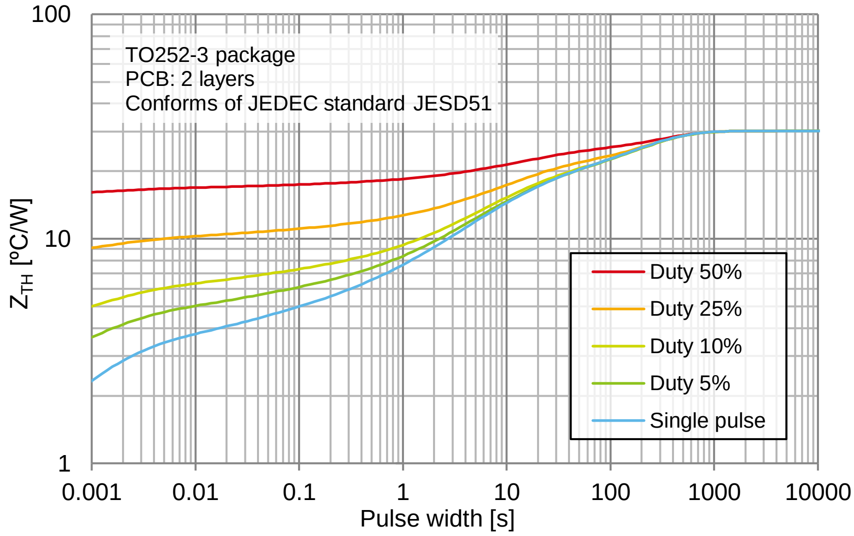
**Power Devices**

# Method for Calculating Junction Temperature from Transient Thermal Resistance Data

The value of thermal resistance can be used to estimate the junction temperature of power devices. However, the value of transient thermal resistance must be used if the power loss varies with time. This application note explains how to calculate the junction temperature from the transient thermal resistance data as a simplified estimate during the initial stage of thermal design.

## Transient thermal resistance data

Figure 1 shows an example of the transient thermal resistance data.




Graph descriptions

- The X-axis represents the pulse width, which is the time during which the power is applied to a device.
- The Y-axis represents the value of the transient thermal resistance.
- The multiple curves represent the transient thermal resistance data.
- The difference among the multiple curves indicates the difference in the duty ratios of the power application pulses. Figure 2 shows the waveforms showing the pulse widths and the duty ratios used for the measurement.

Figure 1. Example of the transient thermal resistance data

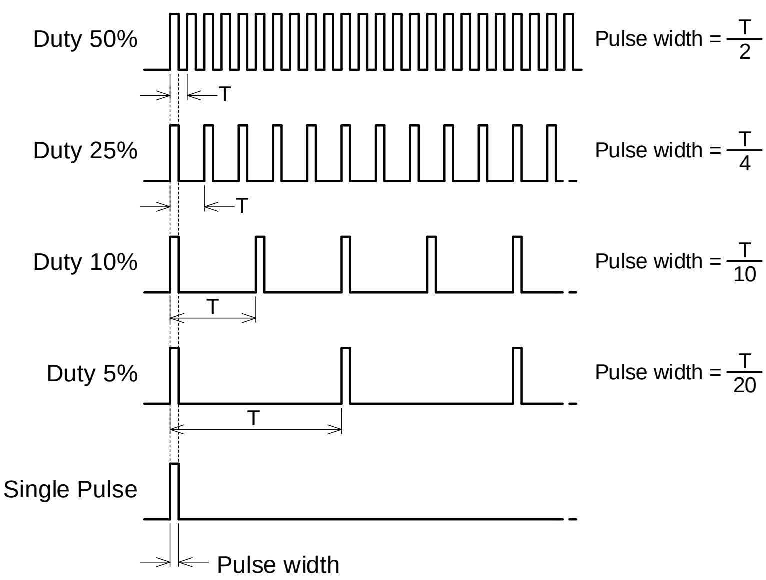



Figure 2. Waveforms showing the pulse widths and the duty ratios used for the measurement

## How to calculate the junction temperature

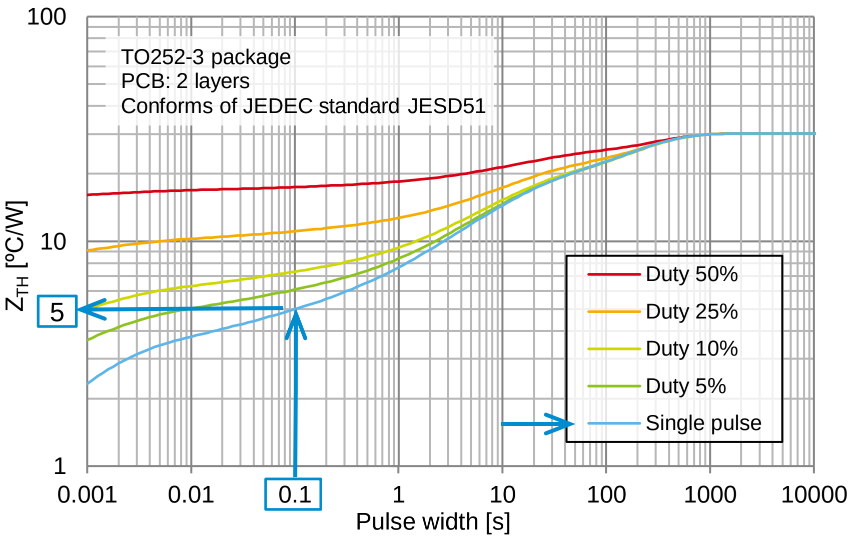
Step 1. Check the pulse width and the duty ratio of the power applied to the device and record the values.

Example: Pulse width $= 100\ [ms]$

Duty ratio $= Single\ Pulse$

Step 2. Using the values recorded above, read the value of the transient thermal resistance from the graph.

Example: Transient thermal resistance $Z_{TH} = 5\ [°C/W]$




Step 3. Calculate the junction temperature ($T_J$) using the following equation.

$$T_J = T_A + Z_{TH} \times P\ \ [°C]$$

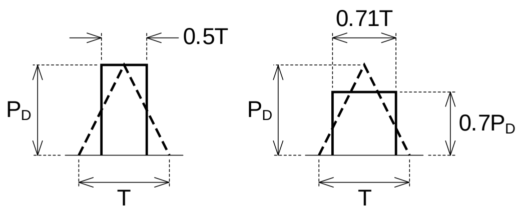
where

$T_A$: Ambient temperature [°C]

$Z_{TH}$ : Transient thermal resistance between junction and ambient environment [°C/W]

$P$ : Device power loss [W]

- Calculate or measure the total loss over time.
- References: Application Note "Calculating Power Loss from Measurement Waveform"
  Application Note "Calculation of Power Dissipation in Switching Circuit"
- The data of the transient thermal resistance is obtained by applying the power as a square wave. Therefore, if the actual power waveform is not square, it must be approximated by a square wave. For example, if the waveform to be converted is close to triangular, it can be approximated as shown in the figure below. The left shows an example where the waveform is approximated with the same peak value and the pulse width of 0.5 T. The right shows an example where the waveform is approximated with the peak value of 0.7 $P_D$ and the pulse width of 0.71 T. Both give the same area.



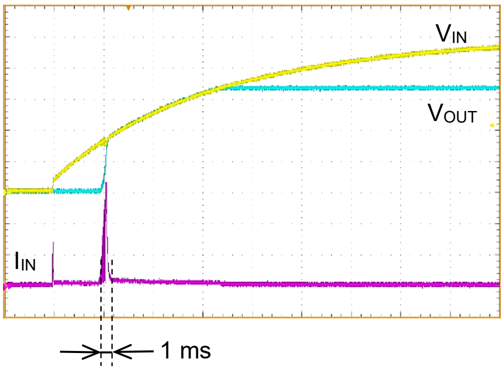

Triangular waveform approximated by a square wave

## Calculation example 1

For phenomena that occur only once in a short time (for example, inrush current flowing to charge capacitors during startup of the circuit), estimate the junction temperature using the curve of “Single pulse”.

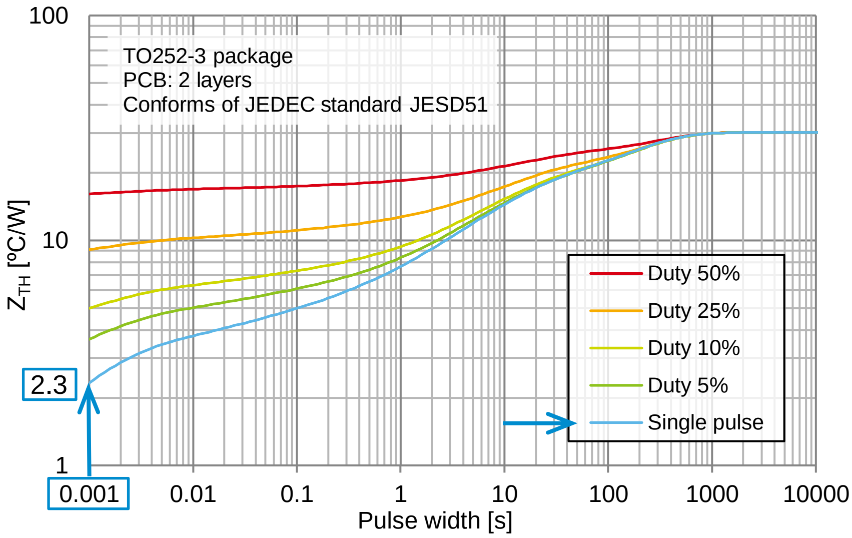
Step 1. Check the pulse width during which a high power occurs in a short time, and record the value.

Example: Pulse width $= 1\ [ms]$




Step 2. Using the values recorded above, read the value of the transient thermal resistance from the graph.

Example: Transient thermal resistance $Z_{TH} = 2.3\ [℃/W]$




Step 3. Calculate the junction temperature ($T_J$) using the following equation.

$$T_J = T_A + Z_{TH} \times P \quad [℃]$$

where

$T_A$: Ambient temperature $[℃]$

$Z_{TH}$ : Transient thermal resistance between junction and ambient environment $[℃/W]$

$P$ : Device power loss $[W]$

For example, if $T_A$ and $P$ are described with the following conditions, $T_J$ can be calculated with the following equation.

$T_A = 60\ [℃]$

$P = 10\ [W]$(calculated or measured)

$T_J = 60 + 2.3 \times 10 = 83\ [℃]$

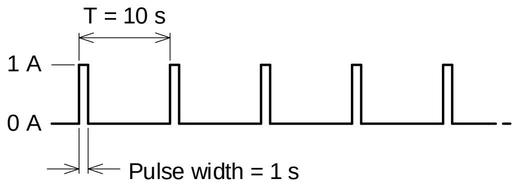
## Calculation example 2

If the circuit is operated intermittently between ON and OFF, estimate the junction temperature using the curves of “Duty xx%”.

Step 1. Check the pulse width and the duty ratio where the power loss occurs, and record the values.

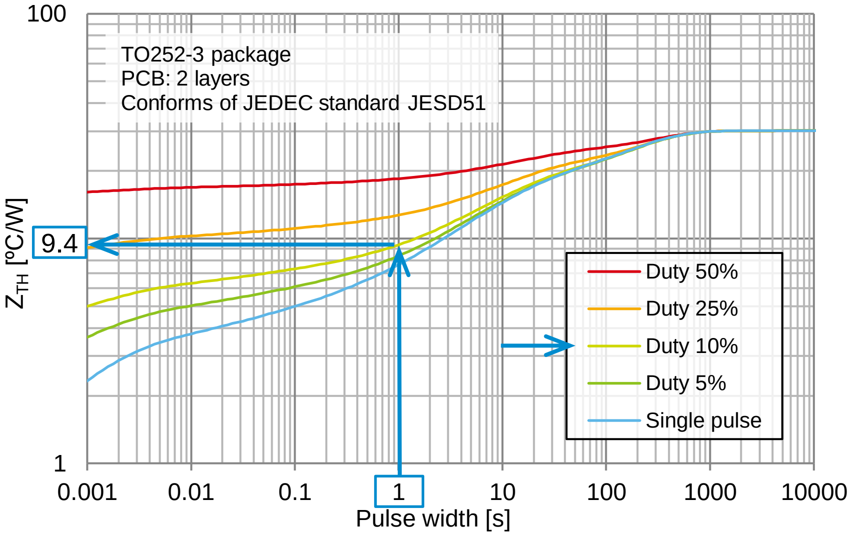
Example: Pulse width $= 1\ [s]$

Duty ratio $= 10\ [\%]$




Step 2. Using the values recorded above, read the value of the transient thermal resistance from the graph.

Example: Transient thermal resistance $Z_{TH} = 9.4\ [℃/W]$




Step 3. Calculate the junction temperature ($T_J$) using the following equation.

$$T_J = T_A + Z_{TH} \times P \quad [℃]$$

where

$T_A$: Ambient temperature $[℃]$

$Z_{TH}$ : Transient thermal resistance between junction and ambient environment $[ºC/W]$

$P$ : Device power loss $[W]$

For example, if $T_A$ and $P$ are described with the following conditions, $T_J$ can be calculated with the following equation.

$T_A = 60\ [℃]$

$P = 2\ [W]$(calculated or measured)

$T_J = 60 + 9.4 \times 2 = 78.8\ [℃]$

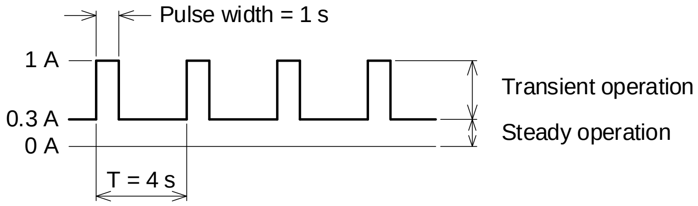
## Calculation example 3

If the circuit is operated intermittently with varying operation conditions, estimate the junction temperature with the values combining the steady and transient operations.

Step 1. Check the pulse width and the duty ratio where the power loss occurs, and record the values.

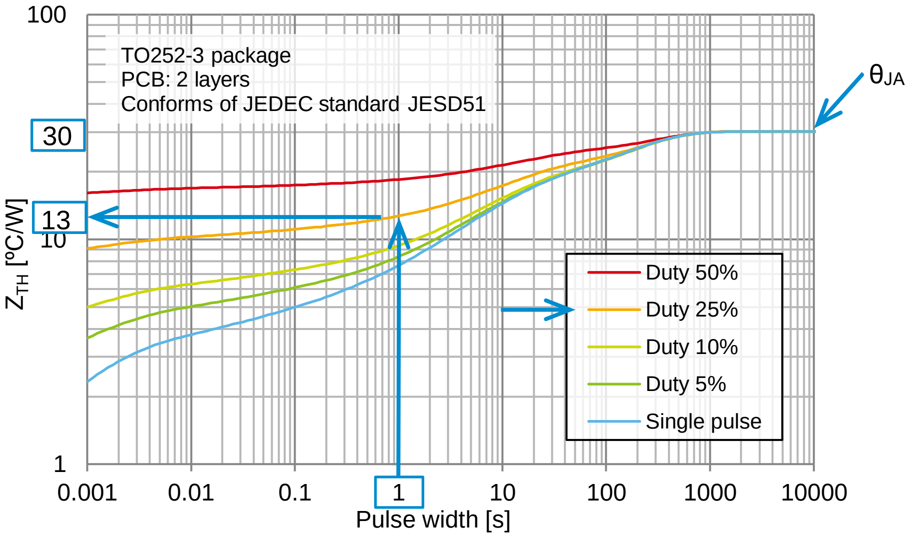
Example: Pulse width $= 1\ [s]$

Duty ratio $= 25\ [\%]$




Step 2. Using the values recorded above, read the value of the transient thermal resistance from the graph. Next, read the thermal resistance ($\theta_{JA}$) during the steady operation. The value of $\theta_{JA}$ is obtained from the right endpoint of the curve.

Example: Transient thermal resistance $Z_{TH} = 13\ [℃/W]$, thermal resistance during the steady operation $\theta_{JA} = 30\ [℃/W]$



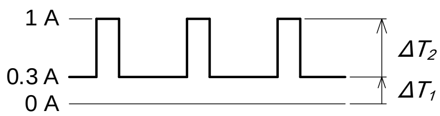

Step 3. Calculate the increase in temperature during the steady operation using the following equation.

$$\Delta T_1 = \theta_{JA} \times P_1\ \ [℃]$$

where

$\theta_{JA}$ : Thermal resistance between junction and ambient atmosphere $[℃/W]$

$P_1$ : Device during the steady operation power loss $[W]$




Range of temperature calculation

Next, calculate the increase in temperature during the transient operation.

$$\Delta T_2 = Z_{TH} \times (P_2 - P_1)\ \ [℃]$$

where

$Z_{TH}$ : Transient thermal resistance between junction and ambient environment $[℃/W]$

$P_2$ : Device during the transient operation power loss $[W]$

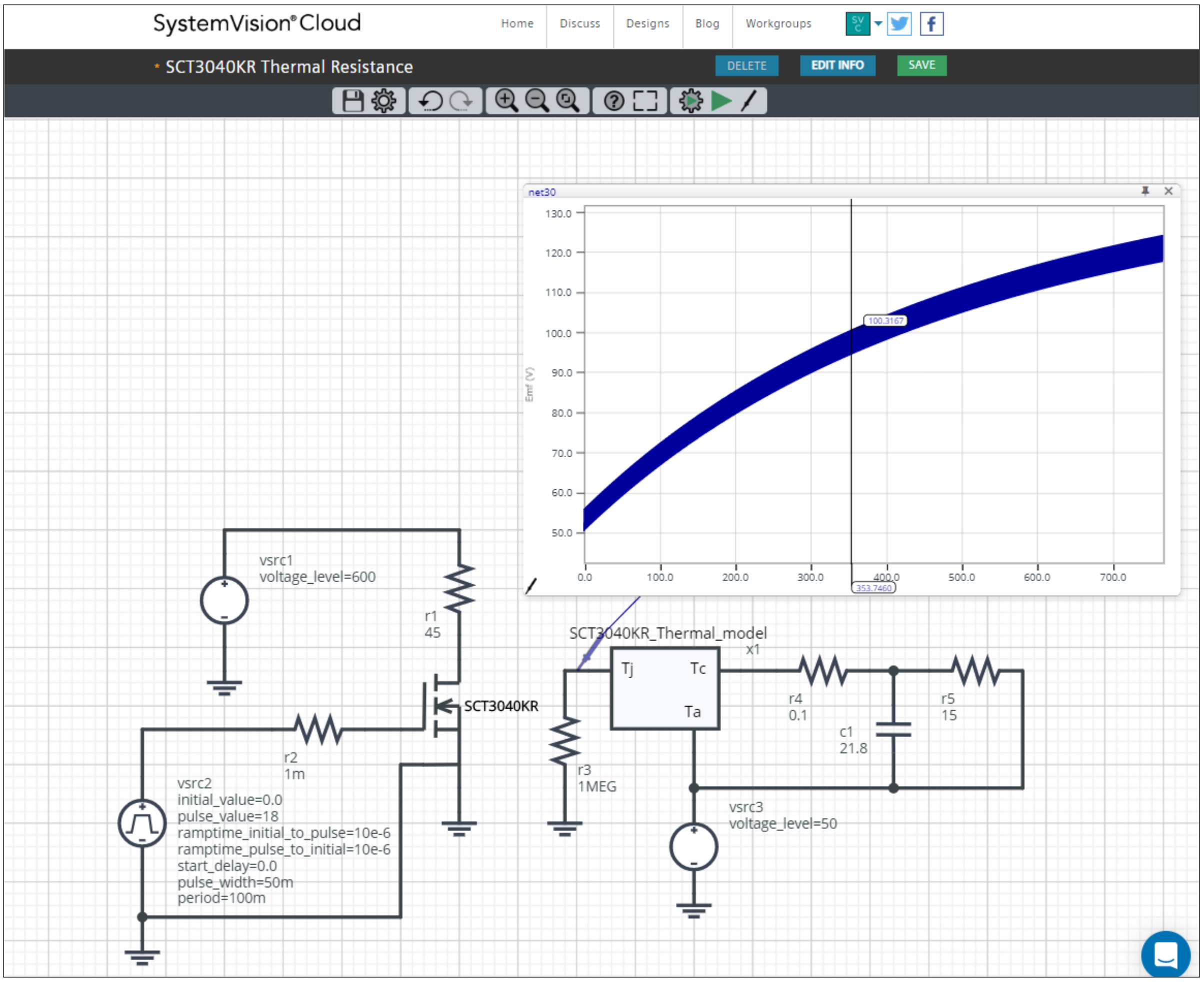
Calculate $T_J$ with the following equation.

$$T_J = T_A + \Delta T_1 + \Delta T_2\ \ [℃]$$

$T_A$: Ambient temperature $[℃]$

## Calculation example 4

If the variation in the power loss is complicated, the junction temperature may be calculated with a simulation using a thermal model. For more details, refer to Application Note "How to Use Thermal Models".



Example of simulation using thermal model

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