Application Note

What is a Power MOSFET/IGBT?

Calculation of Average Loss and Junction Temperature, T_J

Contents

1. Description

This document describes the calculation of the power MOSFET/IGBT average loss and junction temperature, T_J.

2. Calculation of Average Loss

This section describes the calculation of the average loss when the actual waveform is converted to an approximate waveform. Calculate the total average loss by summing the average losses for each block.

Figure 2-1 shows an example of an approximate waveform.

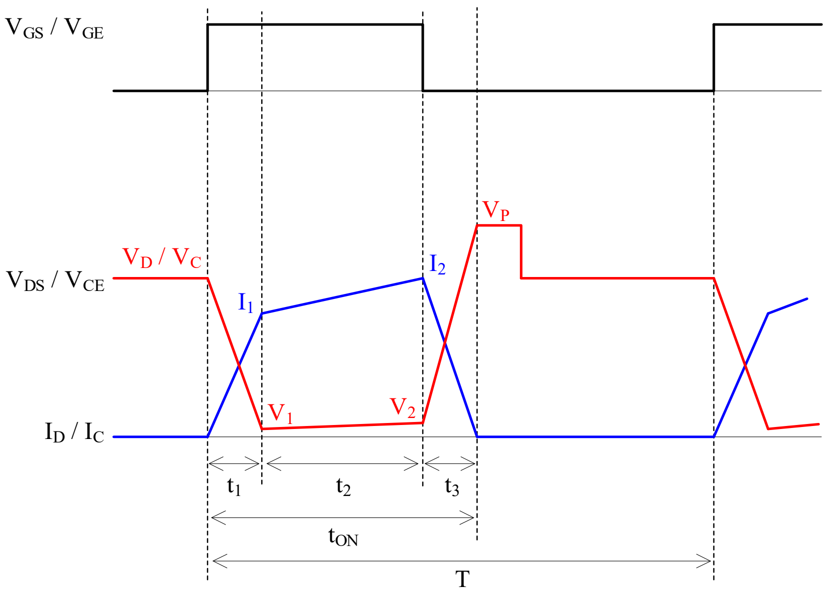

Figure 2-1. Approximate Waveform Example

Where:
t_1 is switching loss time at turn-on,
t_2 is switching loss time at saturation,
t_3 is switching loss time at turn-off,
t_{ON} is on-time, and
T is period.

The average loss, P_1, for the t_1 period is calculated by the following equation.

$$P_1 = \frac{t_1}{6T}(V_D I_1 + 2V_1 I_1)$$

The average loss, P_2, for the t_2 period is calculated by the following equation.

$$P_2 = \frac{t_2}{6T}(2V_1 I_1 + V_1 I_2 + 2V_2 I_2 + V_2 I_1)$$

The average loss, P_3, for the t_3 period is calculated by the following equation.

$$P_3 = \frac{t_3}{6T}(V_P I_2 + 2V_2 I_2)$$

Thus, the total average loss, P_{ON}, is calculated by the following equation.

$$P_{ON} = P_1 + P_2 + P_3$$

3. Calculation of Junction Temperature, T_J

3.1. Calculation from Case Temperature

Junction temperature, T_J is estimated from the measured values of loss and case temperature, T_C during the power MOSFET/IGBT operation and the thermal resistance, $R_{\theta JC}$ described in the electrical characteristics of the data sheet.

Figure 3-1 shows a conceptual diagram of thermal resistance, $R_{\theta JC}$. The specified position of temperature depends on the package and product.

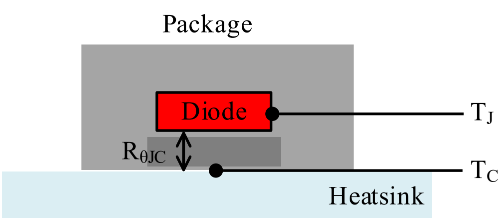

Figure 3-1. Conceptual Diagram of Thermal Resistance, $R_{\theta JC}$ (Case Temperature)

The symbols in Figure 3-1 represent as follows:

T_J is junction temperature,
T_C is case temperature, and
$R_{\theta JC}$ is thermal resistance between junction and case.

T_J is calculated by the following equations.

$$T_J = P \times R_{\theta JC} + T_C$$

Where:
P is the loss of the power MOSFET/IGBT (W),
$R_{\theta JC}$ is thermal resistance between junction and case (°C/W), and
T_C is case temperature (°C).

As an example, when P = 0.6 W, $R_{\theta JC}$ = 20 ° C/W, and T_C = 80 ° C, T_J is calculated by the following equation.

$$T_J = 0.6 \times 20 + 80 = 92\ (°C)$$

3.2. Calculation from Transient Thermal Resistance Characteristics

T_J when power is applied instantaneously is estimated from the transient thermal resistance data. T_J is calculated by the following equation.

$$T_J = P \times r_{\theta JC} + T_C$$

Where:
P is the loss of the power MOSFET/IGBT (W),
$r_{\theta JC}$ is transient thermal resistance between junction and case temperature (°C/W), and
T_C is case temperature (°C).

Figure 3-2 shows the transient thermal resistance characteristics example. For example, when a single square pulse of 100 ms is applied, $r_{\theta JC}$ is 2 °C/W.

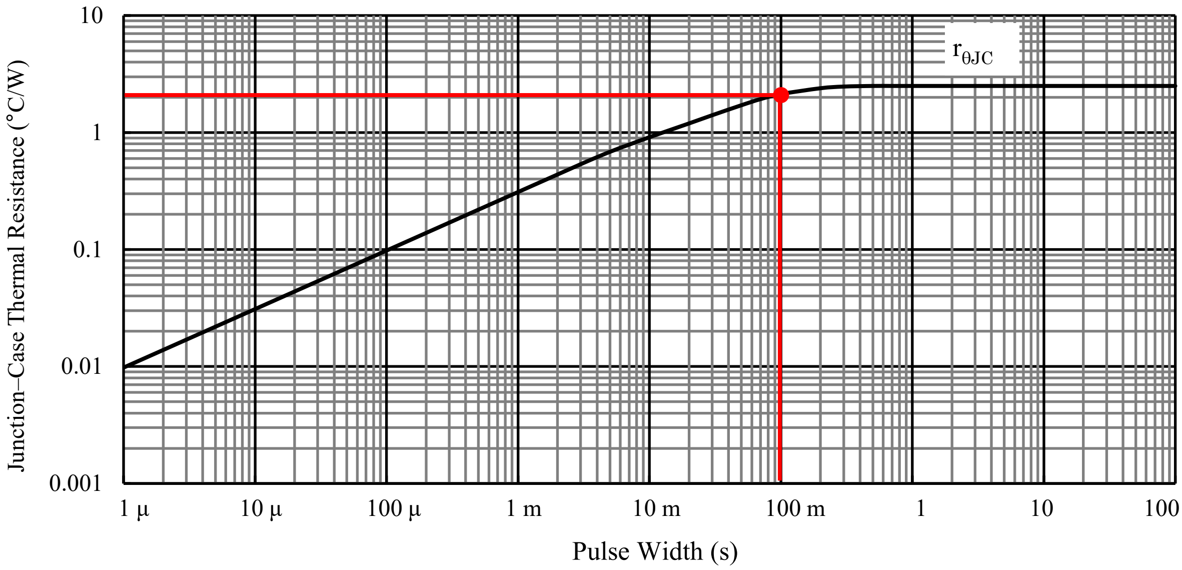

Figure 3-2. Transient Thermal Resistance Characteristics Example

For example, when P = 0.6 W, $r_{\theta JC}$ = 2 °C/W, and T_C = 100 °C, T_J is calculated by the following equation.

$$T_J = 0.6 \times 2 + 100 = 101.2\ (°C)$$

3.3. Calculation Using Superposition Theorem

This section shows the calculation of the junction temperature, T_J, when a regular square wave power loss occurs in the power MOSFET/IGBT and the junction temperature, T_J, when an irregular square wave power loss occurs in the power MOSFET/IGBT. For such power loss waveforms, it is easy and effective to read the thermal resistance in each period from the transient thermal resistance characteristic graph in the data sheet and use the superposition theorem.

3.3.1. Continuous Pulse

(A) in Figure 3-3 shows the calculation of the junction temperature, T_J, when a regular square wave power loss occurs in the power MOSFET/IGBT. To easily calculate T_J, assume that power losses for two cycles occur in the average power loss over the entire period.

As shown in (B) and (C) in Figure 3-3, T_J is calculated by approximating the power loss and using the superposition theorem.

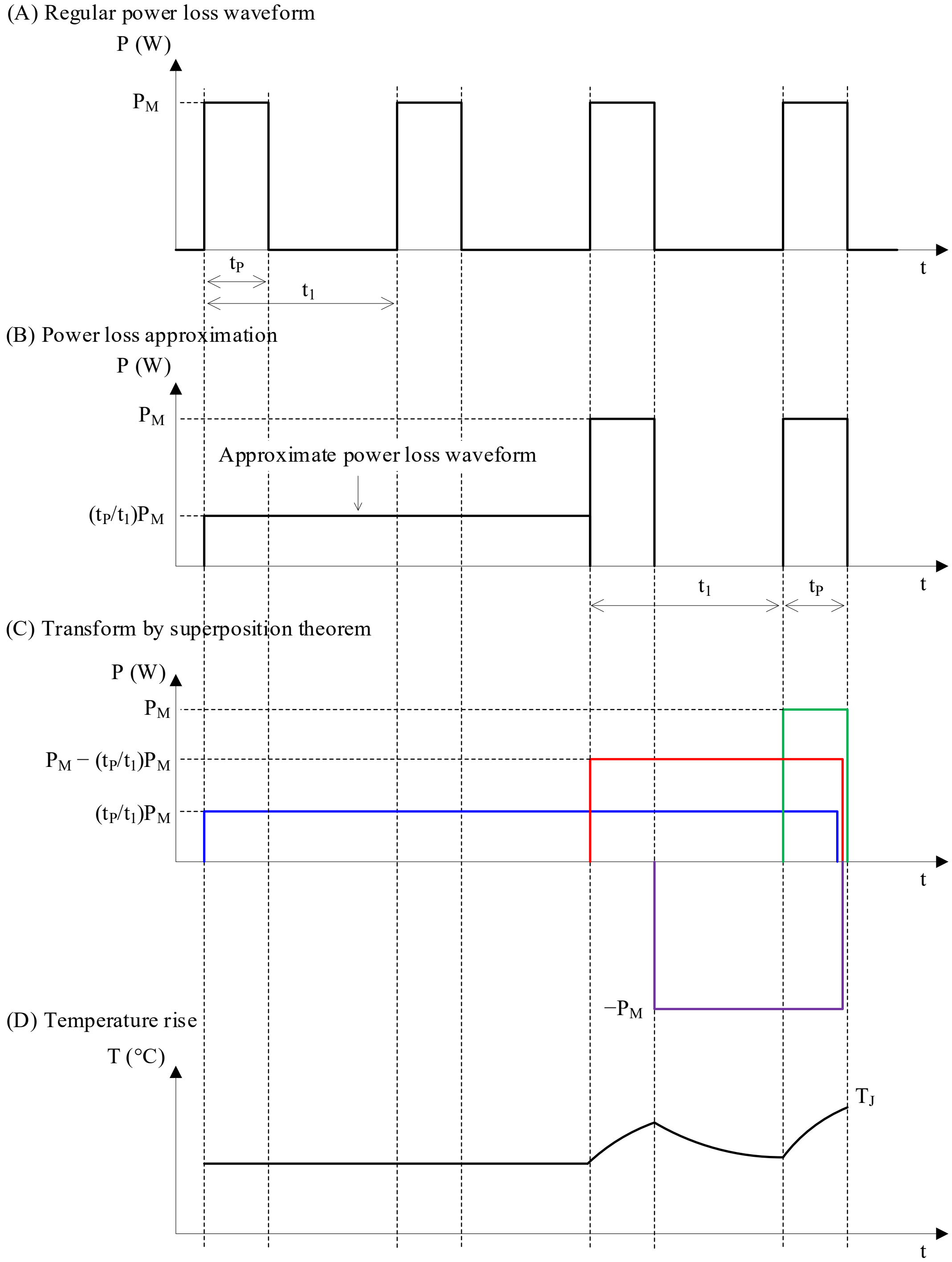

Figure 3-3. Superposition Theorem

Next, the junction temperature is calculated for each block in (C) in Figure 3-3.

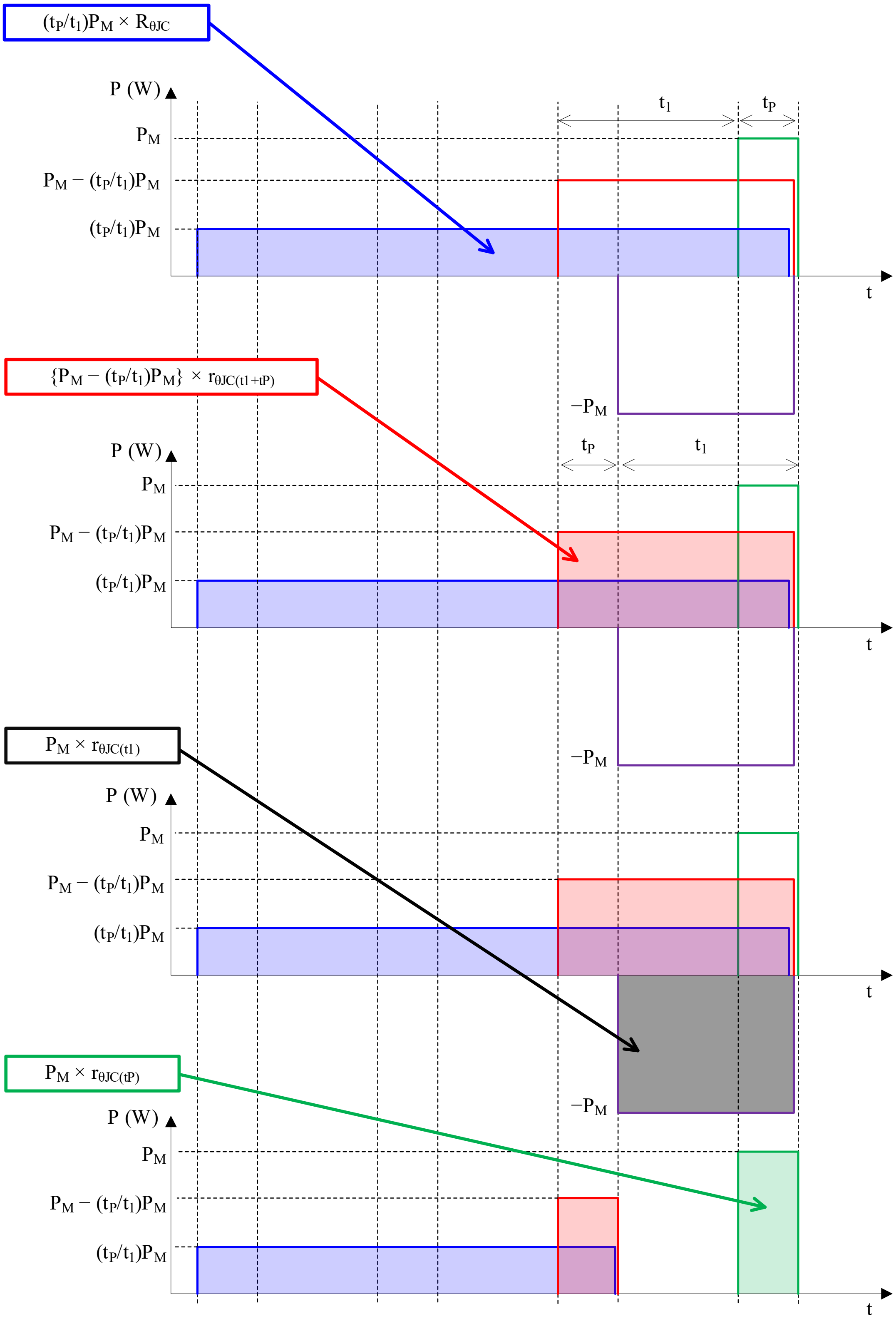

Figure 3-4. T_J of Each Block

Thus, T_J when using the superposition theorem is calculated by the following equation.

$$T_J = T_C + P_M \times \left\{ \left(\frac{t_P}{t_1} \right) \times R_{\theta JC} + \left(1 - \frac{t_P}{t_1} \right) \times r_{\theta JC(t1+tP)} - r_{\theta JC(t1)} + r_{\theta JC(tP)} \right\}$$

Where:
T_C is case temperature (°C),
P_M is average power loss (W),
t1 is period (s),
t_P is pulse width (s),
$R_{\theta JC}$ is the steady-state thermal resistance between junction and case temperature (°C/W),
$r_{\theta JC(t1+tP)}$ is the thermal resistance between junction and case temperature in the period, t_1+t_P (°C/W),
$r_{\theta JC(t1)}$ is the thermal resistance between junction and case temperature in the period, t_1 (°C/W), and
$r_{\theta JC(tP)}$ is the thermal resistance between junction and case temperature in the period, t_P (°C/W).

3.3.2. Irregular Pulse

(A) in Figure 3-5 shows the calculation of the junction temperature, T_J, when an irregular square wave power loss occurs in the power MOSFET/IGBT. As shown in (B) in Figure 3-5, T_J for each block is calculated by using the superposition theorem.

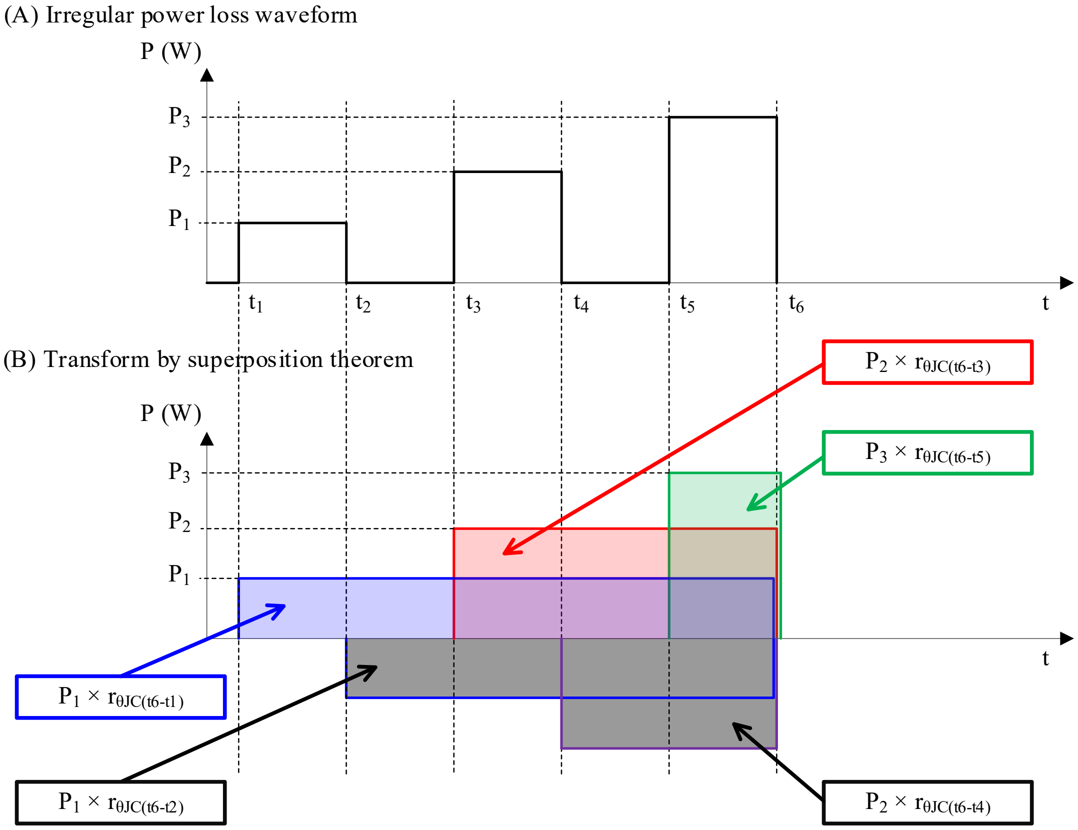

Figure 3-5. Superposition Theorem

Thus, T_J when using the superposition theorem is calculated by the following equation.

$$T_J = T_C + P_1\{r_{\theta JC(t6-t1)} - r_{\theta JC(t6-t2)}\} + P_2\{r_{\theta JC(t6-t3)} - r_{\theta JC(t6-t4)}\} + P_3\{r_{\theta JC(t6-t5)}\}$$

Where:
T_C is case temperature (°C),
P_1 to P_3 is power loss for each pulse (W),
$r_{\theta JC(t6-t1)}$ is the thermal resistance between junction and case temperature in the period, t_6-t_1 (°C/W),
$r_{\theta JC(t6-t2)}$ is the thermal resistance between junction and case temperature in the period, t_6-t_2 (°C/W),
$r_{\theta JC(t6-t3)}$ is the thermal resistance between junction and case temperature in the period, t_6-t_3 (°C/W),
$r_{\theta JC(t6-t4)}$ is the thermal resistance between junction and case temperature in the period, t_6-t_4 (°C/W), and
$r_{\theta JC(t6-t5)}$ is the thermal resistance between junction and case temperature in the period, t_6-t_5 (°C/W).

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