BG471RB5RB will detect an over temperature between approximately 72 °C and 86 °C, and PRF18BD471RB5RB will detect over temperature between approximately 104 °C and 116 °C, because at these temperatures their resistance become 50 kΩ.

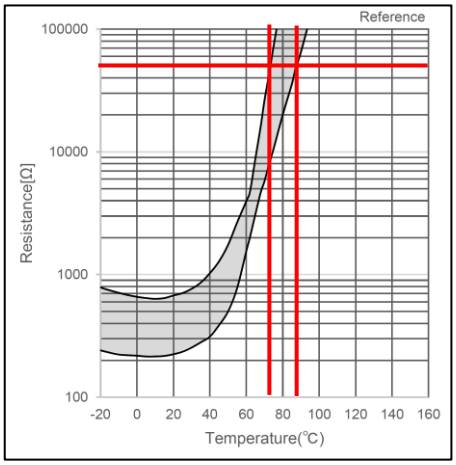



**Fig. 4.2 PRF18BG471RB5RB Resistance-Temperature Characteristic (Quoted from Murata Datasheet)**

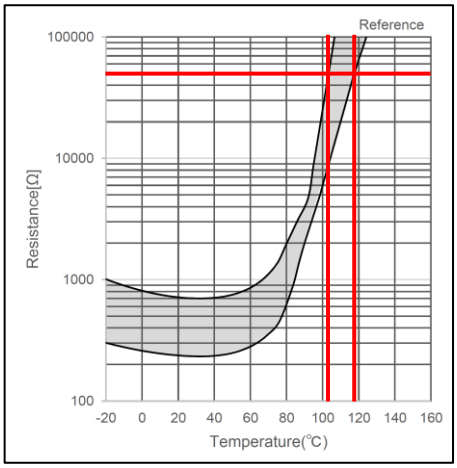



**Fig. 4.3 PRF18BD471RB5RB Resistance-Temperature Characteristic (Quoted from Murata Datasheet)**

### 4.1.2. Over Temperature Detection IC

This circuit is equipped with an over temperature detection IC Thermoflagger™ TCTH021AE (IC1). A constant-current $I_{PTCO}$ of 10 μA (Typical) is output from PTCO pin of TCTH021AE, and a PTC thermistor is connected between this pin and GND. PTCGOOD output pin has a push-pull configuration and outputs the FLAG signal. When the voltage $V_{PTCO}$ at PTCO pin exceeds the specified voltage $V_{DET}$ (0.5 V (Typical)), the FLAG output becomes Low, and when $V_{PTCO}$ falls below $V_{DET}$, the FLAG output becomes high impedance. TCTH021AE's PTCGOOD pin is pulled up by 10 kΩ (R9) to 5 V, so when PTCGOOD pin is in the high-impedance state, FLAG signal output is High level of approximately 5 V.

### 4.1.3. Alert Temperature Variation

Table 4.1 shows the variations in $I_{PTCO}$ and $V_{DET}$ of TCTH021AE.

**Table 4.1 Properties of TCTH021AE ($V_{DD}$=5.0 V, $V_{SS}$=GND, Ta=25 °C)**

| Item | Symbol | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|
| PTCO Output Current | $I_{PTCO}$ | 8.0 | 10.0 | 12.2 | μA |
| Sensing Voltage | $V_{DET}$ | 0.42 | 0.50 | 0.58 | V |

Due to variations in $I_{PTCO}$, $V_{DET}$ of TCTH021AE, the resistance of PTC thermistor must be within the following limits. When designing, enough margin must be considered.

$$\frac{V_{DET}(\text{Min.})}{I_{PTCO}(\text{Max.})} < \text{Resistance of PTC thermistor at alert temperature} < \frac{V_{DET}(\text{Max.})}{I_{PTCO}(\text{Min.})}$$

$$= \frac{0.42\text{V}}{12.2\mu\text{A}} < \text{Resistance of PTC thermistor at alert temperature} < \frac{0.58\text{V}}{8\mu\text{A}}$$

$$= 34.4\text{k}\Omega < \text{Resistance of PTC thermistor at alert temperature} < 72.5\text{k}\Omega$$

Based on the above calculations and PTC thermistor specifications, this design detects over temperature abnormality when the temperature of PRF18BG471RB5RB (R1) is between approximately 71 °C and 90 °C (Fig. 4.4) and when the temperature of PRF18BD471RB5RB (R5) is between approximately 102 °C and 122 °C (Fig. 4.5).

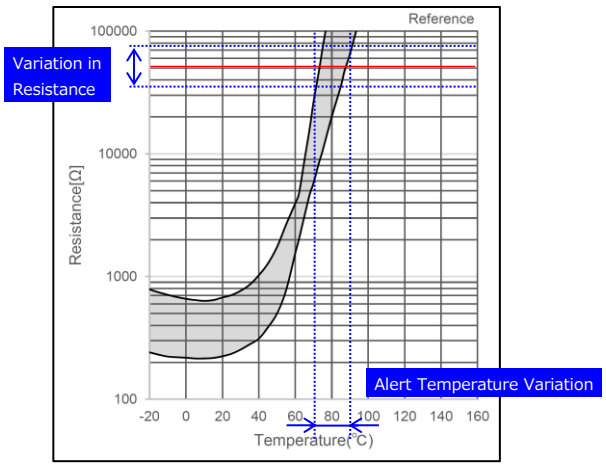



**Fig. 4.4 PRF18BG471RB5RB Resistance-Temperature Characteristic (Quoted from product specifications)**

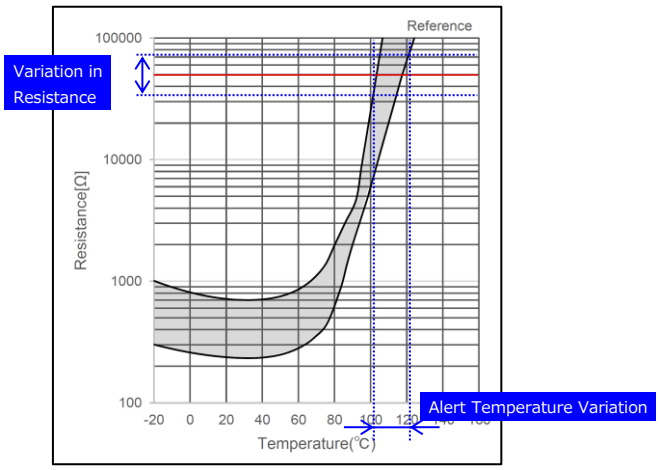



**Fig. 4.5 PRF18BD471RB5RB Resistance-Temperature Characteristic (Quoted from product specifications)**

### 4.1.4. LED Drive Circuit

LED drive circuit consists of a red LED (DS2) which is ON when FLAG signal is Low, a LED current limiting resistor R6, a high-side switch P-ch MOSFET (Q1) that drives the LED, a blue LED (DS1) which is ON when FLAG signal is High, a LED current limiting resistor R2, and a low-side switch N-ch MOSFET (Q2) that drives the LED.

In this circuit the power supply voltage is $V_{DD}$, forward current of LED is $I_F$, ON resistance of MOSFET is $R_{DS(ON)}$ and the value of current limiting resistor is R, thus the forward current $I_F$ flowing through LED is expressed by the following equation.

$$I_F = \frac{(V_{DD} - V_F)}{(R + R_{DS(ON)})} = \frac{5 - V_F}{R + R_{DS(ON)}}$$

The LED drive circuit of the red LED (DS2) is designed in order to have a forward current $I_F$ of about 3 mA.

When FLAG output of Thermoflagger™ is Low, $V_{GS}$ of MOSFET (Q2) becomes approximately -5 V, which turns on the MOSFET and the red LED lights up. At this time, the on-resistor $R_{DS(ON)}$ is approximately 1.4 Ω, and since $I_F$ = 3 mA, and $V_F$ = 2.2 V, thus R ≈ 930 Ω. Therefore, the current limiting resistor R6 is set to 1 kΩ.

The LED drive circuit of the blue LED (DS1) is also designed in order to have a forward current $I_F$ of about 3 mA.

When FLAG output of Thermoflagger™ is High, $V_{GS}$ of MOSFET (Q1) becomes approximately 5 V, which turns on the MOSFET and the blue LED lights up. At this time, the on-resistor $R_{DS(ON)}$ is approximately 3 Ω, and since $I_F$ = 3 mA, and $V_F$ = 3.2 V, thus R ≈ 597 Ω. Therefore, the current-limiting resistor R2 is set to 560 Ω.

### 4.1.5. Power Supply Input Circuit

In this case, power is supplied by connecting a USB charger to USB Type-C® receptable (J1). In order to supply the power (VDD) to this circuit via J1, this circuit must be set as sink side, thus CC1 and CC2 pins of J1 are pulled down with 5.1 kΩ (R3, R4) according to the USB Type-C® configuration.

### 4.1.6. Operation

[At room temperature]
The resistances of the two PTC thermistor R1, R5 are approximately 470 Ω. Since the constant current $I_{PTCO}$ from PTCO pin of the over temperature detection IC Thermoflagger™ is 10 μA, the voltage of PTCO pin $V_{PTCO}$ is 470 Ω x 2 x 10 μA = 9.4 mV and since it is lower than $V_{DET}$, the FLAG signal is High, and the blue LED (DS1) is ON.

[When the temperature of PTC thermistor (R1) is approximately 80 °C or more]
When the temperature of PTC thermistor (R1) rises to approximately 80 °C, its resistance increases to approximately 50 kΩ. Therefore, $V_{PTCO}$ becomes (50 kΩ + 470 Ω) x 10 μA ≈ 0.5 V, and since it is higher than $V_{DET}$, FLAG signal becomes Low, and the red LED (DS2) turns on.

[When the temperature of PTC thermistor (R5) is approximately 105 °C or more]
When the temperature of PTC thermistor (R5) rises to approximately 105 °C, its resistance increases to approximately 50 kΩ. Therefore, $V_{PTCO}$ becomes more than $V_{DET}$, thus FLAG signal becomes Low, and the red LED (DS2) turns on.

When two or more PTC thermistors are connected to PTCO pin, and if the temperature of one of the PTC thermistors increases then its resistance also increases, and if $V_{PTCO}$ becomes greater than or equal to $V_{DET}$ the over temperature detection IC Thermoflagger™ detects an over temperature abnormality. If more than one PTC thermistor is used, the combined resistance of all thermistors at normal temperature (i.e., below alert temperature) must be such that $V_{PTCO} < V_{DET}$ at normal temperature.

# 5. PCB Designs

## 5.1. Component Layout Example

Fig. 5.1 shows an example of component layout.

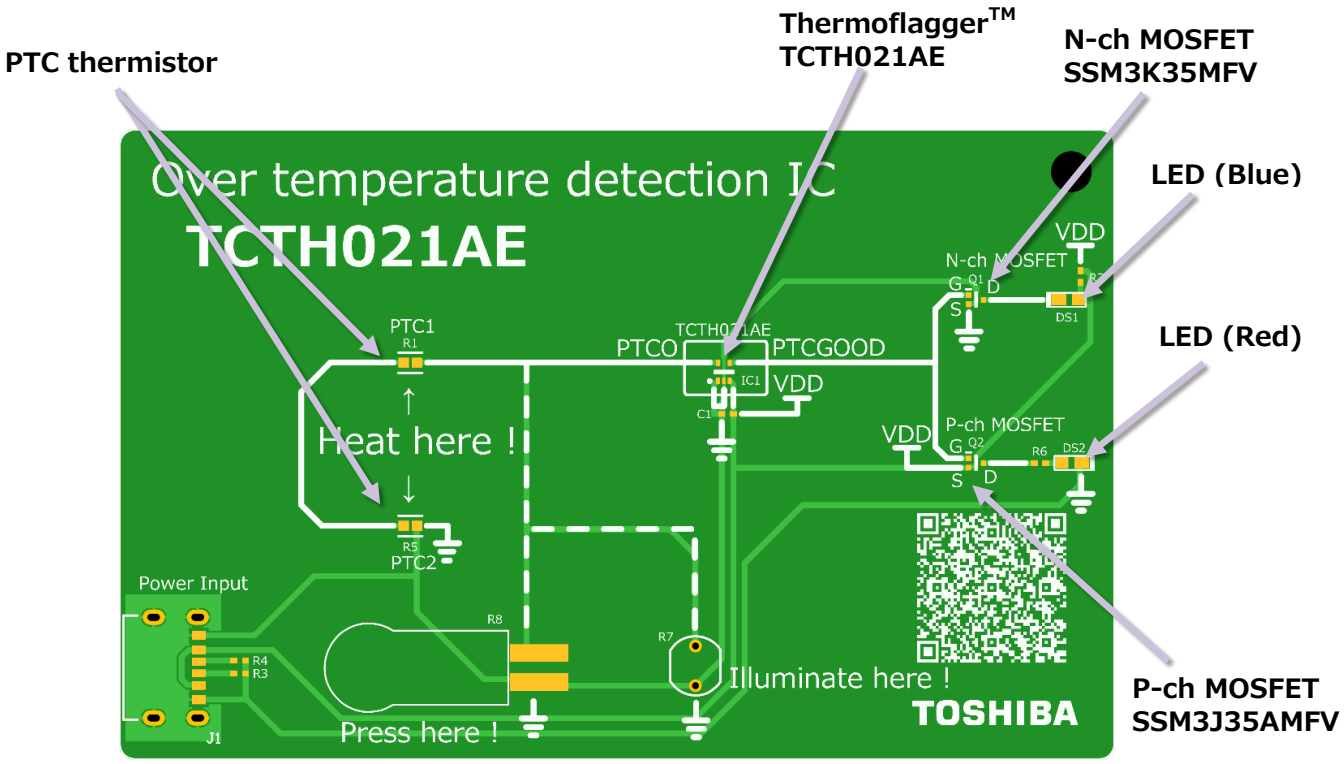



**Fig. 5.1 Layout of PCB Components**

# 6. Other Application Circuit Examples

Thermoflagger™ can be used with various sensors which utilize change in resistance for detection. The block diagrams of light detection circuit (using CdS sensor) and pressure detection circuit (using pressure sensor) are shown in Fig. 6.1 and Fig. 6.2 respectively.

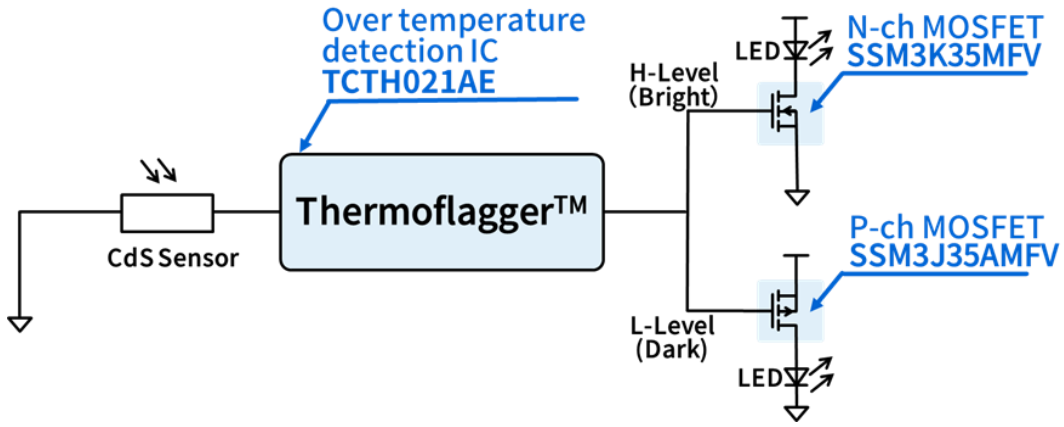



**Fig. 6.1 Block Diagram (Application Example for Light Detection Circuit)**

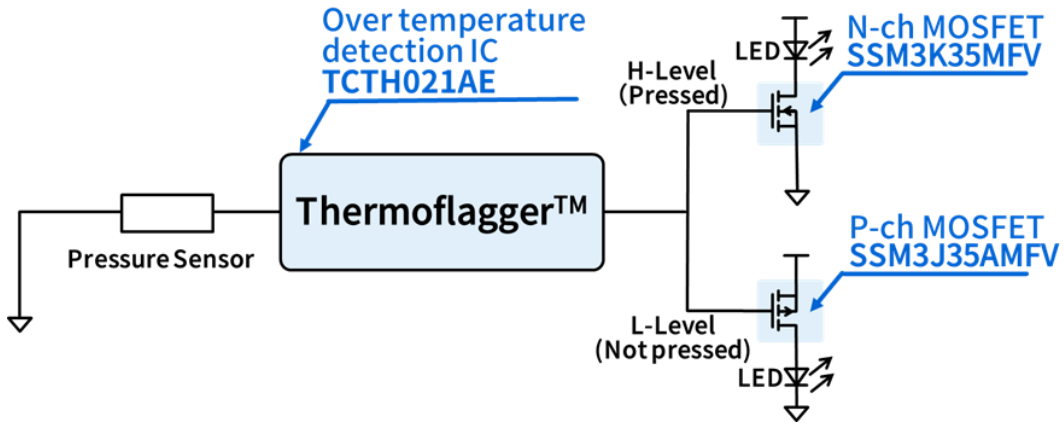



**Fig. 6.1 Block Diagram (Application Example for Pressure Detection Circuit)**

**Table 6.1 Circuit Specifications**

| Circuit Name | Thermoflagger™ | Onboard Sensor | Power Supply | Operation |
|---|---|---|---|---|
| AE2 | TCTH021AE (Push-pull type) | CdS sensor | USB Type-C® | ● Blue LED turns ON if the sensor's surrounding is bright<br>● Red LED turns ON if the sensor's surrounding is dark |
| AE3 | | Pressure sensor | | ● Blue LED turns ON if pressure sensor is pressed<br>● Red LED turns ON if pressure sensor is not pressed |

## 6.1. Light Detection Circuit (Using CdS Sensor)

When the sensor surrounding is dark:
CdS sensor has photoconductive section whose resistance changes according to the incoming light. The resistance increases if the incoming light decreases. When the sensor surrounding becomes dark, CdS sensor resistance increases to 50 kΩ, and since the constant current $I_{PTCO}$ flowing out of PTCO pin of the over temperature detection IC Thermoflagger™ is 10 μA, the voltage $V_{PTCO}$ at PTCO pin rises to 50 kΩ x 10 μA = 0.5 V. At this point, since $V_{PTCO}$ becomes more than $V_{DET}$, the FLAG signal becomes Low, and the red LED turns on.

When the sensor surrounding is bright:
When the incoming light increases, the resistance of CdS sensor decreases (less than 50 kΩ). Therefore, the $V_{PTCO}$ voltage becomes less than 0.5 V ($V_{DET}$), the FLAG signal becomes High, and the blue LED turns on.

## 6.2. Pressure Detection Circuit (Using Pressure Sensor)

When no pressure is applied to the sensor:
This sensor uses PTF (Poly Thick Film) to detect pressure. The resistance of PTF sensor increases when the applied pressure decreases. Therefore, when no pressure is applied to the sensor, its resistance becomes more than 50 kΩ, and since the constant current $I_{PTCO}$ flowing out of PTCO pin of the over temperature detection IC Thermoflagger™ is 10 μA, the voltage $V_{PTCO}$ at PTCO pin rises to 50 kΩ x 10 μA = 0.5 V. At this point, since $V_{PTCO}$ becomes more than $V_{DET}$, the FLAG signal becomes Low, and the red LED turns on.

When pressure is applied to the sensor:
When the applied pressure on the sensor increases, the resistance of PTF sensor decreases (less than 50 kΩ). Therefore, the $V_{PTCO}$ voltage becomes less than 0.5 V ($V_{DET}$), the FLAG signal becomes High, and the blue LED turns on.

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