Pulse power evaluation using equivalent rectangular waves

§0 Abstract

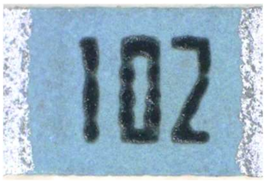
When applying pulse power higher than the continuous power rating to a resistor, it is important to properly evaluate the pulse power capability of the resistor. The evaluation method by converting the waveform of the pulse power into an equivalent rectangular wave is widely used in electronic device development. This technical note explains the benefit of this evaluation, the procedure for converting waveforms and precautions.

§1 Evaluation of pulse power capability

1.1 Failure due to pulse power

Pulse power exceeding the continuous power rating can be applied to a resistor as long as it is within the range of the pulse power capability. However, there has been an increase in the number of failures that are suspected to be caused by excessive pulse power being applied to resistors, which have been miniaturized due to the downsizing of electronic devices and the high-density mounting on printed-wiring boards (PWBs). Overloading duration on a failed resistor can be assumed from its failure condition (Table 1). The color of the whole resistor body changes when a resistor fails because of long-term overload. On the other hand, only a part of the body is usually damaged when a resistor fails because of short-term overload such as pulse power. In order to prevent failures due to pulse power, it is important to properly evaluate the pulse power capability of a resistor. (For details of evaluation on pulse power capability, refer to our technical note “Pulse power capabilities of resistor”.)

Table 1 Failure modes of resistors

Appearance of the resistor	Appearance of the damaged part
	Long-term overload 
	Pulse power overload 

1.2 Conversion of pulse waveform

There are various types of pulse waveforms, such as rectangular waves, CR discharge waves, and sinusoidal waves. When evaluating pulse power capability against these pulses, the waveform of the applied pulse should be converted into a rectangular wave with the same peak voltage or current and the equivalent power (an equivalent rectangular wave). Figure 1 shows the conversion of a typical waveform into equivalent power rectangular wave. This evaluation method is described in "JEITA RCR-2121B Safety application guide for fixed resistors for use in electronic equipment" and is widely used.

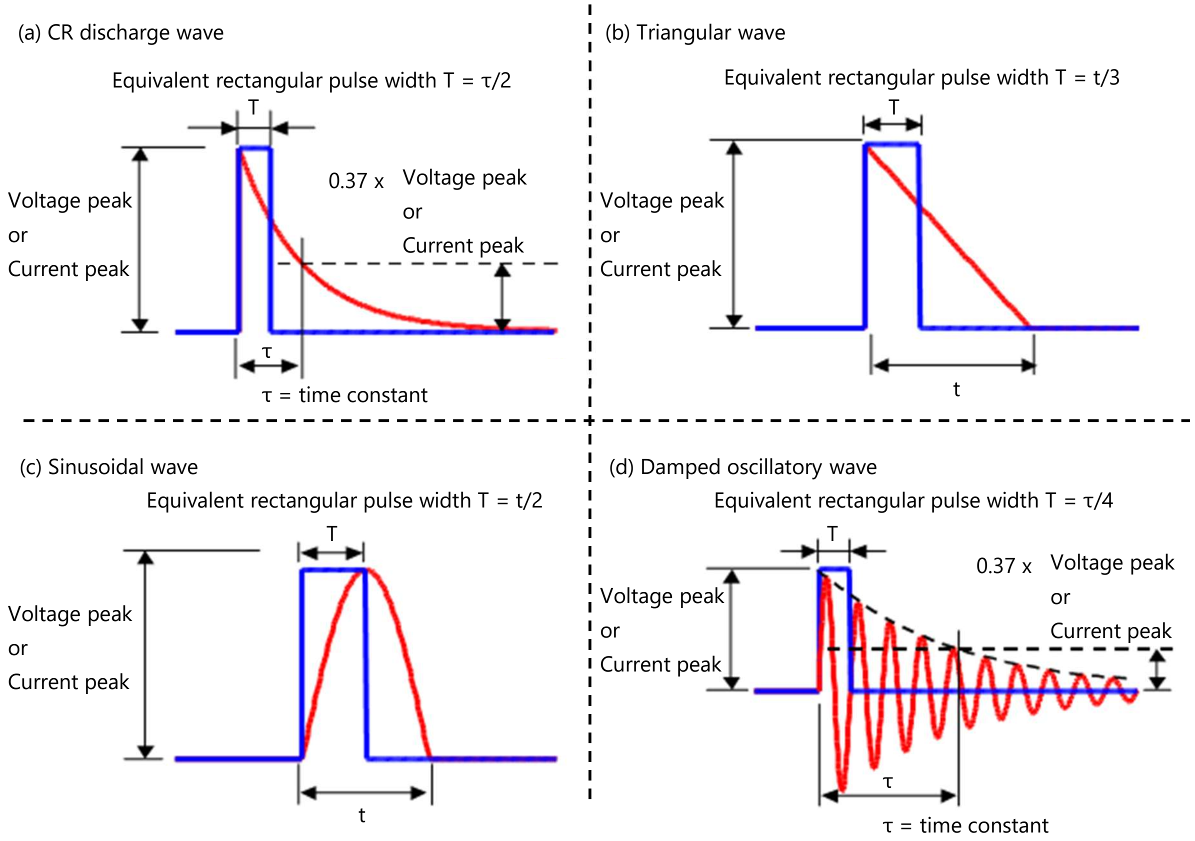


Fig. 1 Conversions to equivalent rectangular wave

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Some pulse waveforms are complex, as shown by the blue line in Fig. 2(a). The conversion method for this waveform is described below. First, divide the waveform into intervals and linearly approximate each of them (Fig. 2 (b)).

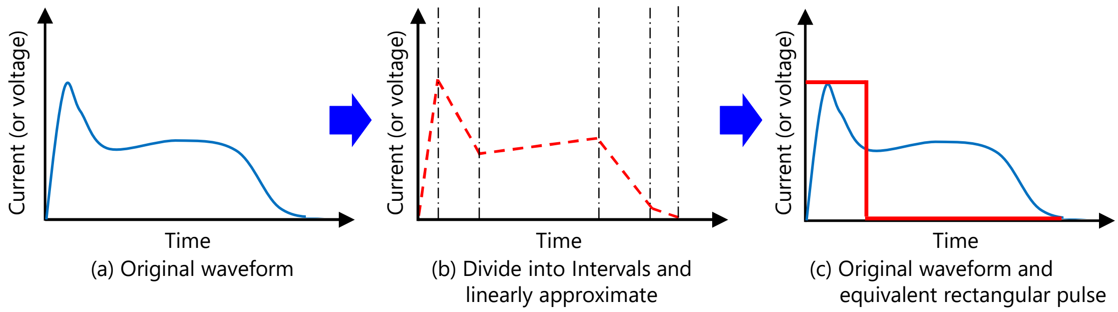
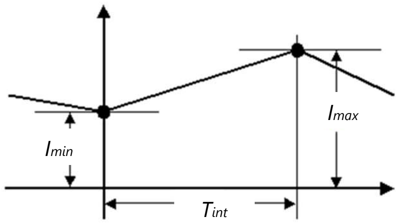


Fig. 2 Conversion procedure for the complex pulse waveform

Next, the energy of each linearly approximated interval is determined using equation (1). The meaning of each variable is described in Fig. 3.

$$\int_0^{T_{int}} R \cdot i(t)^2 \cdot dt = R \cdot \frac{T_{int}}{3} \cdot (I_{max}^2 + I_{max} \cdot I_{min} + I_{min}^2) \qquad (1)$$



R : Resistance (Ω)
I_{min} : Minimum current value of T_{int}
I_{max} : Maximum current value of T_{int}
T_{int} : Interval

Fig. 3 Calculation of energy by interval integration (with current)

Next, all the calculated energy levels of the respective intervals are added up to obtain the total energy. Finally, the peak power is derived from the current (or voltage) waveform of Fig. 2 (a), and the energy of all intervals is divided by the peak power to obtain the pulse width. The equivalent rectangular wave is determined based on the pulse width and the peak current (or voltage). Fig. 2 (c) shows the original waveform and the equivalent rectangular waveform. The pulse power capability is evaluated using this equivalent rectangular wave and the following single-pulse limiting electric power curve (Fig.4).

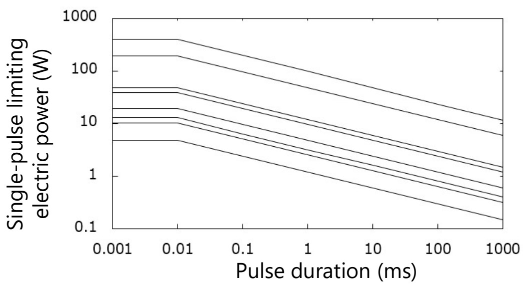


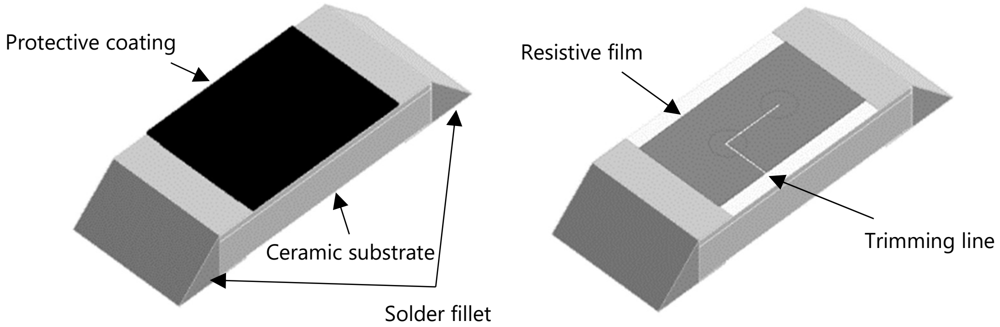
Fig. 4 Single-pulse limiting electric power curve

The following section explains the validity of the evaluation using equivalent rectangular waves.

§2 Temperature rise due to pulse power

The reason why the waveform should be converted into an equivalent rectangular wave, instead of another wave, for the evaluation of pulse power capability is that it gives the greatest temperature rise. In this section, the difference in temperature rise due to waveform is explained with simulation results. Figure 5 (a) shows the model that is used for the simulation, and Fig. 5 (b) shows its internal structure. Figure 6 shows the CR discharge wave, sinusoidal wave and equivalent rectangular wave of the applied pulse power. The simulation conditions are as follows:

Resistor	: Thick film chip resistor
Size	: RR3216M (1206 inch size)
Model	: Resistors and solder fillets
Trimming line: As shown in Fig. 5 (b)	
Pulse waveforms	: CR discharge wave, sinusoidal wave, equivalent rectangular wave



(a) Appearance (b) Internal structure

Fig. 5 Simulation model

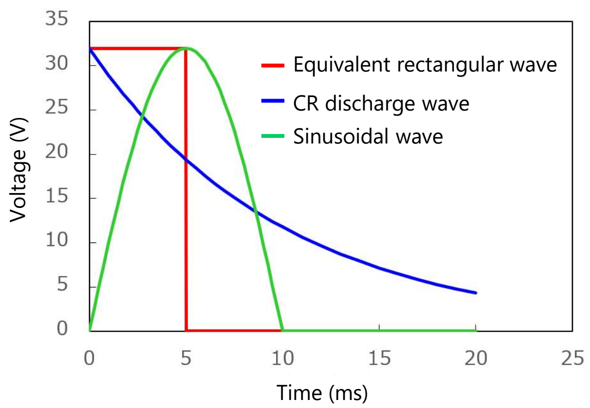


Fig. 6 Pulse waveforms to be applied

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Figure 7 shows the simulation result of the temperature distribution inside the resistor when an equivalent rectangular wave is applied. Red indicates areas with the highest temperature, and the surrounding orange indicates areas with relatively high temperature. As demonstrated by the simulation, when pulse power is applied, intense heat generation occurs in limited parts of the resistor. And the damage is observed only where the heat is concentrated. Therefore, when a failed resistor resembles the one on the bottom of Table 1, it can be assumed that excessive pulse power was applied to the resistor.

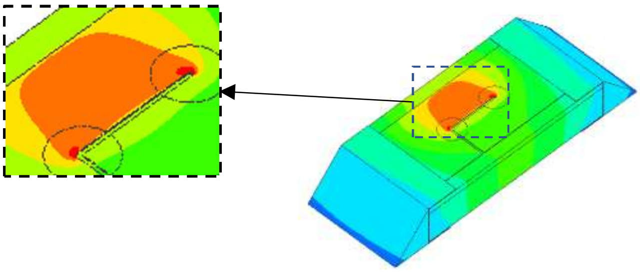

Fig. 7 Simulation result of the temperature distribution inside the resistor

Figure 8 shows the variation of the maximum temperature with time. Though the same energy is applied, the shape of the temperature rise curve and the maximum achieving temperature vary depending on the waveform. Since the maximum voltage is applied only for a short time with a CR discharge wave or sinusoidal wave, the generation of maximum heat only lasts for a short time. On the other hand, with an equivalent rectangular wave, since the maximum voltage is applied for a longer time, the generation of maximum heat also lasts longer. Thus, the maximum achieving temperature of an equivalent rectangular wave reaches higher than that of a CR discharge wave or a sinusoidal wave. The equivalent rectangular wave gives the highest achieving temperature among the various waveforms. Therefore, the applicable maximum pulse power can be determined by using the equivalent rectangular wave and single-pulse limiting electric power curve. Note, however, evaluation using the original waveform is recommended for practical use since the condition using the equivalent rectangular wave may be excessively severe.

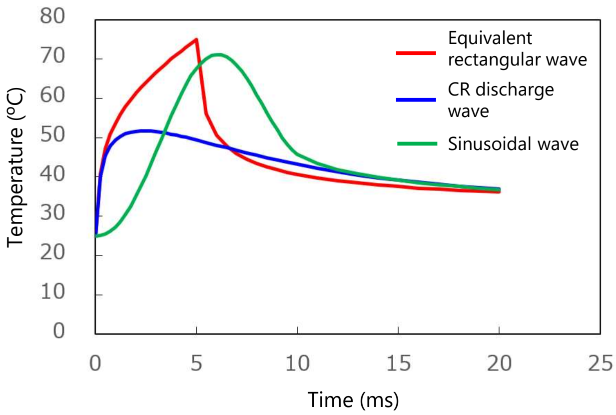

Fig. 8 Simulation result of the maximum temperature by waveforms

§3 Single-pulse limiting electric power curve and equivalent energy conversion

Applicable pulse power can be doubled if the pulse width is halved for some resistors, which means that the energy conversion approach is effective for those. However, since the majority of resistors generate heat locally and the failure mode differs depending on the applied pulse waveform, accurate evaluation based on test results is required, since their pulse power capability is not based on equivalent energy conversion. For reference, Fig. 9 shows a single-pulse limiting electric power curve and a 1-second based equivalent energy line for a certain product. It can be seen that the power that can be applied based on single-pulse limiting electric power curve is significantly lower than that based on the equivalent energy line in the short pulse duration range. Therefore, it is essential to use the single-pulse limiting electric power curve to evaluate the pulse power capability.

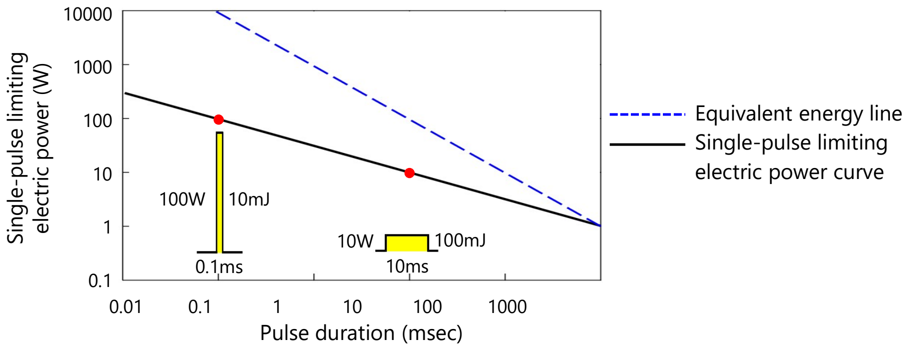

Fig. 9 Single-pulse limiting electric power curve and equivalent energy line

§4 Conclusion

Pulse power exceeding the continuous power rating can be applied to a resistor as long as it is within the range of pulse power capability. In that case, it is important to make a proper evaluation by using an equivalent rectangular wave and the single-pulse limiting electric power curve to prevent failures. The condition using an equivalent rectangular wave is more severe than that using the original waveform, but the applicable maximum pulse power can be determined easily. KOA provides various single-pulse limiting electric power curves for each model to show pulse power capability. Please make sure to check with actual equipment before use.

Our support is available for selecting resistors for the cases where pulse power is repeatedly applied, where evaluation cannot be performed under conditions close to actual pulse power application, or where resistance evaluation is difficult due to a complex pulse waveform. Please contact us with waveform and circuit information.