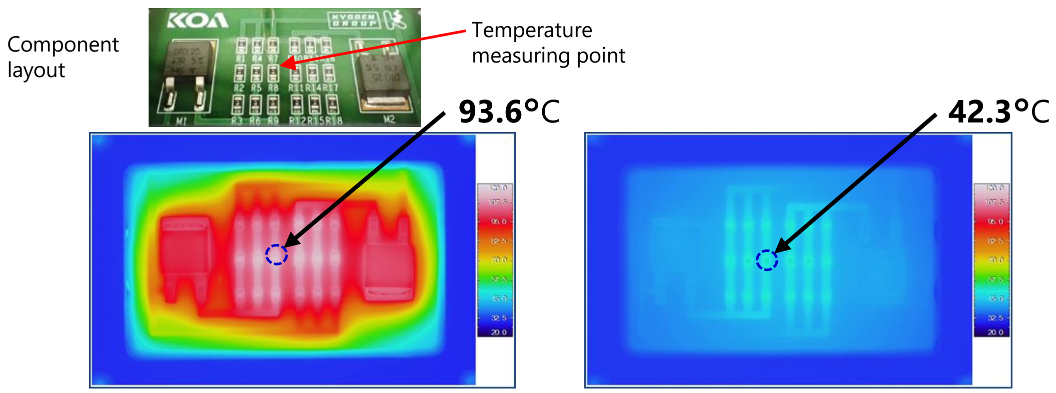
Power derating for surface mount resistors

§0 Abstract

Resistors are subject to maximum values of electric power that can be applied depending on their temperature. In the past, however, designing has often been done without considering the temperature of the resistor. The rule adopted in their design was simply "load power applicable to a resistor is below 30 % of the rated power". In the foregone decades when leaded resistors were mainstream, the design according to such a rule posed little problem of reliability. With surface-mount(SMD) resistors of today, however, this traditional design rule is causing such troubles as resistor failures or fuming of printed-wiring boards (PWBs). It is necessary, therefore, to appropriately reduce the load on SMD resistors and prevent such accidents, while achieving downsizing and using small numbers of resistors in your application.

§1 Temperature rise of SMD resistors

At the time when leaded resistors were in widespread use, few problems of reliability had been caused by the design based on the rule of "load power applicable to a resistor is below 30 % of the rated power." The reason may be as follows. Most electronic components in those days were leaded ones, and most of the heat arising from them were dissipated into the ambient air from the surface.
Electrolytic capacitors in those days were thermally weak and did not feature good lifetime characteristic. Thus they were designed so as to have lower ambient temperature within the chassis in which the circuit was placed. This may have contributed to less frequent problems of resistor reliability.
On the other hand, most of the heat generated by SMD resistors, such as flat chip resistors, is dissipated into PWBs. Additionally, they can easily conduct heat, so that flat chip resistors are more likely to be influenced by the heat from surrounding components. Figure 1 compares thermal images of a PWB which is well heat-dissipated and another which is poorly heat-dissipated when the same power is applied to the flat chip resistors mounted on their respective PWBs. We can see that the temperatures of resistors, even when they are laid out in the same way, can vary greatly, suggesting the importance of controlling the temperature of SMD resistors.



(a) Poorly heat-dissipated (b) Well heat-dissipated

Fig. 1 Difference in temperature of resistors depending on heat dissipation measure

§2 Controlling the temperature of SMD resistors

2.1 Importance of controlling the temperature of SMD resistors

In recent years, controlling the temperature of SMD resistors has been attracting particular attention. There are mainly three reasons for this trend. The first reason is the downsizing of electronic devices. Advances in high-density mounting of PWBs have increased heat generation per unit area. Along with this, PWBs can get heated more easily. The second is the prevalence of higher temperatures of the ambience where PWBs are installed. For example, automotive electronic control units (ECUs), an electronic device to control vehicle-borne equipment, are often placed in high-temperature ambience, such as inside the engine room. As a result, the temperature of the environment in which resistors are used is rising. The third reason is the trend of resistors for downsizing and applying higher power. This is the most prominent reason why controlling the temperature is gaining its importance today. Figure 2 shows changes in recent decades of rated powers (catalogue-listed values) of KOA's general-purpose flat chip resistors. Since the year 2000, we can see that the rated power of flat chip resistors of 1206 (Inch Size Code) size or smaller nearly doubled. This is not a result of changes in resistors themselves, but due to a re-evaluation of rated power which was done on the assumption that controlling the temperature is properly exercised. We can see that it is essential to manage the temperature of resistors if SMD resistors are to be used with a sufficient safety margin.
In the next section, a description will be given of how the heat generated from SMD resistors are dissipated.

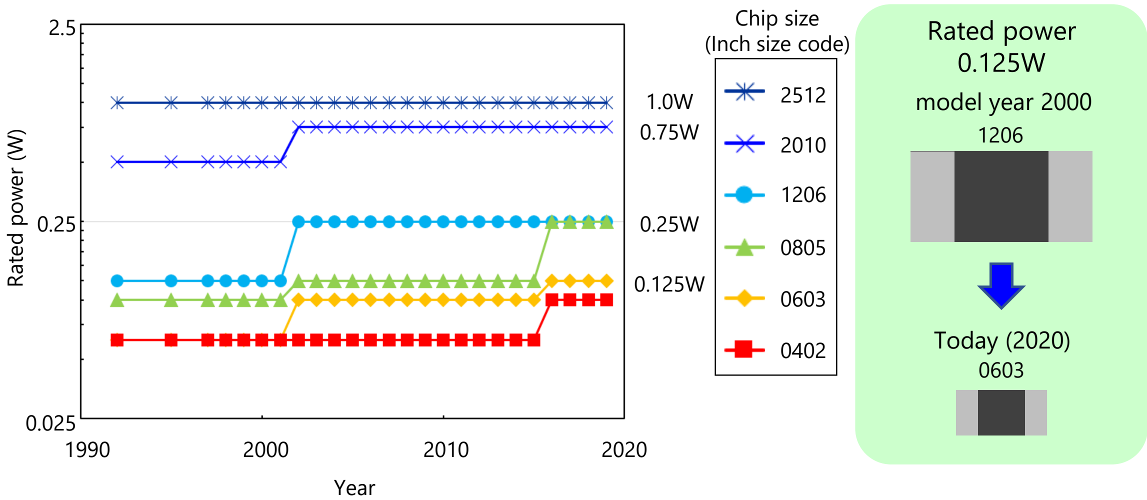


Fig. 2 Changes in rated power of general-purpose flat chip resistors

2.2 Heat dissipation of SMD resistors

SMD resistors are mounted on PWBs using solder or other junction materials. Figure 3 schematically illustrates main heat dissipation paths of a flat chip resistor mounted on a PWB. There are three heat dissipation paths. One is thermal conduction (Conduction) into the PWB with which the resistor is in contact, the second is convection heat transfer (Convection) into the air by natural convection or forced convection by a fan, and the third is infrared radiation (Radiation).
Table 1 shows heat dissipation ratio of the respective heat dissipation paths when each power is applied to flat chip resistors of sizes 0402, 0805 and 2512. We can see that more than 90 percent of heat arising from a flat chip resistor is dissipated by conduction into the PWB. In other words, heat from other components can also be easily conducted to the resistor through the PWB.

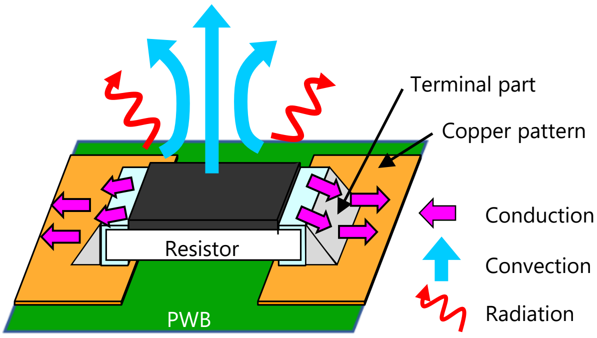


Fig. 3 Heat dissipation paths of a flat chip resistor

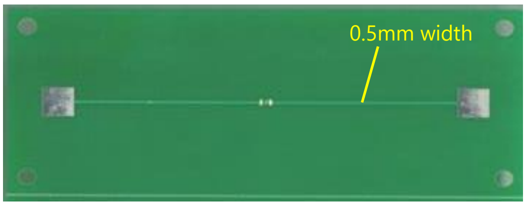
Table 1 Heat dissipation ratio of heat dissipation paths

Size [Inch size code]	2512	0805	0402
Applied Power[W]	1.00	0.125	0.063
Radiation[%]	2.8	0.4	0.2
Convection[%]	5.3	1.1	0.6
Conduction[%]	91.9	98.5	99.2

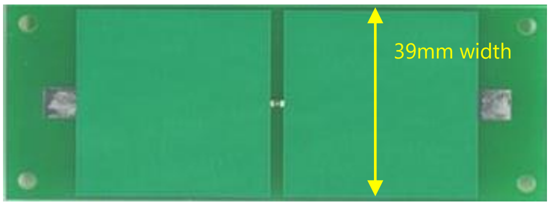
Thus the temperature of a flat chip resistor is highly dependent on the heat dissipation performance of the PWB on which it is mounted. The temperature of a resistor begins to rise at the application of current and stabilizes (reaches a state of equilibrium) at a level where the amount of generated heat is balanced with the amount of heat dissipation. If the heat dissipation capacity of the PWB is high, the temperature of the resistor will be held low. Conversely, if the heat dissipation capacity of the PWB is low, the temperature of the resistor will be high. Additionally, as the temperature of a PWB rises along with the heating of surrounding parts, the temperature of the resistor will rise.
On the other hand, most of the heat arising from the traditional leaded resistors are released into the ambient air, because the ratio of heat conduction through the leads into the PWB are limited. For this reason, leaded resistors are hardly affected by the heat conducted from the PWBs. In the following section, the temperature of an SMD resistor changing with the pattern and components mounted on the PWB will be explained using flat chip resistors as an example.

2.3 Relation between PWB pattern and temperature rise of flat chip resistor

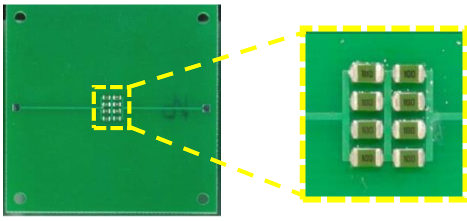
Figure 4 shows cases of endured pulse power flat chip resistors SG73P2A (0805, rated power 0.5 W) mounted on PWBs featuring three different heat dissipation performances. Figure 5 shows the temperature rise ΔT at the terminal part of these resistors when power of 0.125 W (25 % of rated power) per one resistor is applied in a room-temperature ambience.



(a) Single resistor, Copper pattern width: 0.5 mm



(b) Single resistor, Copper pattern width: 39 mm



(c) 8 resistors, Narrow pitch mounting

Fig. 4 Three kinds of mounting of flat chip resistor(s) on PWB

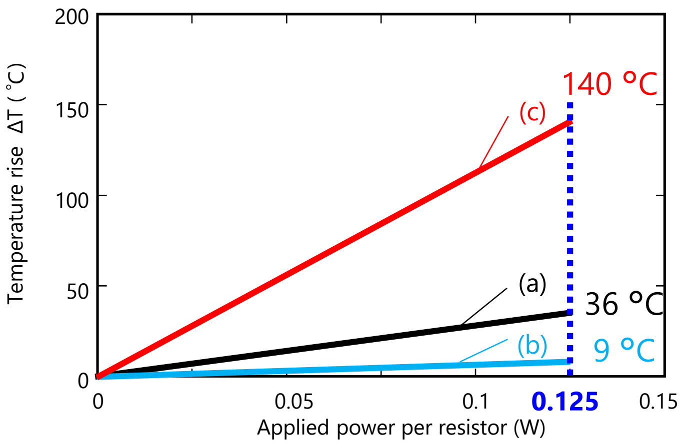


Fig. 5 Temperature rise of flat chip resistors on PWBs by patterns

The temperature rise at the terminal parts of the respective resistors ΔT is (a) 36 °C, (b) 9 °C, and (c) 140 °C. We can see that the temperature of a resistor can vary greatly depending on the pattern and the heat-generating components in the vicinity. It is obvious that the temperature of a flat chip resistor cannot be determined by the ambient temperature and applied power alone, given the fact that the results were obtained from the same ambient temperature and the same applied power. As it has already been mentioned, more than 90 % of the heat dissipation of a flat chip resistor is conducted to the PWB, which means that the PWB works as a heatsink. The differences in temperature rise, as shown in Fig. 5, result from differences in heat dissipation performance of the PWB as a heatsink.

Figure 6 shows the results of thermographic measurement of temperatures of a PWB and the mounted resistors in a pattern of Fig. 4(c) in relation to changes in applied power. It is to be noted that in preparation for thermographic measurement, the temperature measuring point on the PWB and the resistors are pretreated with blackbody paint (the temperature measuring point is on the white line of the thermal image). You can see that as the power applied to the resistors rises, the temperature of the resistors and the PWB rises. Also, you may notice that the temperature of the PWB in-between the two resistors (see red arrow in Fig. 6) are almost the same as that of the resistors. This means that there will be no more heat release from the two resistors to the PWB in-between. Thus the temperature of SMD resistors is determined by the self-heating due to the applied power and the temperature of the PWB heated by components in the vicinity.

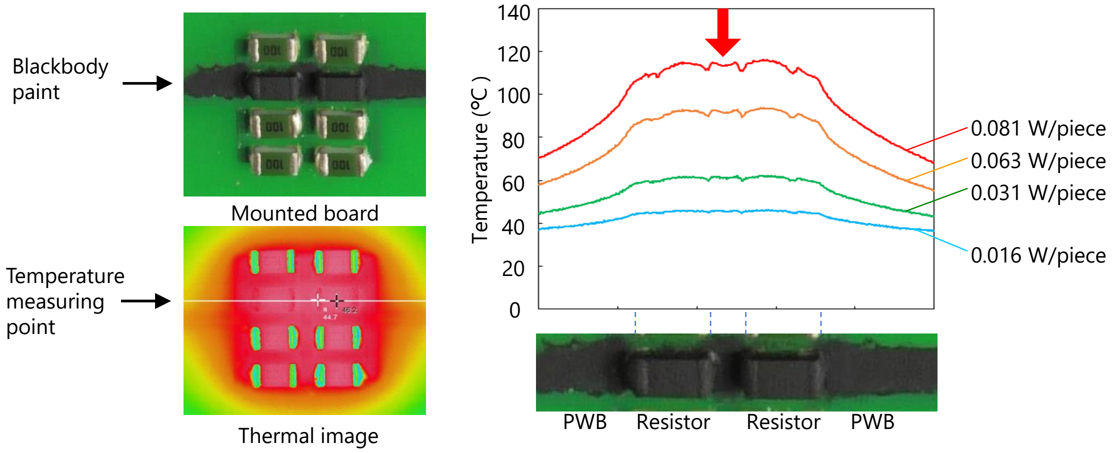


Fig. 6 Temperature distribution observed by thermograph

As is evident in Fig. 5, the temperature of a resistor can vary with the heat dissipation capability of the PWB even when the applied power is the same. That is, the traditional design rule of "load power applicable to a resistor being below (something) % of rated power" cannot be applied to SMD resistors. The continuous operating temperature for generally used PWB (FR-4) is 130 °C, but the temperature of Fig. 5(c) is exceeding it, and such a design may pose the risks of fuming or burnout of the PWB.

§3 Power derating for SMD resistors

Every resistor has a usable temperature range. And heating results as power applied to resistors. So, it is necessary to manage the applied power and temperature in consideration of the temperature rise so that the limit temperature of the resistors is not surpassed. The derating curve shows the relation between temperature and power that can be applied to resistors. Figure 7 shows an example of a derating curve for a flat chip resistor. The vertical axis represents power that can be applied (rated power ratio), and the horizontal axis represents the temperature of the terminal part of the resistor. For the flat chip resistors of this derating curve, the rated power can be applied until they become 125 °C. When they exceed 125 °C, it is necessary to reduce power in response to the temperature. So, you need to pay attention to the temperature of the terminal part since it varies with the pattern and components mounted on the PWB.

§4 Utilization of derating curve

How to use a derating curve for resistors will be explained, citing an example of verifying the adequacy of the flat chip resistor RK73B series in a circuit.

(1) The flat chip resistor, of which the adequacy is to be verified, is of 0805 size, and the applied power is 0.1 W. The terminal part temperature of the resistor is 140 °C, when power is applied to the resistor.
(2) A vertical line is drawn from the position of 140 °C on the horizontal axis and the point intersecting with the derating curve is found (Fig. 7(2)).
(3) A rated power ratio is found by drawing a straight line leftward from the intersection point (Fig. 7(3)). In this example, 50 % of rated power can be applied to the flat chip resistor.
(4) As the applied power is 0.1 W, the rated power necessary for the resistor is more than 0.1 W÷0.5=0.2 W. Since the rated power for 0805 size is 0.25 W, it can be used for this circuit.

The following shows an example of verifying the adequacy of the flat chip resistor under the above conditions, using the traditional design rule of "below 30 % of rated power". The applied power is 0.1 W, so the necessary rated power is
0.1 W÷0.3=0.34 W. Thus, the calculation indicates that the flat chip resistor of above-mentioned 0805 size cannot be used. Among the RK73B series, the smallest size for which the rated power is above 0.34 W is 1210 size. If this traditional design rule is used, a flat chip resistor of larger size must be used.
Figure 8 compares these sizes. By use of the derating curve, however, we know that a smaller flat chip size can be used.

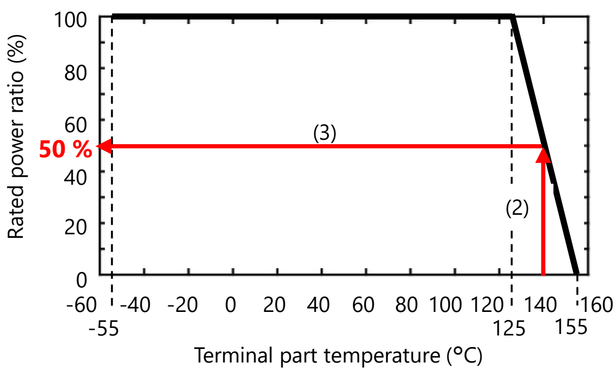


Fig. 7 Derating curve for flat chip resistor (example)

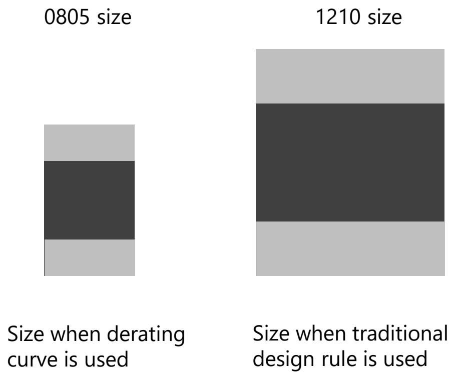


Fig. 8 Comparison in size of flat chip resistors

§5 Conclusion

With the progress of downsizing and higher power applications of SMD resistors, controlling the temperature is gaining importance. Unexpected accidents may occur without proper control. The power to be applied to SMD resistors must be determined in consideration of the temperature of the resistor based on the derating curve and not simply based on the traditional design rule of "below (something) % of rated power." In this way, you can use SMD resistors safely by determining the size and number of resistors appropriate for your application.