TECHNICAL NOTE

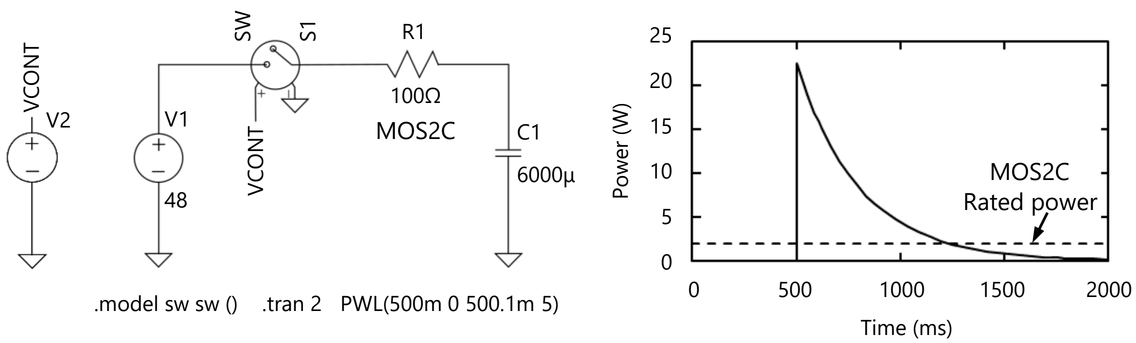
Pulse Power Capabilities of Resistor

§0 Abstract

A resistor can sometimes allow application of power in excess of the power rating for a short duration. However, if a pulse power above the capability acts on the resistor, troubles, such as changed resistance value or disconnection, can occur. Recently, there are increasing cases of failure resulting from improper evaluation of pulse power capability in the selection of the resistor. In this Technical Note, explanations are given of the cases of failure due to the application of pulse power as well as the evaluation and selection of pulse power capabilities of resistors.

§1 Cases of failure resulting from pulse power

The electric power applied in excess of the power rating of a resistor in a short duration is called pulse power. An example of pulse power application is explained using a simulation (Fig. 1) of power applied on a resistor in a pre-charge circuit. A current limiting resistor (R1) is connected between a switch (S1) and a capacitor (C1). R1 plays the role of preventing the breakdown of the circuit from the flow of excess current when S1 turns on. The time of application of power to R1 is the same as the charging time of C1.



(a) Simulation model

(b) R1 Power waveform

Fig.1 Simulation of pre-charge circuit

With the maximum power applied to R1 being over 23 W as shown in Fig. 1 (b), the resistor to be used as R1 under ordinary circumstances must be a resistor which has a power rating of 23W or over. However, the resistor often has a certain degree of capability to withstand power beyond the power rating for a short duration, and therefore R1 to be used may be a resistor of 23 W or below of rated power, provided the pulse power capability is evaluated properly. In the case of Fig. 1, a metal oxide film resistor (MOS2C) of 2W rated power can be used.
Explained in the following pages is the relationship between the types and sizes of resistors and pulse power capability.

§2 Relationship between Types of Resistors and Pulse Power Capability

The resistors come in various types, depending on the shape, resistive element , and other properties. The capability to withstand pulse power also varies with the type and size of resistors. Let us consider the cases with ceramic resistors (HPC 1/2C) and special power type film resistors (SPR 1C). HPC 1/2C and SPR 1C are similar size. The rated powers of these resistors are 1/2W and 1W, respectively, and that of SPR 1C is higher. However, comparison of one-pulse limiting electric power (Fig. 2), which are the plots of limit values of pulse power that can be applied at one time to the resistors, show higher pulse power capability of HPC 1/2C. Details of one-pulse limiting electric power will be explained in §3.

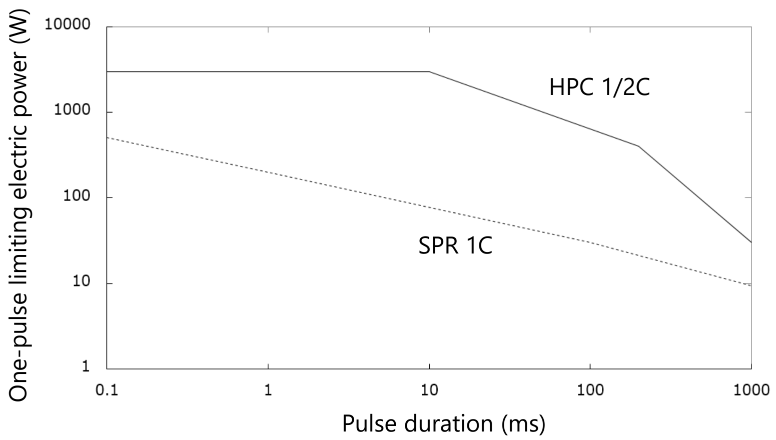


Fig.2 One-pulse limiting electric power diagram of HPC 1/2C and SPR 1C

Generally, the pulse power capabilities depending on the types of resistors show relationships as shown in Fig. 3. For the same type of resistor, the larger the size, the greater the pulse power capability. Since the pulse power capability varies with the type and size of resistors, it is necessary to carefully select resistors that are used in circuitry susceptible to pulse events.

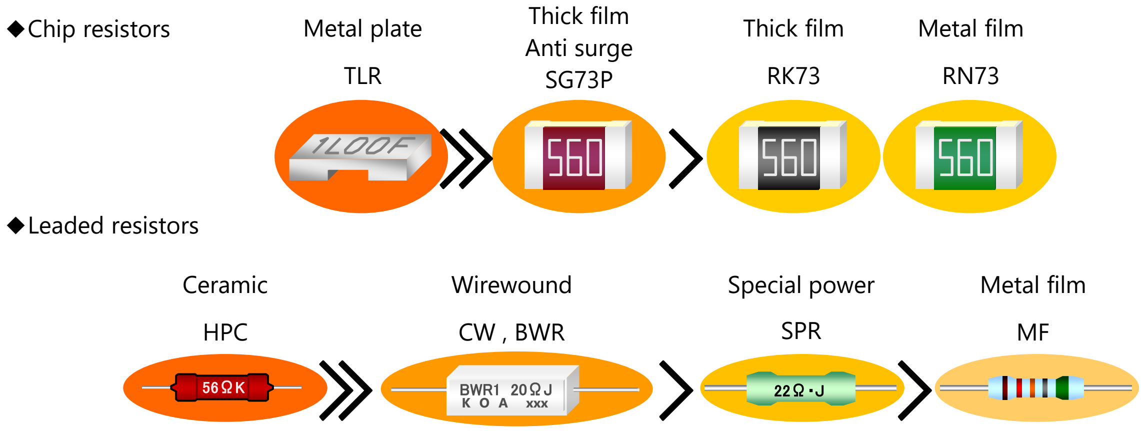


Fig.3 Types of resistors and pulse power capabilities

§3 Evaluation of Pulse Power Capability

3.1 One-pulse limiting electric power

One-pulse limiting electric power curves are each a plotting of the application power of one-time of pulse power (square wave) on the horizontal axis and the limit value of power that can be applied on the resistor on the vertical axis (see Fig. 4). It is to be noted that the one-pulse limiting electric power represents capability values of pulse power capability of a resistor, not the guaranteed value (although there are some partial exceptions).
Also, while there may be cases of using equivalent energy conversion in estimating the pulse power capability, the pulse power capability of a resistor is not the same as the result of equivalent energy conversion. Instead, one-pulse limit power curves are to be used in evaluating the pulse power capability.
Outlined below is how to evaluate resistors using one-pulse limit power curves.

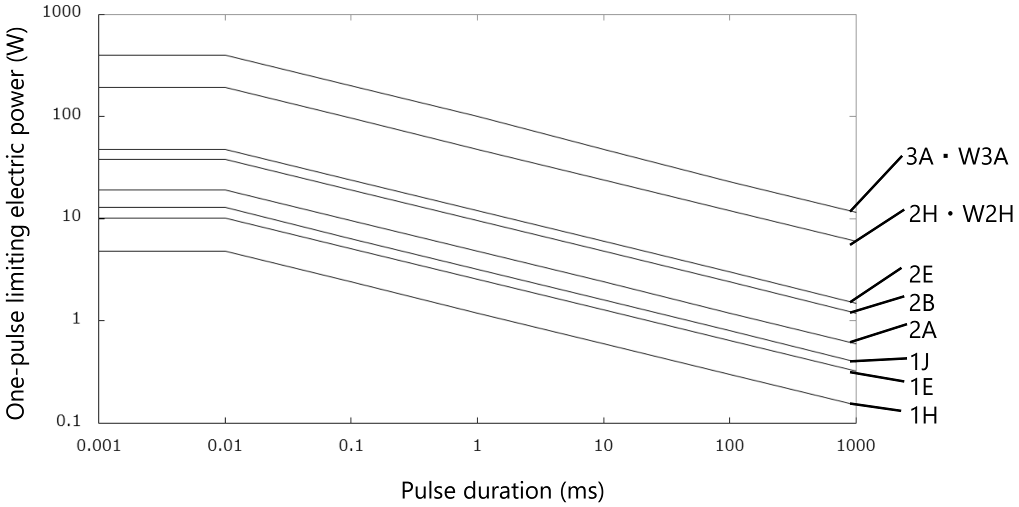


Fig.4 One-pulse limiting electric power of RK73B

3.2 Procedure of evaluation

Fig. 5 shows the procedure to be used in evaluating the capability of a resistor for one time of pulse power application.
Firstly, an assumed voltage (or current) waveform is converted to a square waveform of the same peak voltage and equal energy. Next, this equivalent voltage square wave is converted to a power waveform, and finally the pulse power capability of the resistor is evaluated using the equivalent power waveform and one-pulse limiting electric power.

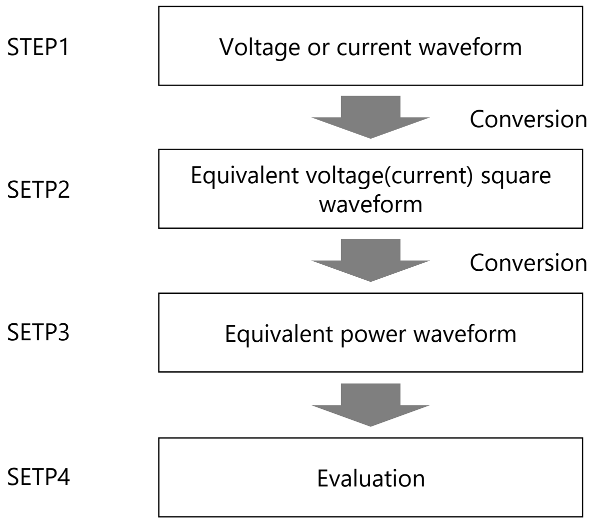


Fig.5 Evaluation procedure of pulse power capability

3.2.1 Conversion of pulse waveform to equivalent square wave

A square waveform is used in evaluating the pulse power capability of a resistor. This is because the square wave causes the greatest temperature rise in resistors when pulses of various waveforms having the same peak voltage (current) and energy are applied to resistors. The pulse waveforms other than square wave (e.g., CR discharge waveform, triangular waveform, half-wave rectification waveform, damped oscillation waveform) are to be converted to square waves of the same peak voltage (current) and equal energy. Fig. 6 shows methods of conversion to equivalent square waves of various waveforms.

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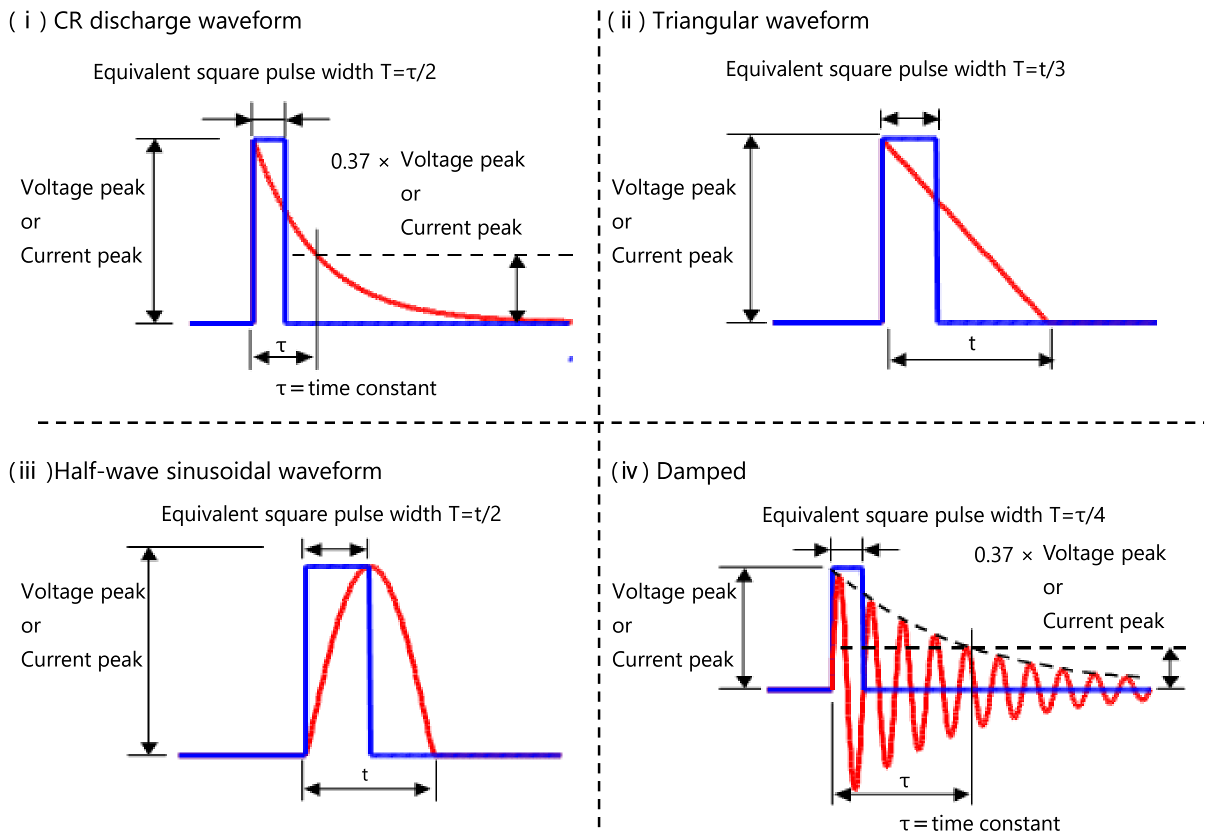
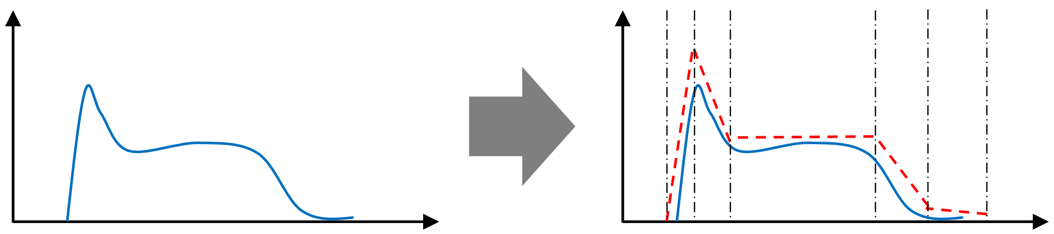


Fig.6 Methods of conversion to equivalent square waves

A conversion to a more complex pulse waveform is done by a procedure as shown below. Firstly, the pulse waveform is linearly approximated (Fig. 7).



(a) Voltage (current) waveform

(b) Linear approximation

Fig.7 Linear approximation of pulse waveform

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Next, the energies of respective linearly approximated intervals are determined using equation (1) (Fig. 8)
Energies of respective intervals are added up to obtain the total energy.

$$\int_0^T R \cdot i(t)^2 \cdot dt = R \cdot \frac{T}{3} \cdot \left(Ie^2 + Ie \cdot Is + Is^2\right) \qquad (1)$$

R：Resistance（Ω）
Is：Minimum current value of interval T
Ie：Maximum current value of interval T

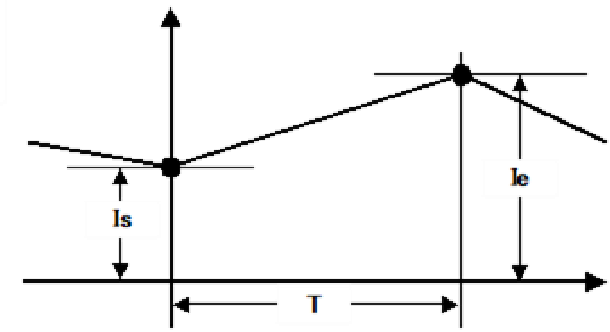

Fig.8 Calculation of energy by interval integration (with current)

Finally the peak power is derived from the voltage (current) waveform of Fig. 7(a), and the energy of all intervals is divided by the peak power to obtain the pulse width. This completes the conversion to an equivalent power waveform.

3.2.2 Evaluation of pulse power capability

The pulse power capability is evaluated using the equivalent power square wave and one-pulse limiting electric power.

The following explanation is about the method of evaluation using an example of a thick film chip resistor (RK73B) when an equivalent power square wave on the left side of Fig. 9 is applied once. The pulse duration of 0.1ms and pulse power of 70W are plotted on the one-pulse limiting electric power of RK73B. If the plotted position is below the limiting line of the resistor, the resistor can be understood to have the capability to withstand the pulse power. In this example, the plotted position is above the limiting line of 2E size , and as such the pulse power capability of this resistor is not adequate. With 2H which is larger in size, the plotted position being below the curve indicates a sufficient pulse power capability.

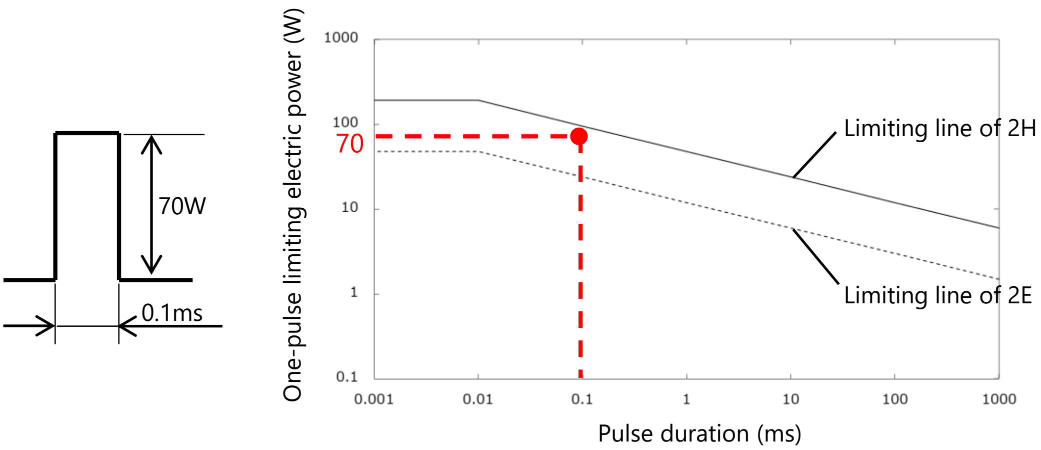

Fig.9 Example of evaluation using one-pulse limiting electric power of thick film chip resistor (RK73B)

§4 Heating of Resistors by Pulse Power

In §3, the procedure for evaluating pulse powers was discussed, and explained in this section will be the mechanism of heating in a resistor when a pulse power works on it and the reason why an equivalent energy conversion cannot be applied in evaluating the capability of the resistor against pulse power.
A pulse power acting on a resistor may cause a locally significant heat generation. If a pulse power in excess of one-pulse limiting electric power works on a resistor, a precipitous temperature rise may damage the resistor, thus presenting the possibilities of changing resistance value or disconnection.
The following explanation is given of an example of a flat chip resistor (RK73).
The temperature of a resistor in a steady state is determined by a balance between heat generation and heat release. Heat release from a resistor occurs through three paths of convection, radiation, and conduction. In a steady state, more than 90% of heat generated in a mounted flat chip resistor is released by conduction to the patterns of printed circuit board (PCB) through the terminals of resistor (see Fig. 10).

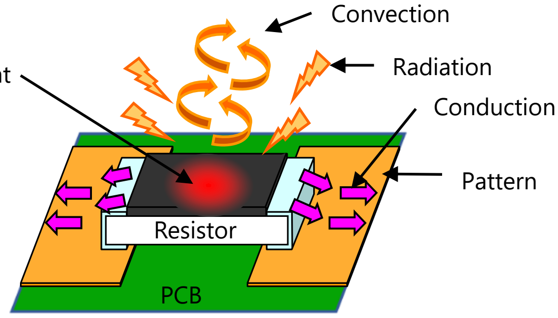

Fig.10 Image of heat generation and heat release of resistor

On another front, however, heat release to the outside of a resistor can be negligible in the occurrence of pulse power. This is because the heating of a resistor by the effect of pulse power is a short-duration phenomenon, in which the heat generated in the resistive element moves within the resistor, that is, heat conduction from resistive element to alumina substrate, is the dominant part of thermal migration.
Accordingly, the heating of a resistor when a pulse power acts on it can be calculated in a simplified manner based on the conduction of heat in the resistive element to the alumina substrate.
Here, the relationship between electric power and temperature rise is explained using a simplified model (Fig. 11) of a resistive element formed on an alumina substrate of infinite thickness.

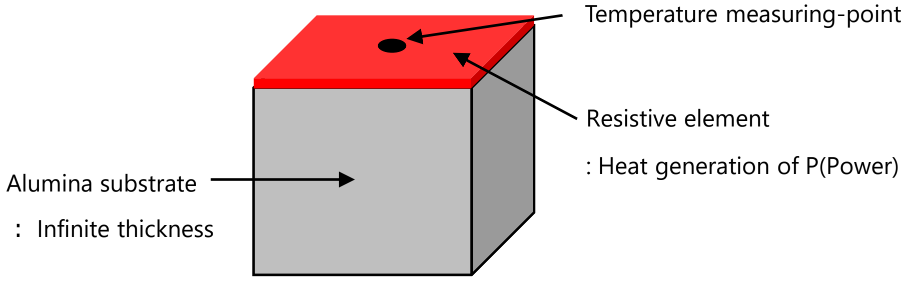

Fig.11 Simplified model for confirmation of temperature rise

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The relationship between power P and surface temperature rise △T in the simplified model of Fig. 11 can be expressed as equation (2). This relationship can be represented by a graph of Fig. 12, which indicates rapid temperature rises in a short time range.

$$\triangle T = A \times P \times t^{1/2} \qquad (2)$$

△T : Temperature rise at temperature measuring point (℃)
A : Constant（Constant to be determined by thermal conductivity, specific heat, density, etc., 100 in this graph）
t : Time（S）
P : Power（W）

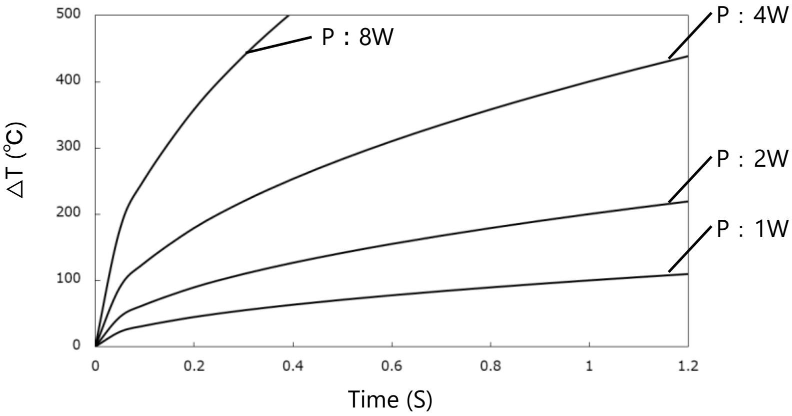

Fig.12 Temperature rise in resistor body resulting from electric power

Obtaining a transitional temperature rise by an equivalent energy conversion can end up in estimating temperature rise far lower than the actual rise. As an example, Fig. 13 shows a comparison of results between calculation using equation (2) and equivalent energy conversion. Note that the equivalent energy conversion is based on the energy that causes 400℃ of temperature rise in one second. The value of temperature rise calculated by an equivalent energy conversion is much lower than the actual temperature rise. This suggests that use of equivalent energy conversion in evaluating pulse power capability cannot lead to accurate results.

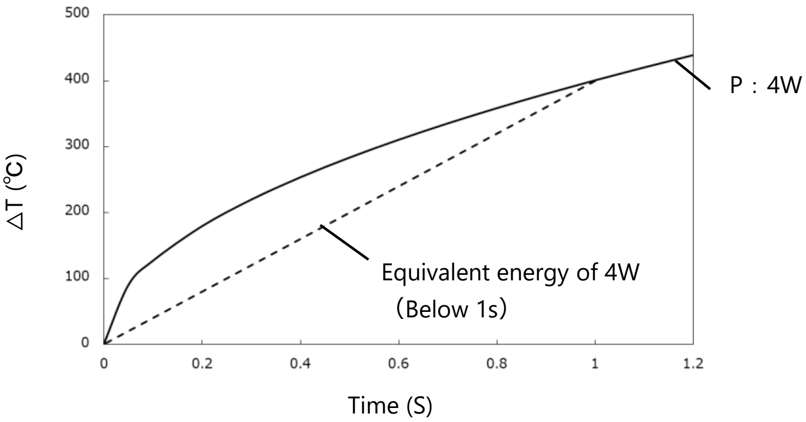

Fig.13 Comparison between calculation using equation (2) and equivalent energy conversion

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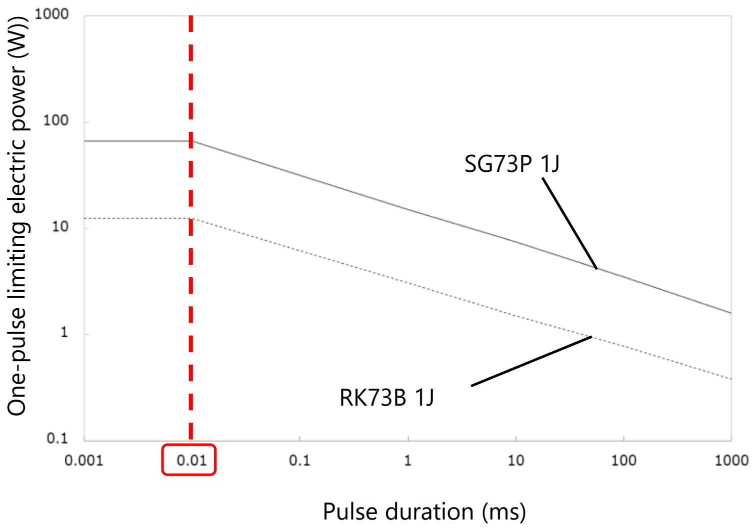
It is impossible to evaluate instantaneous events like pulse power working on a resistor by use of an equivalent energy conversion. Use of equivalent energy conversion may end up selecting resistors that do not actually have the pulse power capability, which may result in a failure of a device.

§5 Proper Selection of Resistors

With circuitry which is subject to the events of voltage pulses, it is necessary to evaluate the pulse power capability and select proper resistors. When the result of evaluation does not produce a satisfactory pulse power capability, it will be necessary to use a resistor of larger size or change to the type having higher pulse power capability.
For example, with a square chip resistor, it is possible to select a pulse-resistant chip resistor (SG73P) featuring higher pulse power capability than that of a general-purpose type RK73B (Fig. 14).



Size (Inch Size Code)	One-pulse limiting electric power(W) (Pulse duration : 0.01ms)	
	RK73B	SG73P
1J (0603)	13	68
2A (0805)	20	220
2B (1206)	40	500
2E (1210)	52	1300
2H (2010)	210	3600
3A (2512)	420	11000

Fig.14 One-pulse limiting electric powers by type and size of resistors

§6 Conclusion

A resistor can sometimes allow application of power in excess of the rating for a short duration. However, if a pulse power above the capability acts on the resistor, troubles, such as change in resistance value or disconnection, can occur. Hence, it is important to properly evaluate the pulse power capability of a resistor in relation to the pulse power that can work on it. In particular, care must be exercised for small-size resistors which have low capabilities to withstand pulse power.
KOA offers a wide variety of resistor types featuring various one-pulse limiting electric power. You have therefore more options in evaluating pulse power capabilities. It is to be noted, however, that the evaluation of pulse power capabilities is in calculated values, and so confirmation with actual resistors is advised for actual applications.
Also, we provide selection support for your applications with frequent occurrence of pulse powers or applications where evaluation of pulse power capability is difficult because of complex pulse waveforms. Please make an inquiry with us by providing information on your waveform, circuitry, and other conditions.